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FOUNDATION FOR ORAL REHABILITATION

A FOR consensus conference on

The rehabilitation of missing single teeth

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Editorial

This supplemental issue of *EJOI* is dedicated to the Foundation for Oral Rehabilitation (FOR) consensus conference, 'The rehabilitation of missing single teeth', which was held on the 7th and 8th October, 2015. Scientific associations and other organisations using *EJOI* as their official publication are welcome to publish the outcome of their consensus conferences or working groups in the journal.

It is the policy of *EJOI* that these publications will not be peer reviewed as they are normally. Consequently, readers are encouraged to critically evaluate the findings presented, as they would with all scientific publications. Guidance on how to develop critical skills for research, analysis and the evaluation of scientific publications (an important mission of *EJOI*) can be found in the 'educational articles'[1-4] and on the EQUATOR (Enhancing the QUAlity and Transparency Of health Research) website (http://www.equatornetwork.org/). The EQUATOR Network is aimed at helping authors properly report their health research studies. After selecting the 'Resource Centre', please click on the 'Library for health research reporting' and you will access a comprehensive list of reporting guidelines, organised by study type. More specifically, to evaluate systematic reviews please go to the PRISMA transparency guidelines (http://www.prisma-statement.org/).

The results of consensus conferences or working groups can be interpreted differently, depending on people's perspectives and circumstances. Please consider the conclusions presented carefully. They are the opinions of the review authors, and are not necessarily shared by *EJOI* editors.

We would like to thank all contributors to the present supplement for their efforts.

Marco Esposito, Reinhilde Jacobs and Michele Nieri

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Guest Editorial

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It has been repeatedly demonstrated and declared by the World Health Organization that oral health is an integral part of the well-being of man and crucial for general health.

A missing single tooth is not a minor health issue considering it has high prevalence and since it can seriously effect the comfort of patients, chewing ability, self-esteem and can impact on the neighbouring dentition. As P-I Brånemark liked to reiterate, a missing tooth is an amputation. Attitudes vary according to countries in how to deal with the issue of a single missing tooth. The universality and consistency of science is well known but its application and related technology are often pragmatic and local. The Foundation for Oral Rehabilitation (FOR), a universal not-for-profit organisation aims to promote patient-oriented oral rehabilitation, thus opting to investigate holistically the issue of missing single teeth, evaluating if patients' knowledge and professional attitudes towards this problem are matching the present state of science.

The second half of the twentieth century saw exceptional progress in health care due to scientific discoveries and newly available technologies. But there has also been in recent decades a growing understanding that economic, educational and cultural determinants play a significant role in health issues and modulate the impact of available preventive or curative treatment modalities. Thus, due to different educational backgrounds, local traditions and economic interests, the therapeutic options towards a missing single tooth may vary widely. It ranges from a removable or fixed partial denture to a single implant-borne prosthesis. The cost-effectiveness, the need to grind the neighbouring dentition, the predictability and the available skills of the clinician are all impacting the decision taken. Some clinicians are still hesitant towards the team approach, although treatment should always aim to meet the patient's interest rather than conform to personal limitations or preferences.

The thorough reviews of the literature concerning diagnostics and therapeutics of missing single teeth which these proceedings provide, allows everyone to find out by themselves what is state of the art and what is best for the patient.

This meeting was a privilege for the both of us as we were allowed to interact with 11 top experts in the field, originating from six countries, who were selected on the basis of objective criteria, such as publications or their major contributions to the subject of missing single teeth, citation indices and their willingness to work through the predefined meeting format without any compensation. Only travel and hotel costs were taken care of by the FOR. Once the specific subject was allocated to each one at the end of 2014, they started to work on their reviews, which were not limited to the highest level of evidence thus not neglecting too much informative data. The experts were able to develop extensive critical reviews with a clear clinical message from what at first sight seemed a limited issue. Manuscripts were exchanged amongst experts prior to the face-to-face meeting and comments were eventually exchanged.

The meeting itself took place in the premises of the University of Mainz and was limited to 2 days. No formal presentations were given, only a brief outline of the conclusions, in order to invite discussion. The consensus text was then iteratively produced and finalised after the meeting through an email exchange. There were no minority statements. The finalising of the consensus text was an elaborate process reflecting the investment of time and meticulous interest of those involved.

We are convinced that through this type of consensus meeting and proceeding, the FOR fulfills its mission of providing globally reliable and objective scientific messages which will be beneficial for patient treatment.

Wilfried Wagner and Daniel van Steenberghe

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Treatment options for congenitally missing lateral incisors

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Key words *agenesis of maxillary lateral incisors, orthodontic space closure, prosthetic rehabilitation, systematic review*

Aim: The aim of this systematic review was to identify studies that examined maxillary lateral incisor agenesis treatment, by either orthodontic space closure by canine mesial repositioning and reshaping, or by a prosthodontic intervention, in order to compare the biological, functional and aesthetic outcomes of these two approaches.
Materials and methods: An electronic MEDLINE search was conducted by two independent reviewers in order to isolate English language articles, published in scientific journals between January 1975 and March 2015, reporting on treatment of agenesis of maxillary lateral incisors, accomplished either by canine orthodontic repositioning or prosthodontic intervention. The search terms were categorised into the four groups comprising the PICO (problem, intervention, comparison and outcome) question. Supplementary manual searches of published reviews and other full-text articles were also performed.
Results: The initial database search produced 8,453 titles. After careful examination and discussion, 12 articles were selected for inclusion, where 5 of them compared the two therapeutic options directly. No randomised controlled trials were identified.
Conclusions: Definitive conclusions cannot be drawn, since randomised controlled trials and more prospective and retrospective studies directly comparing the two therapeutic options are required. According to this systematic review, both therapeutic options are effective. However, it seems that the orthodontic space closure, whenever this is possible, is advantageous over the prosthodontic rehabilitation.

■ Introduction

Congenitally missing tooth or tooth agenesis describes one of the most frequent developmental anomalies in human dentition[1-4]. Maxillary lateral incisor agenesis is, according to some researchers, the second most common agenesis, after that of the third molar[5-10]. However, there is some published evidence showing that the second premolars have a higher incidence of agenesis than that of lateral incisors[11-13]. A clinical study by Muller et al has concluded that, while premolars are the most frequently missing teeth when more than two teeth are absent, lateral incisors are the ones which are most frequently missing, when less than two teeth are absent, with a range between 1% and 4%[8,14]. Nevertheless, it has been demonstrated that there are large variations in the prevalence of dental agenesis amongst different races[15-27].

The genetics of tooth agenesis has recently been the focus of research[3]. A recent article has demonstrated the involvement of five genes, namely PAX9, EDA, SPRY2, SPRY4 and WNT10A, as risk factors for maxillary lateral incisor agenesis. Furthermore, the same research group has proven that there are three synergistic interactions between maxillary lateral

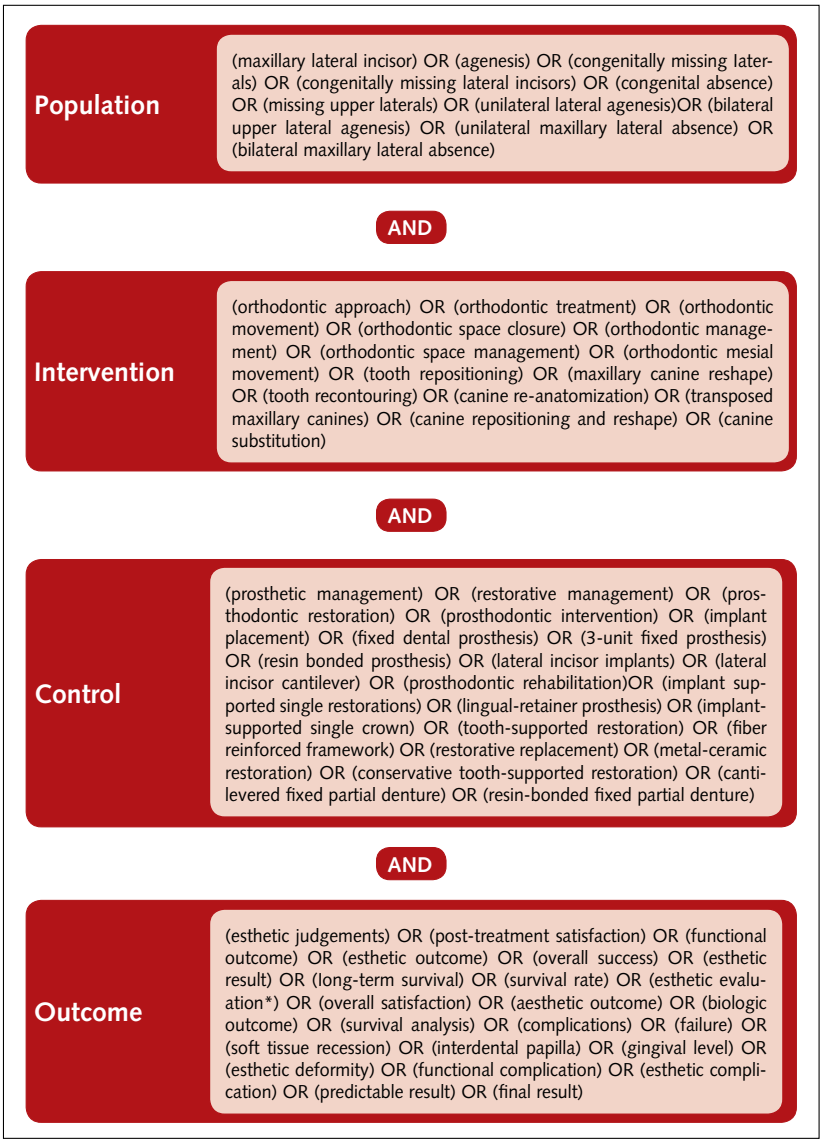

Fig 1 Focused PICO question.

incisor agenesis liability and MSX1-TGFA, AXIN2-TGFA and SPRY2-SPRY4 gene pairs[28].

Besides the basic research taking place in this field, the agenesis of lateral incisors has also drawn the attention of both patients and clinicians due to their location in the aesthetic zone of the dental arch. The treatment approaches for this clinical situation can consist of: I) orthodontic space closure by mesial repositioning of the canine, followed by reshaping in order to resemble a lateral incisor; II) endosseous implant placement, with or without orthodontic movement, for space requirements or site development; III) two- (cantilever) or 3-unit resin-bonded prostheses; IV) full coverage 2- (cantilever) or 3-unit fixed dental prostheses. Each one of these therapeutic approaches present advantages and disadvantages, with regard to treatment time, cost, invasiveness, treatment efficacy, biologic outcome, esthetic outcome, functional outcome and patient satisfaction.

All of the above-mentioned treatment approaches have, in the past, been employed to restore the missing maxillary lateral incisor. However, these modalities have not been thoroughly evaluated, making the decision of which approach to adopt difficult, and often the procedure is a personal preference. Nevertheless, the treatment is better to be based on solid scientific criteria, if these exist. The purpose of this systematic review, therefore, was to identify studies that examined maxillary lateral incisor agenesis treatment by either orthodontic space closure, by canine mesial repositioning and reshaping, or by a prosthodontic intervention, in order to compare all the available published outcomes of these approaches.

Materials and methods

The focused PICO (population, intervention, comparison and outcome) question of the present systematic review was whether the treatment time, invasiveness, treatment efficacy, biological outcome, aesthetic outcome, functional outcome and patient satisfaction of orthodontic mesial canine repositioning are similar to those obtained by the prosthodontic intervention (implant placement, resin-bonded or conventional fixed prosthesis). It was the intention of the authors to determine whether or not the available literature offers enough scientific data on which therapeutic approach to follow or to when the orthodontic treatment is preferred over the prosthodontic one.

Search strategy and study selection

An electronic MEDLINE search was conducted by two independent reviewers in order to isolate English language articles, published in dental journals between January 1975 and March 2015, and to report on treatment of agenesis of maxillary lateral incisors, accomplished either by canine orthodontic repositioning or prosthodontic intervention. The search terms were categorised into the four groups comprising the PICO question, after the following

limits were activated: human; clinical trial; meta-analysis; randomised controlled trial; review; case reports; clinical trial phases I, II, III and IV; comparative study; controlled clinical study; and multicenter study. The search strategy consisted of free-text words, as illustrated in Figure 1.

The search was supplemented with manual searches of published reviews and other full-text articles, which were identified from the electronic-search. In addition, a hand-search was conducted by the reviewers in the following journals published between January 2010 and March 2015: Angle Orthodontist, American Journal of Orthodontics and Dentofacial Orthopedics, Clinical Implant Dentistry and Related Research, Clinical Oral Implants Research, European Journal of Oral Implantology, European Journal of Orthodontics, Journal of Oral and Maxillofacial Implants, Journal of Prosthetic Dentistry, Journal of Prosthodontics, International Journal of Prosthodontics.

Prospective, retrospective, cross-sectional and case series studies retrieved through the electronic- and hand-searches were the basis of this systematic review, as no randomised controlled trials could be identified. The additional criteria set for inclusion in this study were:

- report on treatment of maxillary lateral incisor agenesis of one or both sides;
- inclusion of detailed information on treatment procedures;
- inclusion of a clinical evaluation of the treatment outcome;
- report of the presence or absence of biological, functional and/or aesthetic complications at follow-up appointments.

All studies that did not satisfy the above-set criteria, including *in vitro* studies, *in silico* studies, animal studies, reviews, systematic reviews, as well as clinical studies reporting on tooth agenesis in other locations, were excluded.

The titles and abstracts retrieved from the advanced search were initially evaluated by two reviewers (MS and YK) for possible inclusion in this systematic review, based on the aforementioned set criteria. A discussion with all four authors resolved any disagreement during the search. After this procedure, abstracts of all approved titles were downloaded and evaluated individually. Full texts were obtained, if the abstracts met the inclusion criteria. Furthermore, if inadequate information was included in either the title or the abstract, the full-text was retrieved in order not to exclude any articles relevant to the topic of this systematic review. Moreover, on many occasions the authors of the articles were contacted for additional information, when this was necessary and this complementary information was taken into consideration[63,64,66,68-70]. Following the collection of all full-text articles, the inclusion/exclusion criteria were used to focus on those that would be included in this systematic review. The two reviewers (MS and YK), who conducted electronic-searches (PICO question) and hand-searches independently, generated 40 and 41 studies, respectively. Of the above, 38 studies (88.37%) were overlapping with each other. As a result, a total of 43 studies were included in the discussion for the final study selection. All four reviewers approved the selected articles (Fig 2).

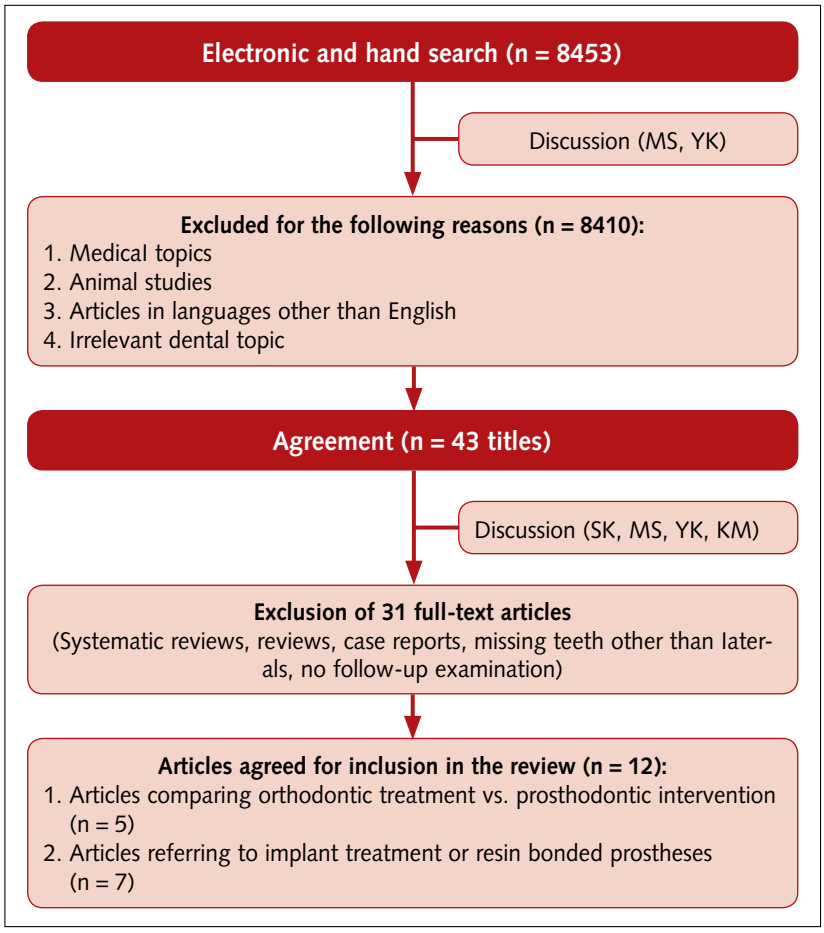

Fig 2 Flow chart of article selection for inclusion in the systematic review.

Extraction of data

Information regarding the following parameters were extracted from each article: study design; setting of study; patient number; gender; age; treatment option; tooth agenesis; orthodontic space opening; time of evaluation; periodontal soft tissue assessment; gingival biotype; temporomandibular disorders; occlusal assessment; and aesthetic assessment. Additional parameters extracted from the articles on implants vs resin-bonded prostheses, included the following categories: implant brand; loading (months); prostheses; follow-up time; survival rate; success rate; complications; and hard tissue assessment.

Results

The two reviewers (MS and YK), who conducted the electronic-search (PICO question) and hand-search independently, concluded in 40 and 41 studies, respectively. Of the above, 38 studies (88.37%) were overlapping with each other. As a result, a total of 43 studies were included in the discussion for the final study selection, from an initial yield of 8,453 studies. All four reviewers approved the selected articles. A second discussion amongst the reviewers took place for evaluation of these articles (Fig 2). Of the 43 full-text articles obtained and studied, 31 were excluded and were not analysed further (Table 1)[4,29-58]. Five studies comparing orthodontic treatment and prosthodontic intervention[59-63] (Table 2) and seven studies referring to implant treatment or resin-bonded prostheses[64-70] (Table 3) were included in the review.

Four retrospective clinical studies[59,60,62,63] and one cross-sectional study[61] on the direct comparison of orthodontic space closure and prosthodontic intervention (direct comparison group) were included in this review (Table 2). No randomised controlled studies comparing the two different therapeutic options were available in the literature. Three of the included studies were conducted in a university[59,60,62], one in a private dental office[63], while no information was given about one study[61]. One hundred and thirty-seven patients were included in the direct comparison group of studies[59-63], aged between 14 and 54, with a mean age of 23.94 years. In one study[61], the authors do not provide information concerning the age of the patients with maxillary lateral agenesis. As far as the gender of the patients is concerned, four studies reported on this subject. Specifically, there were 28 males (27%) and 76 females (73%). Furthermore, the agenesis appears to be bilateral in 94 cases (68.61%) and unilateral in 43 cases (31.38%). Regarding the gingival biotype, it was reported to be thin for 25 cases (54.35%), thick for 21 cases (45.65%), while no information was provided for the majority of the patients. Treatment approach included orthodontic space closure and canine recontouring for 142 sites (61.47%) and prosthodontic rehabilitation in 89 sites (38.57%). The latter 34 sites (14.71%) received by implant placement and 55 sites (23.86%) received a conventional prosthodontic approach (fixed or removable partial denture or resin-bonded prostheses). The time of evaluation ranged from 0.42 to 25.50 years. The prosthodontic rehabilitation took place after orthodontic space opening and/or maintenance in 85 sites (95.50%), whereas for four sites (4.50%), no information was provided concerning whether orthodontic space opening pretreatment took place or not.

Furthermore, one prospective clinical study[70], five retrospective clinical studies[64-66,68,69] and one case series[67], examining two different prosthodontic approaches, were also identified and included in this review (Table 3). The therapeutic options in the above studies include implant and resin-bonded prostheses. Unfortunately, no randomised controlled studies directly comparing different prosthodontic approaches, were available in the literature. Five of the studies[64-66,68,70] took place in a university, one[68] in a private dental office, while no information was given for one study[67]. One hundred and forty-nine patients were treated with one of the above prosthodontic interventions. The age of these patients ranged from 13 to 45 years. It should be mentioned however that in two studies[68,69] information concerning the age of the sample is not reported or cannot be extracted from the given data. As far as the gender of the patients is concerned, one study[68] did not report on the patient's sex, while another one[69] did not give information regarding the gender of the patients with a congenitally missing lateral incisor. In the remaining five studies, 84

Table 1 Studies excluded from the systematic review.

First author	Year	Study	Reason for exclusion
Andrade et al[45]	2013	Systematic review	Systematic review
Balshi[40]	1993	Case report	Case report
Benzos[37]	1996	Case report	Case report
Bidra[44]	2012	Case report	Case report/bilateral cleft palate
Cakan et al[29]	2009	Case report	Case report
De Marchi et al[57]	2012	Cross-sectional	Same cohort with De Marchi et al[59]
Fisher and Jones[41]	1990	Case report	Case report
Duarte et al[30]	2010	Case report	Case report
Jackson and Slavin[47]	2012	Case report	Case report
Jackson and Slavin[46]	2013	Case report	Case report
Kinzer and Kokich[33]	2005	Review	Review
Kinzer and Kokich[34]	2005	Review	Review
Kokich and Kinzer[35]	2005	Review	Review
Krassnig and Fickl[4]	2011	Review	Review
Mummidi et al[55]	2013	Case report	Case report
Nissan et al[54]	2011	Prospective	Data extraction could not be performed
Oliveira et al[53]	2013	Case report	Case report
Oosterkamp et al[42]	2010	Retrospective	Bilateral cleft lip and palate
Paduano et al[52]	2014	Case report	Case report
Park et al[51]	2010	Case report	Case report
Piero et al[32]	2007	Case report	Case report
Pini et al[58]	2013	Cross-sectional	Same cohort with De Marchi et al[60]
Robertsson et al[56]	2010	Cross-sectional	Data extraction could not be performed
Savarrio and McIntyre[36]	2005	Review	Review
Slutsky and Greenberg[43]	2011	Case report	Case report
Small[38]	1996	Case report	Case report
Strong[31]	2008	Case report	Case report
Trushkowsky RD[39]	1995	Case report	Case report
Tuna et al[50]	2009	Case report	Case report
Uribe et al[49]	2013	Retrospective	Data extraction could not be performed
Zachrisson et al[48]	2011	Review	Review

patients (61.3%) were women and 53 (38.7%) were men. Moreover, 54 patients (36.24%) had bilateral agenesis, while 95 patients (63.75%) presented with unilateral agenesis. Regarding the treatment options, 116 patients (57.14%) were treated with a single implant crown, while 87 patients (42.85%) received resin-bonded prostheses. One hundred and eighty-three sites (96.8%) were treated by opening lateral incisor spaces prior to the prosthodontic rehabilitation, 6 sites (3.1%) did not receive orthodontic treatment prior to prosthetic intervention, whereas no information was given in two studies. As far as the implant dimensions are concerned, the diameter ranged from 3.3 mm to 4.8 mm, while the length ranged from 10.0 mm to 16.0 mm. Twenty-eight implants (45.1%) were immediately loaded, 34 (54.9%) were loaded 4 months after the surgical procedure, whereas four studies did not report on the time of loading. In 52 cases (59%), titanium abutments were used; in 36 cases (41%) zirconium abutments; while in two studies no information was given regarding the type of abutment. Regarding the type of the implant restoration, 55 crowns were metal-ceramic (50.9%), 53 crowns (49.1%) were all-ceramic, while no information was given in one study. Concerning the construction of the

Table 2 Orthodontic space closure versus space opening/ retention and prosthodontics.

Study	Study design	Setting	Patient no	Gender	Age	Treatment Option (n: sites)	Tooth agenesis (n: patients)	Orthodontic space opening	Time of evaluative (years)	Periodontal Biotype
DeMarchi et al (2012) and DeMarchi et al (2014)	Cross	Univ	46	9M, 37F	14-45, Mean: 25	OSC (n = 43)	9 Uni and 17 Bi		3.90 ± 3.48	19 thin and 7 thick
						Impl (n = 30)	10 Uni and 10 Bi	YES	3.54 ± 2.39	6 thin and 14 thick
Nordquist and McNeil (1975)	Cross	NR	33	NR	NR	OSC (n = 39)	8 Uni and 25 Bi		2.3-25.5	NR
						FDP (n = 13) RPD (n = 6) (n = 19)		YES		
Robertsson and Mohlin (2000)	Retro	Univ	50	14M, 36F	19.4-54.9 Mean 25.8	OSC (n = 53)	7 Uni and 23 Bi		7.1 ± 3.3	NR
						FPD, RBP (n = 36)	4 Uni and 16 Bi	YES	7.2 ± 3.8	
Jamilian et al (2015)	Retro	PO	8	5M,3F	19.4-22.8 Mean 21.02	OSC (n = 7)	5 Uni and 3 Bi		5.6 ± 0.4	NR
						Impl (n =4)		NR		

AL: abfraction lesions; Av: average; Bi: bilateral; BI: bleeding index; Cross: cross-sectional study; CS: case series; DCNBE: data cannot be extracted; EEI: Eastman Esthetic Index; F: females; FPD: fixed partial denture; Gd: Good; Impl: Implant; M: males; NA: not applicable; NR: not reported; NS: not significant; Nss: not statistically significant; OT: orthodontic treatment; PO: Private practice; Pr: poor; OSC: orthodontic space closure; RPD: removable partial denture; RBP: resin-bonded prostheses; PI: plaque index; PD: probing depth; PpI: papilla index; Retro: retrospective; RI: retention index; Ss: statistically significant; Univ: university; Uni: unilateral; VAS: Visual Analogue Scale.

resin-bonded prosthesis, 73 restorations (83,90%) were made of nickel-chromium alloy retainers, sandblasted with 50 to 250 μm alumina and luted with adhesive resin, while 14 resin-bonded prostheses (16.10%) were all-ceramic. Reported follow-up periods ranged from 1.30 to 8.33 years in five studies[64-67,70]; two studies did not specify the follow-up period for patients with lateral agenesis, from the whole sample of patients[68,69]. The implant-crown survival rate ranged from 97.06% to 100% for 108 sites (93.10%), whereas eight sites (6.89%) demonstrated a 87.5% survival rate. As for the implant-crown success rate, it ranged from 94.12% to 100% for 108 cases (93.10%); one study[67] did not report on implant-crown success rate. Furthermore, 14 resin-bonded prostheses (16.09%) have reported a 100% survival rate, while one study[65] did not give any information regarding the survival rate. Finally, none of the studies[65,67-69] reported on the success rate of this type of prosthesis.

Perio soft tissue assessment	TMDs	Occlusal assessment	Aesthetic assessment
PI: Nss, [OSC:61 ± 13% Impl:52±11%] P > 0.5 BI: Nss [OSC:11 ± 18% Impl:7 ± 6%], P > 0.5 PD: Nss [> 3mm OSC:1% Impl:1.7%] PpI: Ss mesially OSC >Impl [OSC: 2.98 Impl: 2.72] P ≤ o.5 Nss distally [OSC: 2,98 Impl: 2,97] P > 0.5	Nss difference based on Research Diagnostic Criteria (RDC/TMD) and Helkimo Dysfunction Index, P > 0.5	NR	**Patient's satisfaction (VAS):** NSs difference, but the OSC were more satisfied P > 0.002 **Smile attractiveness (VAS):** Nss differences between laypersons and dentists, P = 0.64
PI: Nss FPD and OSC, P > 0.01 GI/BI: Ss FPD > OSC, P ≤ 0.01 PD:Ss in FPD > OSC, P ≤ 0.01	NR	OSC: 100% Group function FDP/RPD: 89% Group Function, 11% Canine rise NS difference in the presence of unilateral contacts in CR and non-working side interferences	NR
PI: Ss ,PR>OSC [OSC: 1.36 PR: 2.81] P ≤ 0.001 BI: Ss ,PR>OSC [OSC: 1.51 PR : 2.61] , P ≤0 .001 PD: Nss, P > 0.001	Nss difference based on Helkimo Dysfunction Index, P > 0.001	Ss difference in the presence of canine rise on laterotrusion in the PFM/RBP group, P ≤ 0.0001 Nss difference in the presence of unilateral contacts in CR and non-working side interferences.	Patient's satisfaction General dental appearance (EEI): Ss [OSC: 93% very or mildly satisfied PR:65% very or mildly satisfied] P ≤ 0.05 Tooth shape: Nss Tooth colour: PFM/RBP ss more satisfied, P ≤ 0.001 Space condition: Nss Symmetry of the maxillary anterior segment: Nss Examiner/panel evaluation: NR
PI:Nss [OSC:3.0 ± 1.1 Impl:3.7 ± 1.0] P > 0.632 PD: SS Impl > OSC [PD > 3mm OSC:1 tooth Impl:3 implants] P < 0.001	Nss difference based on anamnestic questionnaire, P > 0,605	Presence of infraocclusion: [OSC:0, Impl:4]	DCNBE Patient's satisfaction (VAS): Nss difference [Impl: 8.7 ± 1.3 OSC: 8.8 ± 1.2] P > 0.857 (Similar well accepted aesthetic results) Examiner/panel evaluation: NR

Side effects and complications

In the first group of studies[59-63], in which a direct comparison of the two treatment options took place, no occlusal assessment and side effects related to temporomandibular joint dysfunction (TMDs) were reported. More specifically, there were no statistically significant differences between the two treatment approaches in 104 patients[59,62], concerning the temporomandibular joint dysfunction status, based on the Helkimo Dysfunction Index. No information was reported regarding the status of the TMD for the remaining 33 patients[61,63]. On the subject of the presence of unilateral contacts in centric relation and non-working side (mediotrusive) interferences, there were no statistically significant differences in 83 of the patients between the group that received orthodontic space closure and the group that received prosthodontic rehabilitation, while no information was available for the remaining 54 patients. In addition, the presence of infraocclusion was reported for 4 implants in one study[63].

In the second group of studies[64-70], which deals with the two different prosthodontic approaches, the reported complications were different for each intervention. With regard to implant restorations, one technical complication was reported which consisted of porcelain chipping. Two biological complications were reported and included one implant loss[67] and a 0.2 mm neck exposure in one implant[70].

Table 3 Orthodontic space closure versus space opening/ retention and prosthodontics.

Study	Study type	Setting	Patient No	Age (years)	Gender	Agenesis	Orthodontic Space Opening	Treatment option (n: sites)	Implant	Loading (months)
Branzen et al (2014)	Retro	Univ	36	Range: 14,3-26,7	17M 19F	18 Uni and 18Bi	YES	Impl (n = 54)	Branemark system MKIII, Nobel Biocare, Dimensions: 3.3 mm x 15.0 mm (n = 45) 3.75 mm x 13.0 mm (n =9)	NR
Garnett et al (2006)	Retro	Uni	45	Range: 13-44, Mean: 17	14M 31 F	17 Uni and 28 Bi	YES	RBP (n =73): Canine Cantilevered (n = 38); Central Incisor Cantilevered (n = 24); Conventional (n = 9); Canine+Premolar Cantilevered (n = 2)	NA	NA
Mangano et al (2014)	Retro	Uni	20	Range: 19.75-24.25	9M 11F	20 Uni	YES	Impl (n = 20)	Cone Morse Taper, Leone Implant System Diameter: 3.3 mm, 4.1 mm and 4.8 mm	Immediate
Penarrocha et al (2008)	C.S	NR	6	Range: 17-32 Mean:22	2M 4F	4 Uni and 2 Bi	YES only in two cases	Impl (n=8)	Defcon (Impladent, Sentmenat, Barcelona, Spain) titanium surface acid, Avantblast surface implants; Dimensions: 3.6 mm X 13.0 mm (n = 3) 3.6 mm X 14.5 mm (n = 1) 3.6 mm X 16.0 mm (n = 2) 4.2 mm X 14.5 mm (n = 1) 4.2 mm X 16.0 mm (n = 1)	Immediate
Sailer et al (2013)	Retro	PO	5(out of 28)	NR	DCNBE	3 Uni and 2 Bi	NR	RBP: single retainer cantilever (n = 7)	NA	NA
Sailer et al (2014)	Retro	Uni	7(out of 15)	DCNBE (13.1-75.1)	DCNBE (6M9F)	7 Uni	NR	RBP: single retainer cantilever (n = 7)	NA	NA
Zarone et al (2006)	Pros	Univ	30	Range: 21-45	11M 19F	26 Uni and 4 Bi	YES	Impl (n = 34)	Straumann ITI, Dimensions: 3.3 mm X 10.0 mm (n = 9) 3.3 X 12.0 mm (n = 17) 3.3 mm X 14.0 mm (n = 8)	4

AL: abfraction lesions; Av: average; Bi: bilateral; BI: bleeding index; Cross: cross-sectional study; CS: case series; DCNBE: data cannot be extracted; EEI: Eastman Esthetic Index; F: females; FPD: fixed partial denture; Gd: Good; Impl: Implant; M: males; NA: not applicable; NR: not reported; NS: not significant; Nss: not statistically significant; OT: orthodontic treatment; PO: Private practice; Pr: poor; OSC: orthodontic space closure; RPD: removable partial denture; RBP: resin-bonded prostheses; PI: plaque index; PD: probing depth; PpI: papilla index; Retro: retrospective; RI: retention index; Ss: statistically significant; Univ: university; Uni: unilateral; VAS: Visual Analogue Scale.

Prostheses	Follow-up (years)	Survival Rate	Success Rate	Complications	Hard tissue assessment	Soft tissue assessment	Aesthetic assessment
Abutments: 44 Custom-made: 36 ZR, 8 Ti 10 Prefabricated Restoration: 53 all-ceramic, cemented, 1 metal-ceramic, cemented	5	100%	100%	Aesthetic: Porcelain fracture in one crown	Marginal Bone Level (distance from the IAJ): Mean: 1.1 ± 0.8 mm 32% ≤ 0.6mm 17% ≥ 1.8mm Bone loss: Mean: 0.6 ± 0.7 mm	PpI: 0 (n = 2, 4%) 1 (n = 7, 13%) 2 (n = 15, 28%) 3 (n = 30, 56%)	Patients' satisfaction: 32.43% desired a crown replacement 56.75% completely satisfied CDA Evaluation: 70% excellent 30% acceptable
Nickel Chromium Retainer alumina sand-blasted (50-250 μm) Panavia cemented	8.33	NR	NR	30 Debonded at least one No significant difference between cantilever design, one vs two retainer Porcelain Fracture: in one pontic	NA	NR	NR
Metal-Ceramic restoration, cemented	3	100%	100%	-	Distance implant shoulder-Bone: Mean: 0.49 ± 0.18mm Bone loss: NR	NR	Patient's satisfaction:NR Independent calibrated examiner evaluation (PES/WES) High aesthetic outcome PES Index: Mean: 8.15 ± 1.69 WES Index: Mean 8.70 ± 0.92
Abutment: NR Restoration: cemented	1.3-2.5 Mean: 1.96	87.5%	NR	One implant failed 3 weeks after implantation	Bone level: NR Mesial bone loss: 0.23-0.63 Mean: 0.48 Distal bone loss: 0.35-0.78 Mean: 0.662	NR	Patient's satisfaction (VAS) High degree of satisfaction Examiner/panel evaluation: NR
All-ceramic restoration (IPS e.max Press/ IPS Empress, Ivoclar Vivadent) Hydrofluoric acid etched (Pulpdent), Silanized (Monobond, Ivocla Vivadent)	DCNBE (0.31-13.5) Mean: 6	100%	NR	DCNBE (chipping of the incisal edge of one pontic (unnoticed by the patient)	NA	DCNBE (no differences in biological outcomes compared to the control teeth.)	DCNBE (High aesthetic outcome)
All- ceramic restoration (IPS e.max Zir CAD, Ivoclar Vivadent and Cerion, Straumann)	DCNBE (1-7.6) Mean: 4	100%	NR	DCNBE (2 debondings)	NA	DCNBE (no differences in biological outcomes compared to the control teeth)	DCNBE (High aesthetic outcome)
Abutments: 34Ti Restoration: 34 metal-ceramic restorations, cemented(zinc-phosphate luting agent)	2-3.3	97.06%	94.12%	Aesthetic: Exposure of 0.2 mm implant neck in one implant.	Bone level: NR Marginal Bone Resorption: 1.20 ± 0.61 mm	PI: 0 (n = 27) 1 (n = 6) GI: 0 (n = 31) 1 (n = 2) BI: 0 (N = 33) PpI: 0 (n = 0); 1 (n = 2); 2 (n = 4); 3 (n = 27); PD: Nss after 0.5, 1 and 2 years of function P > 0.05	Patient's satisfaction: NR Author's evaluation: Optimal aesthetic outcome

No complications were present for the remaining 113 implants. In the cases treated with resin-bonded prostheses, the main complication was the reported debonding, which occurred at least on one occasion for each prosthesis.

Periodontal/peri-implant assessment

In the first group of studies comparing the orthodontic space closure and prosthodontic intervention[59-63], the status of the soft tissues was evaluated by five indices: plaque index (PI), bleeding index (BI), gingival index (GI), probing depth (PD) and papilla index (PpI). As far as the PI is concerned, statistically significant differences were found in 50 patients treated by either orthodontic space closure or prosthodontic intervention. The greatest plaque accumulation was noted in patients who received prosthodontic treatment. In the remaining 87 patients no statistically significance difference was found regarding the PI. Concerning the BI/GI, there was a statistically significant difference in the presence of bleeding on probing in 83 patients, with patients treated by prosthodontic intervention exhibiting the greatest values. In 46 patients, no statistically significant difference was found in the BI, whereas one study[63] did not report on this issue. With regard to the PD, a statistically significant difference was found in 41 patients, with the highest index value in prosthodontic patients compared to the orthodontic ones. Conversely, in 96 patients, no statistically significance difference was found in PD between the orthodontic and prosthodontic treatments. As for the PpI, only one study reported on this index and revealed statistically significant differences between the orthodontic and implant patients, with regard to the mesial papilla of the maxillary lateral incisors; the mesial papilla filling was higher in the interdental embrasure, in patients where the orthodontic space was closed.

The distance between the implant shoulder and marginal bone ranged from 0.49 to 1.10 mm for 74 implants, while no information was given for 40 implants. Regarding the bone loss between examinations, 94 implants exhibited bone resorption from 0.48 to 1.20 mm, whereas no information was provided for 20 implants. As for the implant soft tissue assessment, the following indices were evaluated: PI, GI, PD and PpI. Unfortunately, only one implant study[70] examined the PI, GI and PD. Consequently no information was given concerning these indices for 81 implants included in the other studies. Regarding the PI for the remaining 33 implants, 27 implants scored 0 and six scored 1. Similarly, as for the GI, 31 implants scored 0 while two scored 1. Furthermore, in the same study, PD values did not show statistically significant differences 6 months, 1 year and 2 years after function. Concerning the PpI, only two studies reported on this index. Specifically, two implants (2.30%) scored 0, nine (10.34%) scored 1, 19 (21.85%) scored 2 and 57 (65.51%) scored 3, which represented the optimal interdental papilla fill. Lastly, in the articles examining the resin-bonded prostheses, information concerning the soft tissue evaluation cannot be extracted from the published data.

Aesthetic assessment

In all included articles[59-70], the aesthetic assessment was based on either the patient's satisfaction or examiner/panel evaluation. Regarding the patient's satisfaction, in the group of studies comparing the two different therapeutic options, a statistically significant difference was found amongst 50 patients, those who received orthodontic treatment appeared to be more satisfied than those who received prosthodontic treatment. However, in another study on 46 patients, no statistically significant difference was found regarding the patient's satisfaction and the jury evaluation, either after orthodontic space closure or prosthodontic intervention. In two studies, in 41 patients, no information regarding patient satisfaction could be obtained or could be extracted from the given data[61,63].

In the group of articles referring to the implant treatment[64,66,67,70], only two studies reported on the patient's satisfaction. Specifically, 26 patients (62%) were highly/completely satisfied with the aesthetic outcome, while 16 (38%) were not completely satisfied. The examiner evaluation revealed aesthetic results ranging from acceptable to high for 85 patients, whereas no information was given for five patients. Information regarding the aesthetic assessment was either not reported or could not be extracted from the presented data in articles on resin-bonded prostheses[65,68,69].

Discussion

The purpose of this study was to evaluate the biological, functional and aesthetic outcomes of two different therapeutic approaches in the treatment of maxillary lateral incisor agenesis. The management of patients with congenitally missing maxillary lateral incisors involves two therapeutic options: orthodontic space closure by canine mesial repositioning and reshaping or space opening and prosthodontic intervention (i.e. implant-supported restorations, resin bonded prostheses and fixed partial dentures). A systematic search of the literature was conducted to identify studies that examined maxillary lateral incisor agenesis treatment by either orthodontic or prosthodontic approach, so as to identify high-level evidence. Only 5 articles comparing the two different therapeutic options were extracted from the literature, while no randomised controlled trials could be found. Therefore, it was not possible to draw definitive conclusions about the superiority of one treatment option over the other regarding the biological, functional and aesthetic outcomes.

Our results suggest that the frequency of the congenitally missing lateral incisor in females was higher than in males at a ratio of 2:1. This finding is in agreement with the results of other authors who found that the prevalence of dental agenesis in females was 1.5 to 2.0 times higher than in males[71,72,73]. Concerning the type of lateral agenesis (i.e bilateral or unilateral), the frequency of absence of one maxillary lateral incisor in the same patient, does not differ from the frequency of agenesis of both laterals in the same patient, which is in agreement with the study of Celikoglu et al[74], although, other studies found that there are differences in the distribution of the agenesis type in the surveyed population[72,73]. Moreover, the unilateral incisor agenesis is associated with the contralateral incisor microdontia (peg-shaped teeth). The explanation of this association is that both dental anomalies (peg-shaped teeth and lateral agenesis) have the same genetic origin with different phenotypic expression[75].

Concerning the therapeutic option, the percentage of the sites in the direct comparison group which received orthodontic space closure and canine recontouring was higher than that of the sites which were treated with a prosthodontic intervention. This finding is in agreement with the results of Fekonja et al, who found that 87.5% of the patients with tooth agenesis had been treated by orthodontic space closure[76].

The majority of the patients who were treated with the prosthodontic approach had received orthodontic treatment to open or maintain the space prior to the prosthodontic rehabilitation. This is a reasonable finding, since in most cases the permanent canine inclines and moves mesially due to the absence of the laterals. In the present study, the results demonstrated that the frequency of the implant therapy did not exceed that of the conventional prosthodontic treatment. Regarding the surface characteristics of the implants and the type of the connection, information was extracted from the brand names of the implants. In the majority of the studies, implants with a rough surface were used. Clinical studies have shown that the rough surface implants presented higher survival rates than machined ones[77,78]. Concerning the type of connection, in the majority of the studies, implants with an external connection were used. Additionally, the implant-crown survival and success rate was high, which is in agreement with previous studies[79-86].

In the direct comparison group, none of the studies revealed signs and symptoms of the temporomandibular joint disorders, associated with the orthodontic or prosthodontic intervention. Earlier studies agree with this finding and it has been shown that the occlusal condition did not correlate with signs and symptoms of mandibular dysfuction[87,88]. Regarding the occlusal scheme established after the treatment of lateral agenesis, only two studies mentioned that there were no significant differences in the number of centric interferences and excursive contacts between the orthodontic space closure and the prosthodontic intervention.

The space closure patients in the direct comparison group showed a healthier periodontium than the patients with prosthetic appliances. Regarding the plaque index and bleeding index, greatest plaque accumulation and bleeding on probing scores were noted in patients who received prosthodontic treatment. Similarly, the probing depth was higher in implant patients. As for the papilla index, one study reported on this index and found that the mesial papilla filling in the interdental space was higher in

the space closure patients than in the prosthodontic patients[59].

In the prosthodontic treatment group, the majority of the implants exhibited a bone loss range from 0.48 to 1.20 mm. This finding is in agreement with Thilander et al who found a 0.75 mm marginal bone loss at implants in the upper lateral incisor area[89]. Regarding the condition of the interdental papilla, 65% of the implants showed optimal papilla filling of the interdental space. The prosthodontic intervention showed complications both in the implant and the rehabilitation of the resin-bonded prostheses. The reported complications were both biological and technical and included implant infraocclusion, thread exposure, implant loss, porcelain chipping in implant crowns and resin-bonded debondings.

Concerning the aesthetic assessment, in the direct comparison group, two studies reported on the patients' satisfaction and demonstrated that 52% of the patients showed a significant difference, with greater satisfaction amongst the space closure patients. Although a direct conclusion could not be drawn regarding the patients' preference, it seems that the patients tended to be more satisfied with the orthodontic approach, since they kept their own teeth. In the purely prosthodontic approach group, only two implant studies reported on the patients' satisfaction and found that the majority of the patients were highly satisfied with the implant aesthetic outcome.

Early diagnosis of the agenesis of the laterals at 8 to 9 years of the child's age, is often linked to the kind of suitable intervention that should be followed amongst the various treatment options. However, Hobkirk et al found that more than half of the patients referred to a clinic in the UK, for the rehabilitation of tooth agenesis, were over 12 years old[90]. Clinicians should be aware of clinical signs that indicate maxillary lateral incisor agenesis. Delayed eruption of the permanent tooth, more than 1 year beyond the expected time, or more than 6 months after the eruption of the contralateral tooth, should suggest that the permanent tooth is absent, with subsequent radiographic examination. Similarly, the persistence of a primary tooth may denote developmental absence of the permanent successor[73,91]. Other signs of a congenitally missing lateral incisor include the deviation of the maxillary dental midline, a molar and canine Class II malocclusion, palatal displacement of canines and microdontia of contralateral incisors (peg-shaped maxillary lateral incisors)[92,93,94]. In addition, patients with congenitally missing lateral incisors have narrower teeth than patients without any dental anomalies[95,96].

Orthodontic space closure

Several studies have reported on the advantages of the orthodontic space closure[4,48,97,98]. The main advantage is the longevity of the therapeutic result and the completion of the treatment in early adolescence. Moreover, the early mesial movement of the canine into the edentulous space of the lateral incisor maintains a normal gingival and alveolar architecture which is very important in patients with a high smile line[48,98,99]. Furthermore, the avoidance of demanding prosthodontic procedures, limits the potential risk of complications involved in the prosthodontic intervention. Also, the orthodontic space closure is less costly compared to the implant intervention, often after orthodontic space opening, and it gives the patient the impression that there is no missing tooth[4,98].

Clear indications for orthodontic space closure and canine substitution, in cases of congenitally missing lateral incisors, include two types of malocclusions[35,97,98,100,101]. The first concerns patients exhibiting severe crowding in the mandibular anterior segment and Class I molar relationship. In these cases, orthodontic space closure by canine mesial repositioning, along with mandibular extractions, usually of the mandibular first premolar leads to a predictable final result. The second malocclusion that favours canine substitution in the position of the lateral incisor is an end-to-end or Class II molar relationship, without crowding and dental protrusion in the mandibular anterior segment.

Certain factors that clinicians should consider in the decision- making of whether or not to close the space are the facial profile, the canine dimensions, the colour of these teeth and the gingival height[35,98]. Regarding the facial profile, a straight or slight convex profile is suitable for space closure unlike a serious convex profile with a retrusive mandible[35]. This is to avoid an optimal occlusion with compromised facial aesthetics, where a combination of orthog-

nathic surgery to correct the facial discrepancy and prosthodontic replacement of the laterals should be considered. As far as the size of canine is concerned, an average canine is 1.5 mm broader than the lateral incisor and after recontouring, should be slender than the central incisor. Specifically, canine recontouring should be done so as to eliminate the labial and proximal convexities, the lingual cingulum, and to form the mesioincisal and distoincisal edges. Unfortunately, in many cases, when canines are relatively large compated to the central incisor dimension, canine recontouring requires a significant amount of tooth reduction so as to resemble a lateral incisor, resulting inevitably in a restorative intervention on the shape of the canines and in order to increase the size of the central incisors. The canine width at the cementoenamel junction is decisive on the required interventions, since it determines the amount of possible mesiodistal reduction.

Another point to be considered is the colour difference of the canines that are darker than incisors, a shade that becomes even more yellowish with extensive tooth recontouring[4]. This may be a reason to avoid the labial recontouring, by increasing the palatal root torque of the canine and decreasing occlusally the canine cusp length, which leads to a reduction in the extension of the labial canine convexity. Another approach to overcome the colour difference between canines and incisors is the tooth bleaching or the restorative treatment consisting of composite build-ups, veneers or all-ceramic crowns[102].

Regarding the soft tissue architecture, the gingival zenith of the lateral incisor should be ideally 0.5 to 1.0 mm lower than the central incisors and canines[4]. To achieve an aesthetic gingival contour, the gingival margin of the central incisor and the first premolar should be at the same level, while the gingival zenith of the canine should be slightly incisal, by extrusion of the canine, balanced by grinding of the tip of the cusp and intrusion of the first premolar, with a compensatory reconstructive increase of the crown length, parallel to its palatal cusp reduction. Additionally, during the orthodontic space closure, attention should be given to provide a slight mesial titling of the crown of the canine so as to imitate the titling of the lateral; which can occur by full uprighting of the mesially displaced and tilted canine, through extensive mesial root displacement. Moreover, the clinician should bear in mind that after the completion of the mesial movement of the maxillary canine, group function is usually established since the tip of the canine occludes with the mandibular lateral incisor. Last but not least, the stability of the space closure demands long-term retention with direct-bonded lingual retainers[48,98].

Prosthodontic intervention

The second therapeutic option in the treatment of the congenitally missing lateral incisor includes the prosthodontic intervention. Space distribution of the edentulous regions, mesial and distal to the canines and the central incisors, respectively; occlusion; and aesthetics determine whether or not orthodontic space opening is needed prior to the prosthodontic rehabilitation. Canines should allow posterior disclusion during eccentric excursions, while central incisors should be placed in a position dictated by aesthetic and phonetic demands. Regarding the determination of the appropriate spacing needed for the lateral incisor, three methods are described in the literature[33,34]. The first method is based on the golden proportion. According to this, aesthetics and harmony are achieved in the maxillary anterior segment, when the width of each anterior tooth is 61.8% wider than the tooth distal to it, in the facial view. However, Pini et al observed that while the golden proportion was not found in the majority of patients with lateral agenesis, the smiles were still pleasing[103]. This finding demonstrates that the golden proportion may be a useful diagnostic guide, while a certain range of tolerance exists to achieve a high aesthetic outcome. The second method includes the determination of the space needed according to the contralateral incisor, whenever this is present and has a normal size. The third method refers to the Bolton analysis, where in order to obtain the proper interdigitation and arch coordination when the molars are in a Class I relationship, the dimension of the upper teeth has to be proportional to the dimension of the lower teeth. Regardless of the method that will be used, a diagnostic wax-up still remains a useful tool for the evaluation of the space distribution. According to Kinzer et al, the usual remaining space for a lateral incisor restoration should be 5 to 7 mm[33].

Space opening and prosthodontic intervention is indicated in cases of Class I molar relationship without malocclusion, Class III malocclusion with a concave facial profile, and in cases in which the canine recontouring is not recommended[98,104] (see previous chapter). The prosthodontic intervention includes the following therapeutic options: i) single-tooth implant; ii) resin-bonded fixed partial denture; and iii) full-coverage fixed partial denture.

(i) The single-tooth implant option is considered to be the most conservative approach in cases of sound adjacent teeth. However, the clinician should consider several parameters regarding a) the time of implant placement; and b) the time of orthodontic space opening, with respect to the amount of bone available for implant insertion[4,35].

a) The time of implant placement: numerous studies have reported the risk of infraocclusion of the implant crown if the implant is placed before the completion of the facial growth and the dental eruption. As a rule of thumb, females complete their facial growth by 17 years old, whereas males demonstrate a facial growth up to 25 years old[105]. However, large variations exist amongst individuals, therefore different methods are proposed to determine the patient's skeletal maturation. Hand-wrist radiographs and more recently, the cervical vertebral maturation method, have been used to estimate the amount of remaining craniofacial growth[106,107]. However, the reliability of growth prediction with these methods is not high[108]. Moreover, the superimposing of serial lateral cephalometric radiographs obtained 6 months to 1 year apart has been proposed to be useful in the evaluation of the completion of the facial growth. Facial growth could be considered as completed when the distance between the cephalometric points nasion and menton is stable[4]. However, this method is not recommended either, since the patient is exposed to radiation in an accumulative manner, while it has been shown that the facial dimensions are changing also during mature adulthood[109]. The most 'innocent' and inexpensive method is the standardised recording of the body height obtained every 6 months. In general, most of the facial growth could be considered to be completed 1 year after stagnation of the body height increase. Attention should be paid to the fact that the risk of infraocclusion of the implant crown 5 to 10 years after the treatment may happen also during mature adulthood, due to continuous eruption of the teeth long after the completion of the facial growth[110].

b) The time of the orthodontic space opening with respect to the amount of bone available for implant insertion: the procedure to obtain the adequate mesiodistal distance between the central incisor and the canine was linked to the available bone volume of the edentulous space, in patients with congenitally missing lateral incisors, as well as the best time when orthodontic treatment should occur prior to implant placement[111].

Early diagnosis is very important particularly in patients scheduled for future implant therapy. This allows for planned extraction of the primary lateral incisor and the guided eruption of the canine adjacent to the permanent central incisor, avoiding bone loss and ensuring a proper implant site is established in the region of lateral agenesis[33,99]. Few studies have measured and compared changes in the alveolar ridge dimension at the beginning and the end of the orthodontic therapy[49,111,112,113]. In most of these studies, the information was obtained by measuring these changes on plaster models, which may provide indications on the alveolar bone changes only[49,111,113]. Novackova et al found a 4% reduction in the alveolar ridge width and a 0.26 mm reduction in the ridge height at the end of the orthodontic treatment, that was further reduced some years later by 2% and 0.38 mm, respectively. The results of this study showed minimal changes in the ridge width and height, indicating a stable and well preserved alveolar ridge[113]. In contrast, Beyer et al estimated an increase in bone deficiency from 0.26 mm^2, at the beginning of the orthodontic treatment, to 1.92 mm^2 and 3.77 mm^2, at the completion of the orthodontic treatment and implant insertion, respectively. Additionally, the same study has shown that patients who received orthodontic space open-

ing after the age of 13 years, demonstrated more extensive reduction of the alveolar ridge dimensions, than the reduction observed in patients who received orthodontic space opening before the age of 13 years old[111]. Another study on dental cast measurements has also demonstrated a 13% to 15% decrease in the ridge width after orthodontic space opening and a 6% to 12% loss of the ridge height. These authors found an 0.5 mm increase in depth of the labial concavity between the maxillary central incisor and the canine[49]. Similar results were found on a smaller number of patients, using cone-beam computed tomography. Although more invasive than measuring dental casts, this method was more reliable and presented an alveolar bone width reduction by 17% to 25%, and a significant increase in the labial concavity, after the completion of the orthodontic space opening[112]. In cases where the bone width and height have undergone severe reduction, a bone graft may be necessary to establish the appropriate implant site.

Other factors that the clinician should take into consideration are the interradicular spacing and the retention of the space after the completion of the orthodontic treatment[33,114]. During the orthodontic space opening, the coronal mesiodistal space is achieved earlier than the interradicular mesiodistal distance, that is indispensable for the implant placement[4]. Therefore, radiographically evaluating the root distance before the removal of the orthodontic appliance is recommended. Regarding the postorthodontic root approximation after space opening, Olsen et al found that 11% of the patients presented with an inadequate space between roots, preventing the implant placement. According to the author's recommendation, an interradicular distance of 5.7 mm between the central incisor and the canine is considered sufficient for implant placement[114]. Moreover, the use of a fixed bonded lingual wire or a resin-bonded prosthesis is suggested for the retention period, while Krassnig et al recommended the use of a removable retainer such as a Hawley or an Essix retainer, when the retention period is anticipated to be short[4].

Several studies have reported on the successful osseointegration of the single implants placed in the anterior maxilla[79-86]. Despite successful osseointegration, various studies have shown that resorption of the facial bone wall, recession of the midfacial soft tissue, thread exposure and infraocclusion might occur[86,89,110,115-117] . According to den Hartog, Cosyn and Mangano, 40%, 26% and 11% of cases displayed unacceptable aesthetic results, due to the incomplete papilla filling, the facial recession and alveolar bone deficiencies[84,117,118]. Another side effect demonstrated by Bernard et al refers to vertical discrepancies that develop some years later, both in adolescent and adult patients, between adjacent teeth and implants, ranging from 0.10 mm to 1.86 mm[110]. This confirmed and completed the previous findings of Thilander et al, who detected the risk of development of infraocclusion amongst the adolescents[89]. Additional biological complications include fistulas, peri-implant mucositis and peri-implantitis, while the most frequent technical complications were screw loosening and porcelain chipping[80,82,86].

(ii) Amongst the solely prosthodontic interventions, the resin-bonded prostheses are considered to be the most conservative option, since the adjacent teeth are subject to minimal tooth preparation. Except for the conservative nature of the preparation, other advantages include the avoidance of pulpal trauma, the supragingival preparation, the simplicity of the clinical procedures and the reduced cost and chair time, in comparison with the conventional fixed prostheses[119]. To achieve predictable and optimal aesthetic outcomes using resin-bonded prostheses, the clinician should take into consideration specific requirements of each treatment option[34]. The first requirement is related to the vertical position of the abutment teeth. Regarding the vertical position, the shallow overbite is considered to be the ideal interincisal relationship, since it reduces the excessive lateral forces on the abutments and permits sufficient tooth surface for bonding. The second requirement concerns the incisors' inclination. The upright incisors' relationship with an increased interincisal angle leads to the development of shear forces in the abutment teeth, which are more favourable than the tensile forces exerted when incisors are proclined with a smaller interincisal angle[4]. The third requirement is the absence of the teeth mobility. Specifically, the mobility

of the abutments leads to the development of different force vectors under the occlusal load, resulting in increased stress on the prosthesis. Excessive forces are placed on the prosthesis even when only one abutment is mobile[34]. The fourth requirement is related to the labiolingual thickness of the abutments and the translucency of the enamel. When the incisors are too thin, with a high degree of translucency, the extension of the metal retainer on the incisal third leads to an undesirable gray shade abutment[4,34]. To overcome this problem, all-ceramic and/or zirconia restorations can be used, which have high aesthetic outcomes. Furthermore, parafunction activities such as bruxism negatively influence the long-term success of resin-bonded prostheses[120]. Consequently, the patient selection is the most critical aspect when the clinician considers the resin-bonded prostheses as a possible therapeutic option.

Various studies have been published in the literature, regarding the longevity of the resin-bonded prostheses[121-125]. A systematic review conducted by Pjetursson et al on earlier types of resin-bonded prostheses demonstrated a 5-year survival rate of 87.7%. The most frequent complication was debonding[126]. All the included studies except that by Kern et al[127] examined metal-ceramic resin-bonded prostheses. Other reported complications were fractures and slight grayness of the abutments[127,128,129]. However, the change in the prosthesis design from two retainers to a single retainer, as well as the use of all-ceramic restorations, with more recent cementation systems, have decreased the high frequency of debondings and fractures leading to increased survival rates. This is supported by literature on cantilevered all-ceramic resin-bonded prostheses, which exhibited survival rates ranging from 94.4% to 100% [68,69,130,131].

(iii) The full-coverage fixed partial denture is the last prosthodontic therapeutic option in the treatment of congenitally missing lateral incisors. This approach is considered as the least conservative of all tooth-supported restorations and its use is quite rare in the treatment of tooth agenesis in the anterior region. The indications for the full-coverage fixed partial denture include the replacement of an existing fixed partial denture and the presence of adjacent teeth that require rehabilitation due to extensive caries, fractures and/or discolourations. One of the basic principles in the preparation of abutment teeth for fabrication of a full-coverage restoration is the alignment of the abutment teeth along a common pathway. This can lead to extensive tooth reduction, in cases in which one of the two abutment teeth is malpositioned, increasing the risk of pulpal trauma, especially in young patients. This problem can be overcome by orthodontic correction of the proclined abutments[132]. A systematic review conducted by Sailer et al reported a 5-year survival rate of metal-ceramic restorations to be 94.4% and of all-ceramic restorations to be 88.6%. As for the all-ceramic restorations, the most frequent technical complications were marginal discolouration (15.3%) and porcelain chipping (13.6%), while the most serious complication was the framework fracture. Additionally, loss of retention and biological complications (i.e. caries and pulpal necrosis) were frequent for both types of restorations[133].

The treatment choice is based on a complex decision-making procedure. Except for the biological, aesthetic and functional outcomes, financial issues should also influence the final decision-making. Antonarakis et al compared the long-term cost-effectiveness of the different prosthodontic therapeutic options in patients with congenitally missing lateral incisors and found that the least cost-effective therapeutic modality was the full-coverage fixed partial denture, while the resin-bonded prostheses were considered as more cost-effective than the single implant crowns[134]. Other studies demonstrated the superiority of the implant approach over the fixed partial dentures, regarding cost-effectiveness[135,136,137]. However, in most cases of lateral agenesis, an orthodontic space opening is required prior to the implant therapy. Thus, the combination of orthodontic and prosthodontic therapy should be taken into consideration when evaluating the cost-effectiveness of different therapeutic modalities in the rehabilitation of lateral agenesis.

The absence of randomised controlled trials and the limited number of prospective and retrospective studies comparing the two different therapeutic options make it difficult to draw definitive conclusions about the superiority of one treatment option over the other, regarding the biological, functional and aesthetic outcomes. According to this systematic review, both therapeutic options are acceptable. However, it seems that in cases where both the therapeutic approaches are applicable, the orthodontic space closure is advantageous over the prosthodontic rehabilitation, regarding the periodontal health and the aesthetic outcome. Moreover, the main advantage of the orthodontic treatment is the longevity of the therapeutic result and the completion of the definitive treatment during early adolescence, without the risk of long-term biological and technical complications accompanying the prosthodontic rehabilitation. Well-designed randomised clinical trials and multicenter studies are required to compare these different therapeutic options.

In conclusion, early diagnosis of the congenitally missing lateral incisor is important, since it allows for planned extraction of the deciduous lateral incisor and the guided eruption of the canine adjacent to the permanent central incisor, either to proceed to later space closure or to open space for prosthodontic rehabilitation. Consequently, the bone loss is avoided and the alveolar ridge thickness is maintained. Lastly, when both orthodontic and prosthodontic intervention are possible, therapeutic options, the orthodontic space closure is more preferable than space opening, due to its superiority in the periodontal health and aesthetic outcome. Moreover, the early completion of the definitive treatment and the absence of the long-term biological and technical complications make the orthodontic space closure the treatment of choice, in cases where both therapeutic options are indicated.

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Outcome of bonded vs all-ceramic and metal-ceramic fixed prostheses for single tooth replacement

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Key words *all ceramic, fiber reinforced composite, fixed dental prosthesis, inlay-retained, metal ceramic, resin-bonded*

Aim: The conventional treatment of a single missing tooth is most frequently based on the provision of a fixed dental prosthesis (FDPs). A variety of designs and restorative materials are available which have an impact on the treatment outcome. Consequently, it was the aim of this review to compare resin-bonded, all-ceramic and metal-ceramic FDPs based on existing evidence.
Materials and methods: An electronic literature search using "metal-ceramic" AND "fixed dental prosthesis" AND "clinical, all-ceramic" AND "fixed dental prosthesis" AND "clinical, resin-bonded" AND "fixed dental prosthesis" AND "clinical, fiber reinforced composite" AND "clinical, monolithic" AND "zirconia" AND "clinical" was conducted and supplemented by the manual searching of bibliographies from articles already included.
Results: A total of 258 relevant articles were identified. Metal-ceramic FDPs still show the highest survival rates of all tooth-supported restorations. Depending on the ceramic system used, all-ceramic restorations may reach comparable survival rates while the technical complications, i.e. chipping fractures of veneering materials in particular, are more frequent. Resin-bonded FDPs can be seen as long-term provisional restorations with the survival rate being higher in anterior locations and when a cantilever design is applied. Inlay-retained FDPs and the use of fiber-reinforced composites overall results in a compromised long-term prognosis. Recently advocated monolithic zirconia restorations bear the risk of low temperature degradation.
Conclusions: Several variables affect treatment planning for a given patient situation, with survival and success rates of different restorative options representing only one factor. The broad variety of designs and materials available for conventional tooth-supported restorations should still be considered as a viable treatment option for single tooth replacement.

Conflict of interest statement: *The author declares that he has no conflict of interest.*

■ Introduction

The replacement of single missing teeth is of significant clinical importance and several treatment options exist, all having specific advantages and limitations[1-7]. Despite the purportedly advantageous rehabilitation of missing single teeth with oral implants, patients already perceive benefits in chewing ability, aesthetics and satisfaction with their oral situation, after receiving conventional dental prostheses[8]. A variety of restoration designs and materials exist for tooth-supported reconstructions spanning from fiber-reinforced composites to metal alloys and ceramic materials[9]. Numerous clinical

Table 1 Relevant clinical parameters for treatment planning.

Neighbouring teeth[2,10-13]	Caries free? Endodontically treated? Periodontally involved? Deformations / Discolorations? Trauma? Amount of tooth substance available for retention
Location and Occlusion[9,10,14,15]	Anterior vs. Posterior Mandible vs. Maxilla Occlusal relationship
Space and volume requirement[3,16-21]	Restorative space available Bone and soft tissue volume available
Patient status[10,19,20,22,23]	Skeletal growth completed Patient age and co-morbidities
Restoration design and material[15,24]	Metal alloys vs. Ceramics vs. Fiber-Reinforced Composite Cement type End-Abutments vs. Cantilever vs. Resin-bonded
Human factor[25,26]	Experience of treatment provider Patient education

parameters have to be taken into account during the process of treatment planning (Table 1).

An extensive survey amongst 200 patients who received different types of restorations to replace single missing teeth has revealed that restoring aesthetics and function was their main motivation for treatment. Damage of the neighboring teeth, pain, postoperative sensitivity and dental phobia were important factors in selecting a specific type of restoration or no treatment. Patient satisfaction decreased from implant-supported single crowns to conventional and resin-bonded fixed dental prostheses (FDPs). No treatment and removable partial denture treatment showed the lowest levels of satisfaction[26]. On the other hand, a survey amongst general practitioners in Belgium revealed that for 42% of all teeth extracted, no treatment was rendered, due to lack of treatment decision or because tooth replacement was deemed unnecessary. Removable restorations were chosen in 54%, fixed dental prostheses in 24%, single implants in 21% and resin-bonded fixed dental prostheses in 1% of all cases. The authors also pointed out that patient-related socioeconomic factors, as well as the clinician's experience with different treatment modalities had an effect on treatment planning[27].

Given the complexity of the decision-making process for both the clinician and the patient, it was the aim of this review to provide a comprehensive overview on treatment outcomes of resin-bonded versus all-ceramic and metal-ceramic fixed dental prostheses for single-tooth replacement.

Material and methods

An electronic MEDLINE (PubMed) search was conducted using the following combinations of search terms "metal-ceramic" AND "fixed dental prosthesis" AND "clinical (552), all-ceramic" AND "fixed dental prosthesis" AND "clinical (783), resin-bonded" AND "fixed dental prosthesis" AND "clinical (364), fiber reinforced composite" AND "clinical (280), monolithic" AND "zirconia" AND "clinical (45) ". Publications up to the year 1990 were considered. In addition, a manual search of bibliographies from relevant articles was carried out. From an initial yield of 1979 titles, 258 articles were considered as being relevant for this review with no restrictions being applied in terms of study design, patient selection and observation period. Given the availability of recent systematic reviews and meta-analyses for different types of conventional fixed restorations, the focus was a descriptive and critical overview.

Results

General aspects of FDPs

Conventional fixed reconstruction of missing teeth requires the preparation of abutment teeth and the subsequent placement of a fixed dental prosthesis. In addition to losing a significant amount of tooth substance[28,29], preparation of teeth bears the risk of irreversibly damaging pulpal tissue[30].

Besides utilising teeth mesially and distally adjacent to the edentulous site as abutments, cantilevered restorations based on at least two teeth mesially or distally to the edentulous site are an alternative option. Such cantilever FDPs require a more thorough treatment planning[31] and are biomechanically less favourable; furthermore, precautions have to be taken to avoid exaggerated moment loading on the abutment teeth[32]. Comparing different types of FDPs placed on teeth and implants as end abutments or with cantilevers, Brägger et al found after a

mean observation period of 11.3 years, that the success rate was significantly higher in FDPs with end abutments, compared to cantilever FDP designs[33]. This was consistent with a former report[34].

Based on a retrospective chart review, Libby et al identified a list of complications limiting the longevity of FDPs from 4.1 up to 16.0 years. The reasons for failure were dental caries (38%), periapical involvement (15%), perforated occlusal surfaces (15%), a fractured post and cores (8%), defective margins (8%), fractured teeth (7%) and porcelain failures (8%)[35], which is consistent with other clinical reports[34,36].

As a general trend, it has been shown that short-span FDPs predominantly fail due to biological complications, whereas long-span FDPs are prone to technical complications. Overall, short- span restorations exhibit greater survival rates compared to long-span FDPs[37,38]. The performance of short-span FDPs is even better when vital teeth are being used as abutments. No relationship between gender and irreversible complications could be found. Failures occurred in patients who were older when initial treatment was rendered[39].

Heschl et al evaluated extensive FDPs placed in periodontally compromised patients, after a mean observation period of 75.7 months. While probing depths remained at a constant level, significant deteriorations were observed based on plaque index scores and bleeding on probing. The authors nevertheless concluded that treatment with tooth-supported extensive FDPs can be recommended even in patients with a history of periodontitis, given a favourable distribution of abutment teeth[40]. However, it has also been shown that ill-fitting crown margins and excess cement may have a negative impact on periodontal health of the abutment teeth[41]. Similarly, Suárez et al observed gingival bleeding more frequently around crowned teeth compared to contralateral teeth[42]. Robertsson found impaired periodontal health with accumulation of plaque and gingivitis following FDP treatment[43].

Connector dimensions are an important factor for the mechanical reliability of FDPs and material-specific minimal dimensions are recommended by the manufacturers. However, these guidelines are often not adhered to due to space limitations in specific situations[44].

Metal-ceramic FDPs

Aimed at improving aesthetics and survival rates of resin-veneered gold restorations, metal-ceramic systems were developed[45-47]. Based on different reports from that epoch, clinicians considered metal-ceramic restorations to be more aesthetic[48], while metal-resin restorations or metal-ceramic restorations with metal margins were believed to show better marginal adaptation[48-50].

Wear of the opposing dentition was initially described as a clinical problem in porcelain-fused-to-metal restorations, due to the comparatively high surface hardness of the veneering material[51,52]. The occurrence of veneer fractures has been a further problem associated with the composite structure of metal-ceramic restorations, which even warranted the development of special intraoral repair systems[53]. Furthermore, gingival bleeding and the deepening of gingival pockets[54] were described as negative side effects of metal-ceramic restorations, potentially due to insufficient preparation depth of the abutment teeth. Despite these initial shortcomings, resulting in compromised longevity[55], metal-ceramic restorations were in widespread use[56]. Acceptable clinical performance has been reported even for extreme clinical situations including multi-unit restorations, questionable abutment teeth and advanced periodontal involvement[57].

For porcelain-fused-to-metal restorations, allergic reactions[58] to high noble and noble metal alloy cores (palladium and gold) and to base metal alloys (nickel and cobalt) have been reported[59]. However, gingival health around metal-ceramic restorations were reported to be less compromised compared to resin-veneered silver-palladium restorations[60].

A broad range of survival rates for metal-ceramic FDPs has been determined by various authors, ranging from 92.8% to 98.0% after 60 months and from 84% to 87% after 120 months. A recent prospective study even reported a 94.4% survival rate of FDP retainer crowns after 132 months of function (Table 2).

Titanium has more recently been introduced as a core material with contradictory results on the clinical performance in the literature[36]. Substantial differences in the coefficient of thermal expansion between titanium and conventional noble and

Table 2 Clinical performance of metal-ceramic fixed dental prostheses. Note: shaded lines present follow-up studies of the same patient cohort.

Author	Restoration type	Materials	No. of restorations	Observation period [months]	Survival [%]	Remarks
Svanborg et al 2013[61]	FDPs (varying design and number of units)	CoCr	201	60	92.8	Success: 83.8%
Näpänkangas et al 2002[38]	FDPs (majority 3- to 5-unit)	Not specified	195	120	84.0	
Walton 2002[62] and Walton 2003[63]	FDPs (majority 3-unit)	High noble alloys	515	60	96.0	Tooth fractures (38%), caries (11%), loss of retention (13%), periodontal breakdown (27%)
				120	87.0	
				180	85.0	
Behr et al 2012[64]	FDPs (3- and 4-unit)	Precious alloys	654	60	94.0	Chipping fractures 4.3%
				120	87.0	
Reitemeier et al 2013[65]	Posterior metal ceramic FDP retainers	High noble / noble alloys	276*	132	94.4	* retainer crowns Success rate: 81.7% Bruxism as risk factor
Walter et al 1994[66]	Single crowns and FDPs	Ti	88	36	95.0	Success rate: 84%
Kaus et al 1996[67]	Single crowns and FDPs up to 6-units	Ti	84	30	59.0	Survival rate for crowns: 85%
Walter et al 1999[68]	FDPs (3- and 4-unit)	Ti	22	60	84.0	
		Gold alloy	25		98.0	
Boeckler et al 2010[69]	FDPs (majority 3-unit)	Ti	31	36	96.8	Success rate: 76.4%
Hey et al 2013[70]	FDPs (majority 3-unit)	Ti	31	72	88.0	Success rate: 58.6%

non-noble alloys necessitated the development of adequate veneering materials and an additional learning curve[71]. Two reports on a clinical study involving single crowns and a variety of FDP types, fabricated with the Procera system (Nobel Biocare, Zürich, Switzerland), showed favourable outcomes after 5 years of clinical service[72,73]. Similarly, a multicenter university-based study on single crowns and 3-unit FDPs, using the same system, showed that 95% of all restorations performed satisfactorily with respect to surface and colour, anatomic form and marginal integrity, both after insertion and after 1 year of service[74].

In general, the compromised performance of titanium-based metal-ceramic FDPs results in lower survival rates up to 96.8% after 36 months, decreasing to 84% and 88% after 60 and 72 months, respectively (Table 2).

All-ceramic FDPs

In order to overcome limitations of metal-ceramic restorations with respect to aesthetics, invasiveness[1] and biocompatibility[75-78], different all-ceramic systems have been considered for the fabrication of FDPs, ultimately aimed at replacing metal-ceramic restorations[79]. Despite the comparatively short availability of all-ceramic systems, a decrease in complication rates can already be noticed when comparing earlier and later publications. This may be indicative of a learning curve associated with new materials, manufacturing techniques and clinical procedures such as cementation protocols[80-82].

An early approach to all-ceramic restorations was a castable glass ceramic (Dicor; DeTrey-Dentsply, Konstanz, Germany), which was considered to show better aesthetic results, better wear characteristics and diminished oral plaque accumulation, but required a bonding protocol with etching prior to luting for achieving sufficient survival rates[83]. Other approaches in the field of silica-based ceramics included leucite-reinforced glass ceramics (Empress; Ivoclar Vivadent AG, Schaan, Liechtenstein) and lithium disilicate ceramics (Empress 2; Ivoclar Vivadent AG)[84]. Infiltration ceramics (In-Ceram; VITA Zahnfabrik, Bad Säckingen, Germany) constituted a first step towards the use of oxide ceramics as restorative materials[85,86]. The advent of sophisticated Computer aided design / Computer aided manufacturing (CAD/CAM) systems[87-90] facilitated the use of

pure oxide ceramics, such as zirconia ceramic, which can be used in a variety of clinical indications[77,91,92]. Major advantages of zirconia ceramics include high flexural strength, allowing for conventional cementation[93], fracture toughness, biocompatibility, aesthetics[94] and ultimately a greater reliability compared to infiltration ceramics and silica-based ceramics[87]. Consequently, in a series of literature reviews, Raigrodski et al described Zirconia-based FDPs as an acceptable restorative option in both the anterior and posterior segments[88,95-98].

Several authors stressed the excellent biocompatibility of zirconia ceramics did not cause allergy symptoms in a group of patients showing allergic reactions to metal-ceramic restorations[99]. The use of zirconia ceramic also did not deteriorate periodontal parameters[100,101] and avoided marginal discolouration[101].

From a manufacturing point of view, early zirconia restorations were problematic, showing high levels of marginal discrepancy, resulting in secondary caries and consequently lower survival rates[102,103]. More recent reports, however, showed that after short observation periods, 93.75% of zirconia-ceramic FDPs had appropriate marginal matching[101]. Connector dimensions appear to be extremely critical for the performance of all-ceramic restorations, and various authors showed that manufacturer recommendations often cannot be met[104-107]. In a retrospective analysis of 120 zirconia-based FDPs, the incidence of framework fractures during the first year was limited to 1.7%[108].

Chipping of the veneer ceramic seems to be the major technical complication in restorations based on zirconia ceramic[102,103,109,110]. Risk factors which have been identified include FDP span[103], endosseous implants used as abutments[111,112], absence of a nightguard, presence of a ceramic antagonist restoration and parafunctional habits[111]. From a material point of view, a reduction in thermal mismatch between core and veneer[113], as well as anatomically contoured substructures supporting the veneer have been advocated[114,115].

For lithium-disilicate ceramics, the literature reports 10-year survival rates of 71.4% and 87.9% which, overall, seems to be comparable to different types of infiltration ceramics[106,107,117,118]. A good body of literature exists on the clinical performance of zirconia-based FDPs with high numbers of restorations placed and long observation periods. Despite a high incidence of chipping fractures, zirconia-based restorations appear to have good survival rates (Table 3).

Comparison of metal-ceramic FDPs vs all-ceramic FDPs

Different authors directly compared metal-ceramic and all-ceramic restorations with respect to clinical performance, patients' preference and periodontal aspects. In an older study on patients' perception of all-ceramic and metal-ceramic crowns and FDPs, it could be shown that the shade and colour of a restoration are the most discriminating factors for assessing overall treatment quality. Contradictory results were described with patients considering all-ceramic crowns as being more natural and metal-ceramic FDPs as being more natural compared to alternative materials[143].

Both metal-ceramic and all-ceramic FDPs seem to not affect periodontal health, as determined by the plaque index, the gingival index and the probing depth, compared to unaltered teeth[144-146]. This is supported by a study by Zenthöfer et al who could not find a difference in probing pocket depth, probing attachment level, plaque index, gingival index and aesthetic performance between cantilever FDPs, made from zirconia and metal frameworks, respectively[147].

On the other hand, there seems to be a difference between metal-ceramic and all-ceramic restorations, in terms of technical complications with metal-ceramic FDPs being more durable[146,148]. Despite showing a survival rate of 100% for both metal-ceramic and all-ceramic FDPs, Sailer et al reported chipping rates of the veneering ceramic being 25% for zirconia ceramic and 19.4% for metal-ceramic FDPs, with extended fractures of the veneer occurring only in zirconia-based restorations[149].

Based on the results from five clinical studies, it appears that lithium disilicate and alumina ceramic show lower long-term survival rates compared to metal-ceramic restorations. However, hardly any difference in clinical performance seems to exist between FDPs made from zirconia-ceramic and metal-ceramic FDPs (Table 4).

Table 3 Clinical performance of all-ceramic fixed dental prostheses. Note: shaded lines present follow-up studies of the same patient cohort.

Author	Restoration type	Materials	No. of restorations	Observation period [months]	Survival [%]	Remarks
Zimmer et al 2004[104]	3-unit anterior FDPs	IPS Empress 2	31	38	72.4	3 framework fractures (insufficient connector dimensions) 1 veneer fracture 2 biologic failures
Marquardt and Strub 2006[116]	3-unit anterior FDPs	IPS Empress 2	31	50	70.0	3 framework fractures (insufficient connector dimensions) 1 veneer fracture 2 biologic failures
Wolfart et al 2009[117]	3-unit anterior and posterior FDPs	Lithium disilicate	36	86	8 years: 93.0	6% fractures 6% chipping fractures 3% endodontic complication 6% debonding
Kern et al 2012[118]	3-unit anterior and posterior FDPs	Lithium disilicate	36	121	5 years: 100 10 years: 87.9	Success rate 5 years: 91.1% Success rate 10 years: 69.8%
Solá-Ruiz et al 2013[106]	3-unit FDPs	Lithium disilicate	21	120	71.4	Postoperative sensitivity: 14.3% Recession: 24% Marginal discoloration: 7.1%
Reich et al 2014[107]	Anterior and posterior FDPs	Lithium disilicate	32	46	93.0	Success rate: 83% 3 endodontic complications 2 chipping fractures 1 catastrophic fracture
Suárez et al 2004[42]	Posterior FDPs	InCeram zirconia	18	36	94.4	1 root fracture
Eschbach et al 2009[119]	3-unit posterior FDPs	InCeram zirconia	65	54.4	96.8	1 technical failure 1 biologic failure 2 debondings 4 veneer fractures 3 endodontic complications 2 secondary caries
Chaar et al 2015[120]	3-unit posterior FDPs	InCeram zirconia	65	116.4	93.6	
Vult von Steyern 2005[121]	Posterior 3-unit FDPs	InCeram alumina	20	60	5 years: 90.0 11 years: 65.0	Data also reported in Vult von Steyern et al. 2001[122]
	3-unit to 5-unit FDPs	Zirconia ceramic	20	24	100	
Kern et al 2012[105]	3-unit and 4-unit posterior FDPs	InCeram zirconia	20	74.6	85.0	
Philipp et al 2010[123]	3-unit posterior FDPs	Ce-TZP/A-nanocomposite	8	12.8	100	
Vult von Steyern et al 2005[124]	3-unit to 5-unit FDPs	Zirconia ceramic	23	24	100	3 chipping fractures
Sailer et al 2006[125]	3-unit to 5-unit posterior FDPs	Zirconia ceramic	57	36	84.8	Secondary caries in 10.9% of FDPs Chipping fractures in 13.0% of FDPs
Sailer et al 2007[102]	3-unit to 5-unit posterior FDPs	Zirconia ceramic	57	53.4	73.9	Success rate of zirconia frameworks: 97.8% Secondary caries in 21.7% of FDPs Chipping fractures in 15.2% of FDPs

Sax et al 2011[103]	3-unit to 5-unit posterior FDPs	Zirconia ceramic	57	128	67.0	3 framework fractures 16 chipping fractures (correlation with FDP span) Marginal discrepancy in 90.7% of FDPs
Raigrodski et al 2006[126]	3-unit posterior FDPs	Zirconia ceramic	20	31.2	100	5 chipping fractures
Raigrodski et al 2012[127]	3-unit posterior FDPs	Zirconia ceramic	20	60	90.0	Success rate: 79%
Edelhoff et al 2008[128]	3-unit to 6-unit FDPs	Zirconia ceramic	22	39	90.5	2 chipping fractures
Beuer et al 2009[129]	3-unit posterior FDPs	Zirconia ceramic	21	40	90.5	
Beuer et al 2010[130]	3-unit and 4-unit anterior and posterior FDPs	Zirconia ceramic	18	35	55.6	3 biologic failures 5 technical failures
Crisp et al 2008[131]	3-unit and 4-unit anterior and posterior FDPs	Zirconia ceramic	41	12	100	1 chipping fracture 2 endodontic treatments
Crisp et al 2012[132]	3-unit and 4-unit anterior and posterior FDPs	Zirconia ceramic	41	36	100	2 chipping fractures 3 endodontic treatments
Burke et al 2013[133]	3-unit and 4-unit anterior and posterior FDPs	Zirconia ceramic	41	60	97.0	8 chipping fractures
Sorrentino et al 2012[134]	3-unit posterior FDPs	Zirconia ceramic	48	60	100	3 chipping fractures
Roediger et al 2010[135]	3-unit and 4-unit posterior FDPs	Zirconia ceramic	99	48	94.0	13 chipping fractures 6 loss of retention 3 secondary caries 1 loss of vitality
Rinke et al 2013[110]	3-unit and 4-unit posterior FDPs	Zirconia ceramic	99	84	83.4	12 technical complications (framework fracture, veneer fracture, loss of retention) 6 biologic complications
Wolfart et al 2009[136]	3-unit and 4-unit posterior FDPs	Zirconia ceramic	end abutment: 24	48.7	96.0	
			cantilever: 34	50	92.0	
Schmitt et al 2009[100]	3-unit and 4-unit posterior FDPs	Zirconia ceramic	30	34.2	100	Success rate: 96.3%
Schmitt et al 2012[137]	3-unit and 4-unit posterior FDPs	Zirconia ceramic	30	62.1	92.0	
Lops et al 2012[138]	Anterior and posterior FDPs	Zirconia ceramic	28	78	88.9	Success rate: 81.8%
Tsumita et al 2010[139]	Posterior FDPs	Zirconia ceramic	21	28.1	100	
Molin and Karlsson 2008[140]	3-unit FDPs	Zirconia ceramic	19	60	100	1 debonding
Tinschert et al 2008[141]	Anterior and posterior FDPs	Zirconia ceramic	65	anterior: 38 posterior: 37	100	4 chipping fractures 2 decementations 3 endodontic complications
Sagirkaya et al 2012[142]	3-unit to 6-unit FDPs	Zirconia ceramic	160*	48	99.4	*Units

Table 4 Clinical performance of metal-ceramic vs. all-ceramic fixed dental prostheses.

Author	Restoration type	Materials	No. of restorations	Observation period [months]	Survival [%]	Remarks
Sailer et al 2009[149]	3-unit to 5-unit posterior FDPs	Zirconia-ceramic	38	40.3	100	25% minor veneer chipping
		Metal-ceramic	38		100	19.4% minor veneer chipping
Pelaez et al 2012[144]	3-unit posterior FDPs	Zirconia-ceramic	20	50	95.0	2 minor chippings 1 biologic complication Data also reported in Pelaez et al. 2012[145]
		Metal-ceramic	20		100	
Zenthöfer et al 2015[147]	3-unit cantilever FDPs	Zirconia-ceramic	11	36	100	6 complications (endodontic treatment, ceramic chipping)
		Metal-ceramic	10		100	
Makarouna et al 2011[150]	FDPs	Lithium disilicate	18	72	63.0	
		Metal ceramic	19		95.0	
Christensen and Ploeger 2010[148]	3-unit posterior FDPs	Metal-ceramic	293	36	84.0 – 100	Variety of material combinations
		Zirconia-ceramic			81.0 – 88.0	
		Alumina-ceramic			54.0 – 76.0	

Resin-bonded FDPs

In an attempt to reduce the amount of tooth substance which has to be removed for placing conventional restorations, and concomitant with the development of adhesive strategies, resin-bonded fixed dental restorations were introduced in the 1980's[151] and have since then been well-documented as a treatment modality[152-154]. Different authors advocated resin-bonded FDPs (RBFDPs) merely as long-term provisionals[19,155] although anecdotal case reports show long-term survival of RBFDPs up to 15 years[156].

Following minimal or even no preparation of oral or buccal tooth surfaces, RBFDPs are placed using adhesive cements which constitute their sole form of retention. The predominant indications for RBFDPs are congenitally missing teeth[157]. This treatment modality has been described as not affecting the periodontal condition of the abutment teeth, although higher levels of plaque accumulation and gingivitis have been reported[158,159]. To some extent this may be seen as a consequence of overcontouring, which occurs in minimally invasive preparation designs[160]. The most frequent complication in patients treated with RBFDPs is debonding of the restoration[11,161-165], which is in contrast to conventional FDPs where biological problems seem to be the most common cause for failure[34,35,166]. Rebonding of RBFDPs is possible but may lead to lower retention compared to originally bonded restorations[163,167,168]. Moreover, newer bonding systems show improved performance[169,170] compared to former materials[160,171], but have to be selected with respect to the material used for fabricating the restoration[172]. While metal substructures have predominantly been used in the past, causing discolouration of abutment teeth [20,173-175], the development of high-strength ceramics allows for the fabrication of metal-free RBFDPs[176]. Furthermore, the incidence of debondings seems to be affected by a variety of additional factors, including the location in the oral cavity, the preparation technique applied and the design of the restoration[177].

In this context, RBFDPs in anterior locations seem to perform better compared to those in posterior locations[14,178]. However, this is contradicted by a clinical study by Dündar et al, who reported that factors such as jaw type and adhesive protocol did not affect the short-term performance of RBFDPs[179]. While a variety of different minimally invasive preparation techniques have been described[180-182], including the creation of retentive features[164,172,183], novel developments in bonding technology may even allow for RBFDPs on unprepared teeth[184]. In a 6-year longitudinal study on 141 restorations, Rammelsberg et al found that retentive tooth preparation, as well as the use of silane-coating of retentive elements improved the longevity of the restorations, while the intraoral location did not affect survival time[162].

Besides the classic two-retainer design, single-retainer cantilever RBFDPs[23,185] have been reported to show better clinical performance[170,186]. The higher debonding rates observed in two-retainer designs, predominantly in the form of unilateral debondings[180], have been claimed to result from differences in tooth mobility of the abutment teeth[172]. Potentially negative side effects of cantilever RBFDPs such as permanent movement of the abutments has not been found[187].

High levels of patient satisfaction and oral health-related quality of life following treatment with RBFDPs has been described by several authors[157,174,188,189]. Although reporting only 1-year results on a limited number of patients, either treated with conventional or resin-bonded cantilever FDPs in posterior locations, Prasanna et al did not find a significant difference in the performance of both treatment modalities[190].

Cautiously interpreting the survival rates reported by different authors, it may be concluded that single-retainer, cantilever RBFDPs perform better compared to RBFDPs with two retainers. Also, anterior restorations have a better prognosis than posterior ones. The restorative material used for fabricating RBFDPs only has a minor effect on long-term outcome, particularly when current materials i.e. zirconia-ceramic and metal-ceramic are considered (Table 5).

Inlay-retained fixed dental prostheses

Inlay-retained fixed restorations have been introduced as a further option to conventional FDPs, with the primary goal of reducing the invasiveness of the treatment rendered[28,29,206-208] without jeopardising aesthetics, functional performance and periodontal parameters[208,209].

Similarly to RBFDPs, the development of proper bonding techniques was a prerequisite for achieving sufficient clinical stability[210-212]. Furthermore, the restorative material used, the size of the adhesive surface, as well as the connector size constitute the parameters governing clinical longevity[213].

Hence, in 1995 Quinn et al reported a 76.5% survival rate for partial coverage crown-retained FDPs after 10 years, with the main reason for failure being loss of retention and caries[214]. More recently, resin-bonded cast metal onlays used for the retention of FDPs, with other indications, showed an overall success rate of 94% and a high level of patient satisfaction after a mean observation period of 42 months[215].

When analysing the long-term success of inlay-retained fixed dental prostheses (IRFDPs), this restorative option appears to be regularly problematic as survival rates decreased to 80% after 12 months and even to 57% after 60 months. On the other hand, 100% survival has been reported after a service life of 20 months. One study directly comparing conventional and inlay-retained FDPs clearly showed lower survival rates for IRFDPs (Table 6). The use of different restorative materials may cause the deviations in survival time described.

Fiber reinforced composite

As an alternative and cost effective material, fiber reinforced composites have been introduced for a variety of indications including the chairside creation of RBFDPs[219]. In posterior locations, bonded inlay-retained fixed fiber reinforced composite (FRC) restorations have been described as an aesthetic alternative treatment entity[5,82,220-222], with reduced treatment costs[6,223].

In this context, Freilich et al evaluated the clinical performance of FRC restorations, with a variety of designs. Excluding patients with severe parafunctional habits, the survival rate was 95%, at a mean survival period of 3.75 years. The authors pointed out that survival was associated with substructure design volume whereas retainer configuration did not have a significant effect. Surface defects and a reduction in the luster of the restorations occurred frequently[224]. In a retrospective study, Bohlsen and Kern showed that the survival rate of both single crowns and fixed dental prostheses made from FRC was low. At a mean follow-up time of 4 to 6 years, survival rates ranged from 59.9% to 67.9%, depending on the type of cement used[225]. In contrast, a cumulative survival rate of 80% after 5 years was reported for FRC restorations replacing anterior teeth in periodontally compromised patients[226]. Cenci et al also found a 81.8% survival rate for FRC restorations after an observation period of 7 years, with fractures of the restorations constituting the most important technical complication[227]. Similarly, a multi-center

Table 5 Clinical performance of resin bonded fixed dental prostheses. Note: shaded lines present follow-up studies of the same patient cohort.

Author	Restoration type	Materials	No. of restorations	Observation period [months]	Survival [%]	Remarks
Sailer et al 2014[191]	Anterior single retainer RBFDP	Zirconia ceramic	15	53.3	100	2 debondings
Saker et al 2014[192]	Anterior cantilever RBFDP	Metal ceramic	20	34	100	
		InCeram Alumina	20		90.0	2 fractures 3 debondings
Sailer et al 2013[193]	Anterior / posterior single retainer RBFDP	Glass ceramic	35	72	100	No debondings Ceramic chipping 5.7%
Spinas et al 2013[22]	Anterior, double wing retention RBFDP	Fiber Reinforced Composite	32	60	93.7	
Izgi et al 2013[194]	Posterior slot-retained RBFDP	Cast metal	41	75.6	83.0	
Younes et al 2013[19]	3-unit RBFDP, double wing retention	Cast metal	42	> 192	5 years: 95.0 10 years: 88.0 20 years: 66.0	Success rates: 5 years: 75%; 10 years: 58%; 20 years: 45% Reasons for failure: debondings, caries, periodontal breakdown
Sun et al 2013195	Anterior veneer retained cantilever RBFDP	IPS e-max Press	35	46.57	100	
Kern 2005[196]	Anterior two retainer RBFDP	In Ceram alumina	16	75.8	67.3 / 73.9	
	Anterior single retainer RBFDP		21	51.7	92.3	
Kern and Sasse 2011[197]	Anterior two retainer RBFDP	In Ceram alumina	16	120.2	67.3 / 73.9	
	Anterior single retainer RBFDP		22	111.1	94.4	
Sasse et al 2012[198]	Anterior cantilever RBFDP	Zirconia ceramic	30	41.7	100	2 debondings
Sasse and Kern 2013[199]	Anterior cantilever RBFDP	Zirconia ceramic	30	64.2	100	2 debondings
Sasse and Kern 2014[200]	Anterior cantilever RBFDP	Zirconia ceramic	42	61.8	100	2 debondings 1 carious lesion
Howard-Bowles et al 2011[25]	Anterior and posterior RBFDP	Metal-ceramic	222	41	Overall: 84.1 Anterior: 91.5 Posterior: 75.9 Cantilever: 90.3 Fixed-fixed: 75.7	Based on questionnaire
Boening and Ullmann 2012[155]	Anterior RBFDP	Metal-ceramic	56	76	84.0	5 debondings 1 chipping fracture 1 carious lesion
Dündar et al 2010[179]	Anterior and posterior two retainer RBFDP	Metal-ceramic	58	20.3	Maxilla: 93.2 Mandible: 92.9	4 debondings
Botelho et al 2000[187]	2-unit cantilever RBFDP	Metal ceramic	33	30	97.0	
Botelho et al 2002[201]	2-unit cantilever RBFDP	Metal ceramic	82	36.7	95.1	
Botelho et al 2006[189]	2-unit cantilever RBFDP	Metal ceramic	269	51.7	95.5	Success rate: 94.8%
Botelho et al 2014[14]	Cantilever RBFDP	Metal ceramic	211	113.2	90.0	28 debondings Success rate: 84.4
Hussey and Linden 1996[153]	2-unit cantilever RBFDP	Metal-ceramic	142	36.2	94.0	Success rate: 88%
Ketabi et al 2004[202]	Anterior and posterior RBFDP	Metal-ceramic	74	93.6	83.0	9 debondings 6 carious lesions 3 veneer fractures
Samama 1996[203]	RBFDP	Cast metal	145	68.4	83.0	
Corrente et al 2000[204]	RBFDP	Metal-ceramic; Metal-resin	150	80.4	76.2	
Zalkind et al 2003[205]	RBFDP	Metal-ceramic	51	60	67.0	Success rate: 48%
Chai et al 2005[166]	3-unit FDP	Metal-ceramic	61	48	82.0	
	2-unit cantilever FDP	Metal-ceramic	25		77.0	
	3-unit RBFDP	Metal-ceramic	77		63.0	
	2-unit cantilever RBFDP	Metal-ceramic	47		81.0	

Table 6 Clinical performance of inlay-retained fixed dental prostheses. Note: shaded lines present follow-up studies of the same patient cohort.

Author	Restoration type	Materials	No. of restorations	Observation period [months]	Survival [%]	Remarks
Abou Tara et al 2011[216]	3-unit posterior IRFDP	Zirconia ceramic veneered	23	20	100	2 veneer fractures 1 debonding
Wolfart et al 2005[217]	3-unit anterior and posterior FDP	Lithium disilicate ceramic (IPs e.max Press)	36	48	4 years: 100	
	3-unit anterior and posterior IRFDP		45	37	4 years: 89.0	Reasons for failure: debonding/fracture
Harder et al 2010[218]	Posterior IRFDP	Lithium disilicate ceramic (IPs e.max Press)	45	70	5 years: 57.0 8 years: 38.0	Survival of FDPs with crown and inlay retainer: 100% (5 years), 60% (8 years)
Ohlmann et al 2008[209]	Posterior IRFDP	Zirconia ceramic veneered	30	12	80.0	1 chipping fracture 3 veneer delaminations 6 decementations 3 framework fractures

clinical study using different restoration designs with respect to the retentive element, showed a 5-year success rate of 71.2% and a survival rate of 77.5% for FRC restorations. The retention type (wing vs inlay) did not show a significant effect[228].

Monolithic zirconia restorations

In response to the high incidence of veneer chipping fractures in all-ceramic restorations, the use of zirconia ceramics, without the addition of veneering material was introduced[229]. Nowadays various companies offer modified zirconia ceramics which are pre-stained[230], and which require higher sintering temperatures. These materials are frequently referred to as 'translucent' zirconia[231]. The characterisation of such restorations is based on the use of staining liquids prior to sintering[231,232], a process requiring the experience of a dental technician. From a materials perspective, the following three factors may be problematic. Depending on the staining technique applied, the material properties may deteriorate[233,234]. Additionally, masticatory loads acting on unveneered zirconia ceramic, as well as the conditions within the oral cavity, may cause low temperature degradation phenomena[235,236]. Also, the risk of antagonist wear is discussed[237]. From an aesthetics point of view, monolithic zirconia restorations seem to be of limited applicability in the aesthetic zone[231]. Despite some promising clinical results[238], the correct long-term documentation for this treatment modality is missing thus far[231].

Systematic reviews and meta-analyses

Several systematic literature reviews and meta-analyses can be found, addressing the clinical performance of various types of FDPs (Table 7). Ignoring different clinical situations and restoration types, the overall survival rate of FDPs after 5 years was reported in the range of 89.2% to 95.5% and 65.5% to 89.4% after 10 years[239,242,243].

For RBFDPs, survival rates in the range between 87.7% to 92.3% have been calculated after 5 years of service[248,249]. For cantilever FDPs, a survival rate of 91.4% after 5 years and 80.3% to 81.8% after 10 years was described[241,242]. All-ceramic restorations showed survival rates of 90% after 3 years[244], and a range between 88.6% to 94.3% after 5 years[240,246,247]. For metal-ceramic FDPs, survival rates of 97% after 3 years[244] and 94.4% after 5 years[240] were calculated (Table 7).

In a critical review on the performance of all-ceramic and metal-ceramic FDPs, also elaborating on the shortcomings of existing meta-analyses, Layton concluded that the survival rate of metal-ceramic FDPs would be significantly higher than that of all-ceramic FDPs, and that all-ceramic FDPs experienced a high incidence of technical failure[250]. A recent review by Pjetursson et al reporting 5-year survival rates for FDPs, based on different materials, showed the highest survival rate (94.4%) for metal-ceramic restorations, while different all-ceramic options were below 91%[245].

Table 7 Overview of existing systematic reviews.

Author	Restoration type	Observation period [years]	Survival [%]	Remarks
Tan et al 2004[239]	FDPs	10	89.1	Caries 2.6% Periodontitis 0.7% Loss of retention 6.4% Abutment fracture 2.1% Material fractures 3.2%.
Sailer et al 2007[240]	All-ceramic FDPs	5	88.6	Framework fractures 6.5% Veneering material fractures 13.6%
	Metal-ceramic FDPs		94.4	Framework fractures 1.6% Veneering material fractures 2.9%
Pjetursson et al 2004[241]	Cantilever FDPs	10	81.8	Loss of pulp vitality 32.6% Caries at abutment teeth 9.1% Loss of retention 16.1% Material fractures 5.9% Fractures of abutment teeth 2.9%
Pjetursson et al 2007[242]	FDPs	5	93.8	Biological complications after 5 years (caries, loss of pulp vitality) 15.7%
		10	89.2	
	Cantilever FDPs	5	91.4	Complications after 5 years 20.6%
		10	80.3	
Pjetursson et al 2012[243]	tooth-supported and implant-supported FDPs and single crowns	5	89.2 - 95.5	Annual failure rates FDPs 1.14% Cantilever FDPs 2.20% RBFDPs 4.31%
		10	65.0 - 89.4	
Heintze and Rousson 2010[244]	All-ceramic FDPs (Zirconia)	3	90.0	Core fractures < 1.00 % Veneer chipping 24.0 % - 54.0 %
	Metal-ceramic FDPs		97.0	Core fractures 0% Veneer chipping 34.0 %
Pjetursson et al 2015[245]	Metal-ceramic FDPs	5	94.4	
	Reinforced glass ceramic FDPs		89.1	
	Glass infiltrated alumina FDPs		86.2	
	Zirconia FDPs		90.4	
Le et al 2015[246]	All-ceramic FDPs (Zirconia)	5	93.5	Complication rate 27.6%
Schley et al 2010[247]	All-ceramic FDPs (Zirconia)	5	94.3	Technical complication free rate 76.41% (chipping fractures) Biological complication free rate 91.72%
Wassermann et al 2006[248]	Resin bonded FDPs (single retainer and InCeram Alumina)	5	92.3	
Pjetursson et al 2008[249]	Resin bonded FDPs	5	87.7	Debonding 19.2% Caries 1.5% Periodontitis 2.1%

■ Discussion

Every review publication relies on the quality of the original research reports and consequently has to be interpreted with caution. The publications considered were not limited to robust clinical studies thus a larger database was used. Unfortunately, reporting of clinical outcomes has not been standardised in the past and in some instances it appears that authors unconsciously intended to 'hide' unfavourable outcomes. The inclusion of cumulative survival and success rates should be a prerequisite for any publication. This is particularly problematic in all-ceramic and metal-ceramic restorations, where chipping fractures of veneer materials constitute a frequent complication. As these chipping fractures may vary with respect to their extent, studies reporting on such complications are hard to compare as a uniform classification system has not yet been universally adopted[241]. Furthermore, publications

repeatedly reporting on the same patient cohort or even on subsets of cohorts are misleading[144,145]. Also, follow-up publications after longer observation periods should be clearly marked as such even if the authorship has changed. In the same context, it was noted that obvious facts such as greater removal of tooth structure for a crown, compared to a veneer, have been publishable in the past[28,29]. On the other hand, the rapid development of novel restorative materials such as ceramic systems[251-253] and bonding agents question the validity of older publications in general even if a proper study design had been applied.

Despite not reflecting the highest level of evidence, several clinical studies compared different treatment alternatives not only focusing on numerically measurable facts such as survival and chipping rates. In a retrospective study evaluating 50 patients with missing lateral incisors, following treatment with orthodontic space closure or conventional and resin-bonded FDPs, the authors found higher levels of satisfaction in orthodontically treated patients[43]. A case-control study comparing the longevity of implant-supported crowns and 2-unit cantilevered RBFDPs, proved that both treatment options had similar survival rates, but a greater number of biological complications were observed with implant-supported crowns[254]. Using a theoretical approach, the cost-effectiveness of various treatment modalities for missing maxillary lateral incisors was evaluated[10]. According to this report, cantilever and resin-bonded FDPs appeared to be more cost-efficient compared to single implant crowns, while conventional FDPs would be less cost-effective than latter ones.

Several studies have been conducted comparing the performance of conventional FDPs and implant-supported crowns, with partially contradictory results. In a clinical study comparing the cost-effectiveness of both treatment options, Zitzmann et al found satisfactory long-term results from the patient's perspective in both groups. The lower initial costs, however, were in favour of the implant-supported single crowns[255]. Similarly, Wolleb et al calculated a survival rate of 98.7% for tooth-supported FDPs, and a 100% survival rate for implant-supported single crowns. Biological complications including loss of vitality, endodontic complications, root fractures and caries dominated, while veneer fractures occurred in 3.8% of the FDPs[256]. Technical complications appeared in a systematic review by Pjetursson et al, demonstrating a higher incidence in implant-supported reconstructions compared to restorations on teeth. They included fractures of the veneer, screw loosening and loss of retention[242].

Comparing the economic aspects of 41 FDPs and 59 implant-supported single crowns over an observation period of 4 years, implant-supported restorations required more visits, while the overall treatment time was similar to FDP treatment. The implant solutions were less expensive while the costs for treating complications were comparable in both groups[257]. In a cohort of patients with congenital defects, which affected the formation of teeth, 58% of patients with reconstructions on teeth remained free from all failures or complications, while 47% of patients restored with implant-supported restorations needed retreatment or repair during a mean observation period of 8 years. Patients affected by amelogenesis/dentinogenesis imperfecta demonstrated the highest failure and complication rates whereas in patients with cleft lip, alveolar process and palate or hypodontia/oligodontia, 71% of the single crowns and 73% of the FDPs on teeth remained complication-free over a median observation period of about 16 years[12]. In the same patient cohort, initial treatment costs for implant-supported reconstructions were much higher compared to tooth-supported restorations, whereas the long-term cumulative treatment costs for both groups were not significantly different[258].

Conclusions

Not requiring surgical interventions, conventional tooth-supported restorations appear to be more predictable in achieving initial treatment success with fewer appointments and shorter treatment time. Despite substantial differences in the remuneration of medical services, a basic trend towards higher laboratory fees and lower honorariums for the dental practitioner may be seen for FDP treatment, compared to implant-supported single crowns. Biological complications seem to limit the survival time of FDPs while implant-supported single crowns show a higher incidence of technical problems. Taking

maintenance expenditures into account, the short-term advantage of conventional restorations appears to diminish.

Given the high number of variables affecting treatment decisions, a universally effective solution does not exist; instead clinicians should establish a specific risk profile for each patient situation. Survival and success rates of any restorative option, as well as risk profiles, must not be seen in isolation, but in combination with the patient's wishes and the capabilities of the treatment provider.

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Patient information on treatment alternatives for missing single teeth – Systematic review

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Key words *dental implants, fixed partial dentures, orthodontic space closure, patient information, removable partial dentures*

Aim: This study systematically evaluates existing evidence-based literature covering the topic of patient information about different treatment alternatives for missing single teeth, in order to summarise current evidence.
Material and methods: Three scientific databases – Pubmed, OvidSP and Scopus - were searched for publications up to July 2015, relating to patient information on treatment options for missing single teeth. References of publications and the google scholar database were screened additionally leading to a total of 183 journal articles written in English. Following the selection criteria, 33 articles were included. Twenty-nine questionnaire- based publications were compared by descriptive analysis of six key parameters - awareness of treatment options, source of information, knowledge, attitude to treatment, preference of treatment option and reason for refusal.
Results: Included studies consisted of data from 23,702 responding participants and which were performed in 16 countries. Mean values and standard deviations revealed variations between and within countries. The level of awareness and attitude to treatment in most countries is acceptable. Insufficient knowledge as well as a high demand for knowledge was found. Clinicians are the most important source of information followed by media, family and friends. Dental Implants and FPDs were preferred and high costs would be the major reason for refusal.
Conclusion: Clinicians play an important role in improving awareness and knowledge of patients about treatment alternatives. Non-uniform study designs could lead to variations in results. This systematic review can be considered in further studies, in order to standardise methods using key parameters and a representative study population.

Conflict-of-interest statement: *The authors declare that they have no conflict of interest.*

■ Introduction

In general, clinicians traditionally focus their effort to preserve and if necessary rehabilitate natural teeth. If conservative treatment strategies fail, tooth extraction can be unavoidable leaving a gap behind. To restore function and aesthetics, the replacement of missing teeth should be considered. Evidence-based medicine builds the foundation of modern dentistry involving oral rehabilitation as its discipline including diagnosis, treatment planning, restoration of tooth defects and replacement of acquired or congenitally missing teeth.

The choice of treatment of single missing teeth underlies different factors including empirical evidence of outcomes of treatment, individual patient

conditions, access to technology, experience of clinicians and dental technicians as well as economic aspects. Alternatives of treatment of missing single teeth are the use of dental implants (DI), fixed partial dentures (FPD), removable partial dentures (RPD) or orthodontic space closure. Different treatment options come with different advantages and disadvantages. Orthodontic treatment aimed at the closure of gaps requires multidisciplinary planning and might be restricted to specific clinical situations but can also be combined with implant placement. Several studies and systematic reviews show similar failure rates respectively, long-term survival rates of implant therapy including restoration, and FPDs for the treatment of missing single teeth[1,2]. Survival rates of RPDs are lower due to the causes and risks, which come with the ability to be removable. Mechanical failures but also patients not wearing RPDs can lead to a necessary replacement[3].

However, scientific and empirical evidence is not the only thing to consider. Only in combination with patient-oriented methods can optimal treatment be achieved. Clinical experience, education of clinicians, and the disclosure of information to patients are necessary to lead to an increase in different aspects of patients' knowledge about treatment alternatives. Putting patients' well-being and satisfaction at the center of consideration is one of the most important goals to achieve in oral rehabilitation. For clinicians, knowing these factors aims to inform and educate patients to enable self-determined decisions as well as appropriate maintenance and behaviour. If complication rates are reduced that way, it does not only benefit the patient but also the clinician by saving time and resources.

Akagawa et al[4], Zimmer et al[5] and Best HA[6] began researching aspects of patient information in oral rehabilitation. Berge TI[7] was the first who conducted a study expanding the number of participants to 5,000 people of the general population. Response rate amounted to 70.8%. In 2003, Tepper et al[8] extended the scope of earlier research by adding new aspects of patient information to be investigated. Moreover, a representative sample of 1,000 adults in the household was randomly selected from different groups of the general population (age, sex, profession, income and origin) to create a homogenous study population and to enable the separate investigation of these different groups. In the second part of this study, interviewees were questioned about treatment acceptance, satisfaction and economical aspects[9]. Following studies were based on these earlier publications.

At the time of this systematic review, there was no existing publication reviewing literature about patient information on different treatment options of missing single teeth. Investigation of different aspects of patient information could lead to ideas which improve future treatment strategies and the perception of the need for further studies. Hence, the purpose of this study was the systematic evaluation of existing scientific literature covering the topic of different modalities of patient information about different treatment alternatives.

Material and methods

Search strategy

The authors used the following three online databases of scientific literature in the listed order, continuously discarding found duplicates. Each database was searched from its start date to July 2015 and restricted to publications written in English.

I. Pubmed
II. OvidSP, consisting of:
- Ovid MEDLINE(R) In-Process and other Non-Indexed Citations, and Ovid MEDLINE(R) 1946 to Present;
- Embase 1988 to 2015 Week 29;
- EBM Reviews Full Text – Cochrane DSR, ACP Journal Club and DARE;

III. Scopus, consisting of:
- Health Sciences (> 6,800 titles; 100% Medline coverage);
- Life Sciences (> 4,300 titles);
- Physical Sciences (> 7,200 titles);
- Social Sciences and Humanities (> 5,300 titles).

The search term included specific keywords and was built up to reflect different treatment alternatives of single missing teeth and different forms of patient information:

("Dental Implant" OR "Dental Implants" OR "Partial Denture" OR "Orthodontic Space Closure")

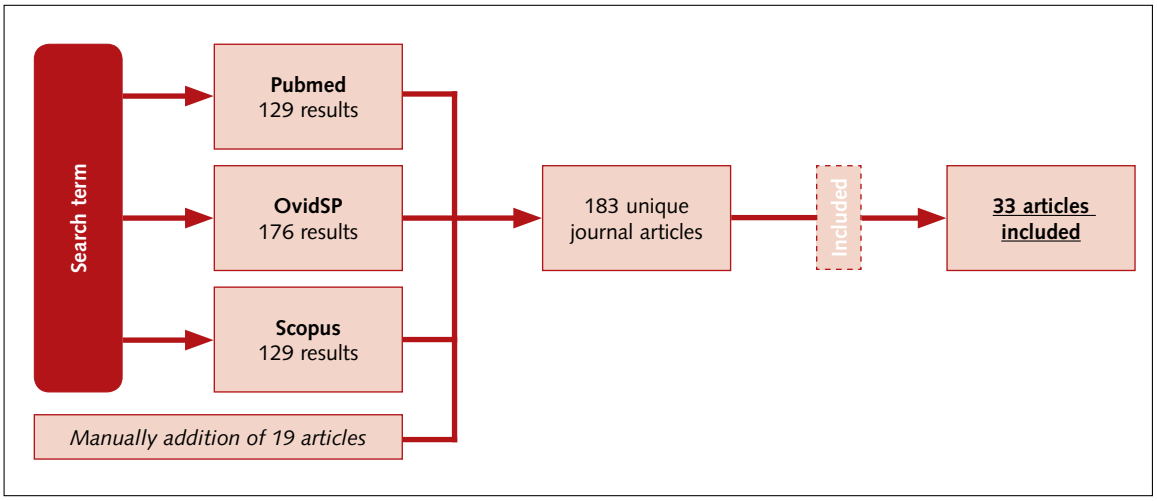

Fig 1 Schematic overview of literature research using three different scientific databases. Literature research was performed by applying a defined search term during the search in three scientific databases and by manually adding literature. One hundred and eighty-three unique journal articles were found and 33 could be finally selected for this systematic review.

AND ("Patient Information" OR "Online Information" OR "Leaflet Information" OR "Informed Consent" OR "Patients' Knowledge" OR "Patients' Awareness" OR "Public Knowledge" OR "Public Awareness")

A Pubmed search revealed 129 findings. Medical Subject Headings (MeSH) combined with keywords were used at first but did not increase the count of results and therefore this search strategy using MeSH terms was rejected. The search term for fixed as well as removable partial dentures could be simplified by searching for 'Partial Denture'. Searching the OvidSP database resulted in 176 results, adding 21 additional journal articles to the Pubmed search results. Finally, when searching the Scopus database, 129 articles were found and an additional 15 articles, which have not been found in the preceding search, were able to be added. By discarding duplicate findings, 434 search results of all three databases could be reduced to 164 unique findings. Screening of reference lists of all eligible publications and the Google Scholar database resulted in an additional 19 publications. Most of these articles were not published in journals listed in previously searched literature databases. Figure 1 shows a schematic overview of the literature research done for this systematic review.

Abstracts of 183 articles were independently screened by the authors to assess which studies met the following selection criteria. Disagreements were resolved through a discussion between the authors.

Selection criteria

Eligibility criteria included:

- Journal article;
- Written in English;
- Studies generated using a search term reflecting aspects of patient information on treatment alternatives of single missing teeth.

Exclusion criteria included:

- Studies not about patient information;
- Studies not about treatment of single missing teeth.

All search results were original journal articles and due to the application of a language filter, they only showed search results written in English and the use of the previously described search term for all publications met the eligibility criteria. One of the publications was a comment and summary[10] of an included study[11] and was therefore excluded. Along with the first exclusion criteria, 69 journal articles had to be excluded. Another 16 findings did not investigate treatment of missing single teeth although they were handling patient information. Sixty-four articles were neither about patient information or about the treatment of single missing teeth. All 19 manually added articles met the selection criteria and were included in this review. In summary, based on the selection criteria, 33 articles were included in this review.

Analysis

Data were summarised in tables, which included publication year, treatment alternatives, investigational method, sample size and outcome parameters. The following six key parameters were compared and analysed using descriptive statistics: awareness of treatment options, source of information, knowledge, attitude to treatment and preference for treatment options as well as reason for refusal. Outcome parameters were graphically displayed using bar charts sorted by the place of origin. Mean values and standard deviations were calculated for available data.

Results

The literature research resulted in 183 unique journal articles. Thirty-three were finally selected for this systematic review. Studies were performed in 16 different countries, with the majority originally from Asia (20 studies). Sample sizes varied from 109 to 10,000. In total, studies reporting on patient information on treatment alternatives for missing single teeth, contained data of 26,393 participants of which 23,702 responded. Kohli et al[12,13] published two studies using the identical study population which was therefore counted once. The targeted subject group was mainly the public population and dental patients, except Mukatash et al[14] who also included 272 medical staff members as well as 261 subjects from the general population as a control group. Treatment alternatives of missing single teeth included dental implants (33 studies; 23,702 responding participants), RPDs and FPDs (both in seven studies; 2,860 responding participants). Five articles about orthodontic gap closure were amongst the search results. All had to be excluded because they did not investigate any aspect of patient information. As a method of investigation, questionnaires were performed in 29 of these articles; two studies assessed the quality of online information, one study examined information leaflets and one study conducted a retrospective analysis of expert opinions about patient information. These four differing articles were described separately in this review (Table 2). Studies using questionnaires were compared to each other depending on the investigated outcome parameters.

Table 1 enables a quick substantial overview of all included studies, alphabetically sorted by authors, showing the publication year, treatment alternatives, investigational method, sample size and outcome parameters.

Publication dates range from 1988 to July 2015. Figure 2 displays included journal articles grouped by their publication year showing that since 1988 there was a positive trend towards more research in this thematic field. Especially since 2010, there was an increase in publications reaching a maximum of 12 in 2014.

Online information

In recent years, studies about the quality and accuracy of health and medical information available on the internet have shown that many sources provide inadequate information. Ali et al[11] and Jayaratne et al[26] investigated the quality of online patient information regarding dental implants. In 2014, Jayaratne et al[26] assessed the readability of patient-oriented online information on dental implants and found out that the number of words varied widely and that 34 of 39 websites (87.18%) were difficult to read[26]. The same year Ali et al[11] reviewed content and reliability of online information on 30 websites regarding dental implants. Overall, website content quality was low (63%/67% of sites below a mean score of content/reliability) and authors were mainly clinicians (73.3%). Of the clinicians, 86.7% were accredited by a recognised body but only 26.7% were affiliated to a professional/medical institution[11].

Information leaflets

Barber et al[20] analysed 23 patient information leaflets from dental implant companies in the UK in 2015. Word count ranged from 88 to 5,434, the majority of images used were decorative and sources of information was not stated in any of the leaflets. The main emphasis was generally describing treatment and advantages with less information about risks of complications, the relevance of smoking and periodontal disease, failure or disadvantages[20].

Table 1 Overview of 33 journal articles included in this review in alphabetical order.

Authors	Year	Treatment alternative	Investigational method	Participants / Responder	Outcomes
Akagawa Y et al[4]*	1988	Implant	Questionnaire	358/199	INF, KNO, ATT, REF
Al-Dwairi ZN et al[15]†	2014	Implant	Questionnaire	150 (RPD group)	AWA, INF, KNO, PRE, REF
Alqahtani F et al[16]	2015	Implant	Questionnaire	360/350	AWA, INF, KNO, ATT, REF
Ali S et al[11]	2014	Implant	Online information	N/A	Content, reliability
Al-Johany S et al[17]	2010	Implant, RPD, FPD	Questionnaire	420/379	AWA, INF, KNO, PRE, REF
Amjad F and Aziz S[18]	2014	Implant, RPD, FPD	Questionnaire	240	INF, PRE, REF
Awooda EM et al[19]	2014	Implant	Questionnaire	384	AWA, INF, KNO, REF
Barber J et al[20]	2015	Implant	Information leaflets	N/A	Information, word count devoted to topics, images, claims, sources of information
Berge T[17]	2000	Implant	Questionnaire	5,000/3,445	AWA, ATT, REF
Best HA[6]	1993	Implant	Questionnaire	N/A	AWA
Bhoomika K and Devaraj CG[21]	2015	Implant	Questionnaire	114	AWA, INF, ATT, REF
Chowdhary R et al[22]	2010	Implant	Questionnaire	10,000	AWA, INF, ATT, REF
Faramarzi MS et al[23]	2013	Implant	Questionnaire	150	AWA, INF, KNO, PRE
Gbadebo OS et al[24]	2014	Implant	Questionnaire	220/199	AWA, INF, KNO, ATT, REF
Hussain M et al[25]	2015	Implant, RPD, FPD	Questionnaire	201	AWA
Jayaratne YS et al[26]	2014	Implant	Online information	N/A	Readability grade level
Kohli S et al[12]	2014	Implant	Questionnaire	1,500/1,013	AWA, INF, ATT, REF
Kohli S et al[13]	2014	Implant	Questionnaire	1,500/1,013	AWA, KNO, ATT
Mukatash GN et al[14] ‡	2010	Implant, RPD, FPD	Questionnaire	612/533 (Total)	AWA, INF, PRE
Ozcakir Tomruk C et al[27]	2014	Implant	Questionnaire	527	AWA, INF, KNO
Pommer B et al[28]	2011	Implant	Questionnaire	1,000	AWA, INF, KNO, ATT, REF
Pragati K and Mayank K[29]	2010	Implant	Questionnaire	200	AWA, INF, ATT, REF
Raj N et al[30]	2014	Implant, RPD, FPD	Questionnaire	300/249	AWA, ATT, PRE
Ravi Kumar C et al[31]	2011	Implant, RPD, FPD	Questionnaire	600/535	AWA, INF, KNO, ATT, REF
Rustemeyer J and Bremerich A[32]	2007	Implant	Questionnaire	400/315	INF
Saha A et al[33]	2013	Implant	Questionnaire	550/483	AWA, INF, KNO, ATT, REF
Satpathy AP et al[34]	2011	Implant, RPD, FPD	Questionnaire	723	AWA, INF, KNO, ATT, REF
Shah RJ et al[35]	2014	Implant	Questionnaire	300	AWA, INF, ATT, REF
Strietzel FP[36]	2003	Implant	Retrospective Analysis of Expert Opinions	N/A	Inadequate patient information, significant associations
Suprakash B et al[37]	2013	Implant	Questionnaire	500/440	AWA, INF, KNO, ATT, REF
Szymanska I et al[38]	2014	Implant	Questionnaire	464	INF
Tepper G et al[39]	2003	Implant	Questionnaire	1,000	AWA, INF, KNO, ATT, REF
Zimmer CM et al[5]	1992	Implant	Questionnaire	120/109	AWA, INF, ATT

Outcomes: awareness of treatment options (AWA), source of information (INF), knowledge (KNO), attitude to treatment (ATT), preference for treatment option (PRE) and reason for refusal (REF).

* This study also includes patients with complete dentures (not numerically specified).

† This study includes data of 300 patients, 150 complete denture and 150 removable denture wearers. Due to the fact this review only includes publication about the treatment of missing single teeth, only the RPD group was considered.

‡ Responding participants of this study consisted of 272 (para-) medical staff and 261 people from the general population.

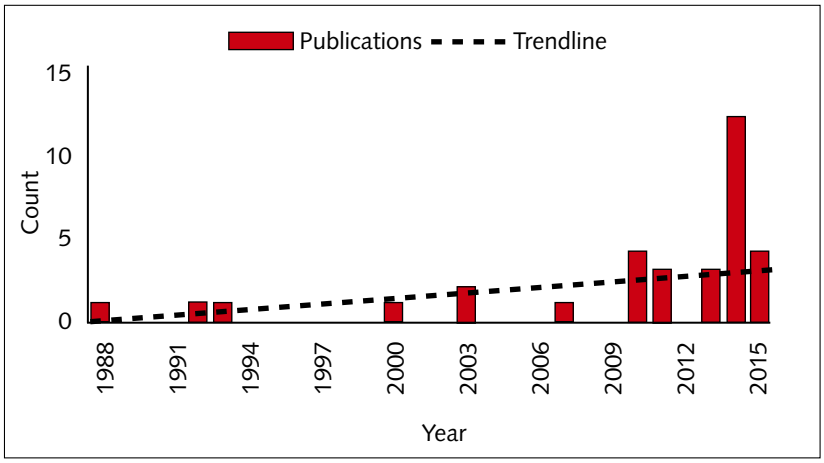

Fig 2 Count of included publications per year from 1988 to July 2015. The first included study was published in 1988. In 2010, the count of publications started to increase to a maximum of 12 published studies in 2014. Few publications before 2010 are the cause for a low upward slope of the trend line.

Expert opinions on patient information

In 28 implant treatment cases, Strietzel[40] analysed expert opinions reports about patient information prior to implant-prosthetic treatment in 2003. The report revealed that in 57% of all cases, general patient information was inadequate. Additionally, a lack of information about complications, treatment risks, cost and alternatives were also found. Diagnostic mistakes were significantly associated with inadequate information about complications that occurred. Insufficient pretreatment of the patient (prosthetic and periodontal) was associated with deficient information about implant and periodontal maintenance as well as insufficient oral hygiene status[40].

The remaining 29 studies using questionnaires as an investigational method were compared and specific study parameters (awareness, sources of information, level of knowledge, attitude to treatment alternatives, preferences for treatment alternatives and reasons for refusal) were analysed. Sorted by the place of investigation, the majority was originally from Asia (20 studies), especially from India where nine studies have been conducted starting in 2010.

Awareness, sources of information, and knowledge

A fundamental aspect of patient information is the awareness of different treatment alternatives of missing single teeth[25], including publications consisting of information about awareness of treatment or treatment options[24], the sources of information the study participants relied on and the knowledge deficiency level or the demand of knowledge of the participants, which was investigated by 15 studies. Table 3 shows a detailed summary with the resulting relative proportion of participants.

Awareness of implants as treatment for missing single teeth was investigated most frequently (25 studies). Interviewees were asked about their awareness about FPDs and RPDs only in 12 studies. Overall, 50.1% ± 24.3% were aware of the implant option, 62.3% ± 22.6% and 54.6% ± 14.3% of the participants were informed about FPDs and RPDs, respectively, as treatment possibilities for missing single teeth. Results of relative proportions are shown in Figure 3.

If people are informed about existing treatment alternatives, it is interesting to know which source of information led to their knowledge. Figure 4 shows that the most common source of information was

Table 2 Overview of four included studies investigating specific topics of patient information in oral rehabilitation and using different investigational methods.

Authors	Year	Treatment alternative	Investigational method	Outcomes
Ali S et al[11]	2014	Implant	Online information	Content, reliability
Barber J et al[20]	2015	Implant	Information leaflets	Information, word count devoted to topics, images, claims, sources of information
Jayaratne YS et al[26]	2014	Implant	Online information	Readability grade level
Strietzel FP[36]	2003	Implant	Retrospective Analysis of Expert Opinions	Inadequate patient information, significant associations

The listed four studies, investigated specific topics about patient information on treatment for missing single teeth. Study outcome parameters give an insight about the investigational focus.

Table 3 Summary of 29 included studies using questionnaires – awareness, sources of information and level of knowledge.

Place of origin of study	Authors	Year	Awareness (%)			Sources of information (%)	Insufficient / Demand for Knowledge (%)
			DI	FPD	RPD	C/M/FF/P	
Australia (New South Wales)	Best HA[6]	1993	64.0	-	-	-	-
Austria							
Nationwide	Pommer B et al[28]	2011	79.0	91.0	45.0	74.0/26.0/30.0/-	-
Nationwide	Tepper G et al[39]	2003	72.0	89.0	57.0	68.0/23.0/22.0/-	42.0 / -
Germany (Bremen)	Rustemeyer J and Bremerich A[32]	2007	-	-	-	41.0/38.3/15.0/-	-
India							
Nationwide	Chowdhary R et al[22]	2010	23.2	-	-	74.1/9.6/-/16.4	-
Ahmedabad	Shah RJ et al[35]	2014	41.3	-	-	69.4/21.0/9.7/-	-
Bhubaneswar & Cuttack	Satpathy AP et al[34]	2011	15.9	46.9	48.6	45.0/31.5/28.1/-	55.3 / 89.4
Chattisgarh	Saha A et al[33]	2013	41.7	-	-	63.2/24.1/12.7/-	- / >50%
Guntur	Suprakash B et al[37]	2013	33.3	-	-	58.4/23.3/18.3/-	- / 70.0
Jaipur	Bhoomika K and Devaraj CG[21]	2015	40.4	-	-	25.4/8.8/6.1/-	-
Jaipur	Pragati K and Mayank K[29]	2010	38.0	-	-	55.2/15.7/-/28.9	-
Khammam	Ravi Kumar C et al[31]	2011	4.8	50.0	37.6	38.3/24.3/28.5/-	- / 85.7
Songadh & Amargadh	Raj N et al[30]	2014	10.8	80.4	43.6	-	-
Iran (Tabriz)	Faramarzi MS et al[23]	2013	60.0	-	-	42.0/22.0/34.0/2.0	70.7 / -
Japan (Hiroshima)	Akagawa Y et al[4]	1988	-	-	-	20.0/62.0/18.0/-	87.0 / -
Jordan							
Amman	Mukatash GN et al[14]	2010	68.7	71.5	54.4	44.7/35.½1.1/-	-
Irbid	Al-Dwairi ZN et al[15]	2014	68.7	-	-	38.9/18.1/58.3/-	62.0, 80.7 / - (general, placement)
Malaysia							
Nationwide	Kohli S et al[12]	2014	76.2	43.0	55.0	53.6/74.¾5.3/33.5	-
Nationwide	Kohli S et al[13]	2014	76.2	-	-	-	65.4 / -
Nigeria (Ibadan)	Gbadebo OS et al[24]	2014	28.9	18.1	50.3	68.0/29.0/-/-	61.4 / 61.8
Norway (Nationwide)	Berge T[17]	2000	70.1	-	-	-	-
Pakistan							
Karachi	Hussain M et al[25]	2015	5.5	60.6	77.0	-	-
Lahore	Amjad F and Aziz S[18]	2014	-	-	-	42.5/9.8/33.8/-	13.6 / -
Poland (Tomaszòw Mazowiecki)	Szymanska I et al[38]	2014	-	-	-	38.4/29.3/32.3/-	-
Saudi Arabia							
Alkharj	Alqahtani F et al[16]	2015	77.7	-	-	23.1/32.3/28.0/16.6	- / 82.8
Riyadh	Al-Johany S et al[17]	2010	66.4	79.4	67.9	28.3/-/31.5/-	49.8 / 82.4
Sudan (Khartoum)	Awooda EM et al[19]	2014	68.5	83.3	83.3	26.0/18.0/27.9/-	27.1, 53.1 / 93.2 (general, placement)
Turkey (Istanbul)	Ozcakir Tomruk C et al[27]	2014	43.5	34.9	34.9	44.5/31.6/17.3/-	47.5 / 68.3
USA (Rochester, MN)	Zimmer CM et al[5]	1992	77.0	-	-	17.0/35.0/35.0/-	-

This table includes 29 questionnaire studies sorted by the place of origin. Resulting relative proportions of study participants about awareness, sources of information and level of knowledge are summarised in this table.

Awareness: dental implants (DI), fixed partial dentures (FPD), removable partial dentures (RPD).

Sources of information: clinician (C), media (M), family and friends (FF) and other patients (P).

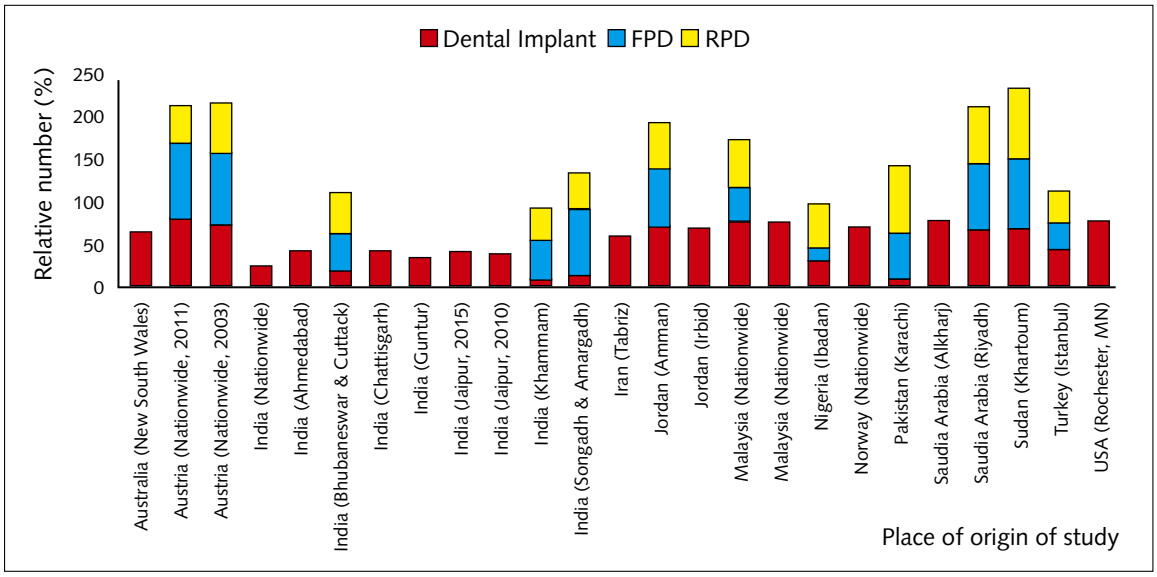

Fig 3 Awareness about treatment alternatives of missing single teeth. In 25 studies, the awareness of participants regarding dental implants as treatment options of missing teeth was investigated. Another 12 studies additionally asked about the awareness of FPDs and RPDs.

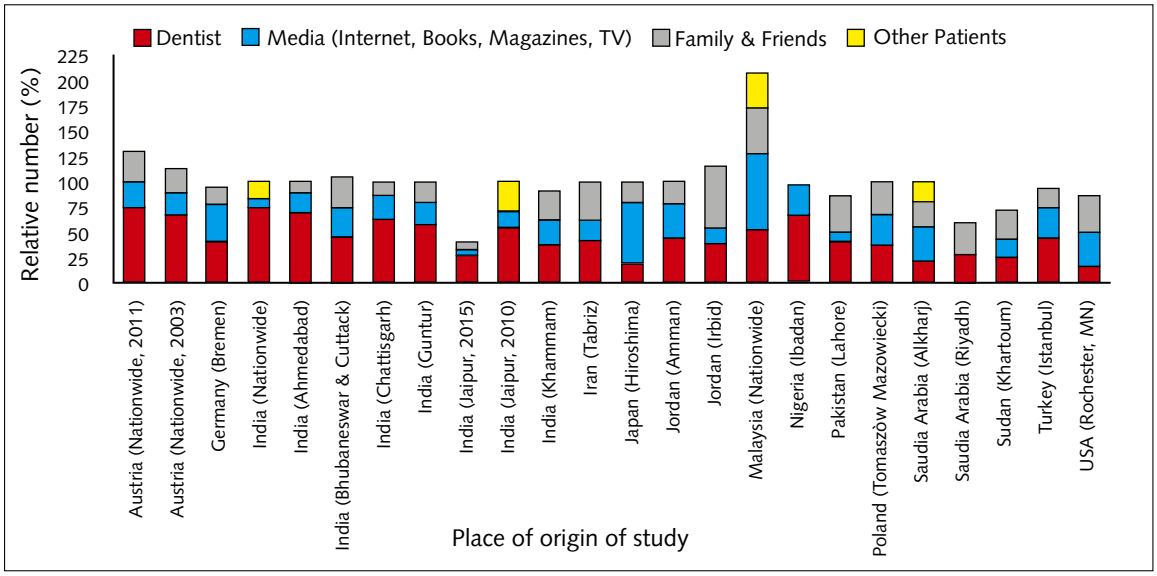

Fig 4 Sources of information about treatment alternatives of missing single teeth. In 24 included publications, interviewees were questioned about their sources of information. Sources could be the clinician, media (e.g. websites on the internet, books, magazines and TV) , their family members and friends or other patients who already received the same treatment.

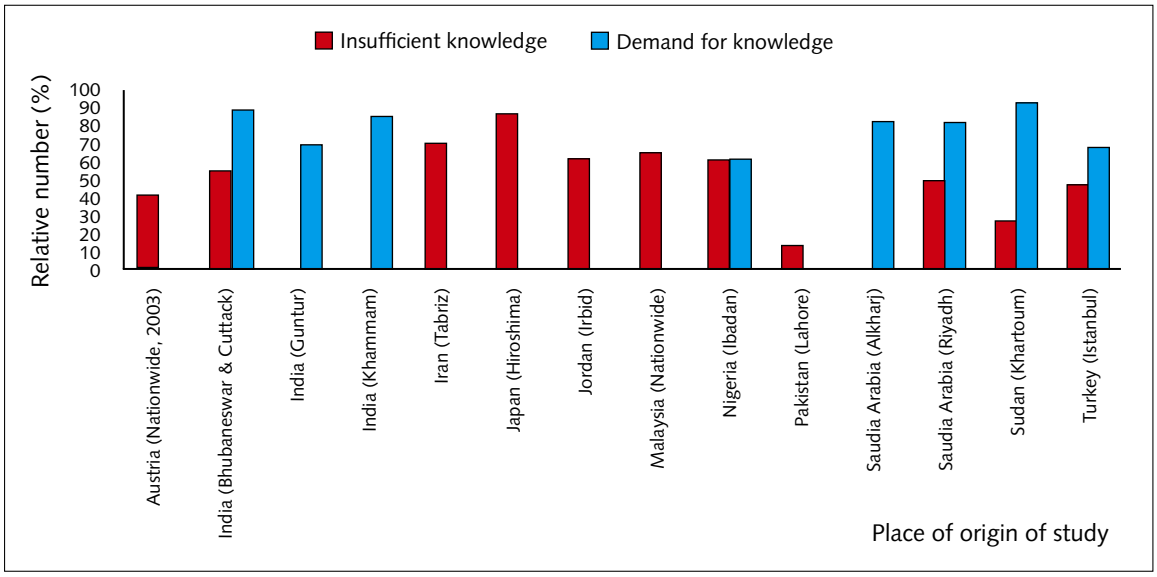

Fig 5 Knowledge of treatment alternatives of missing single teeth. In only less than half (14 of 29) of the included publications using questionnaires as an investigational method, the deficiency level of knowledge (11 studies) or the demand for knowledge (8 studies) about the different treatment options was investigated.

their clinician and or specialist in 45.8% ± 17.2%, followed by the media in 27.9% ± 14.9%, and by friends and family members in 26.3% ± 11.8%. In 19.5% ± 11.0% of the cases, participants obtained their information from other patients.

Eleven studies investigated the deficiency level of knowledge about treatment options (mostly implants) of missing single teeth by asking basic questions (function, durability and placement). In eight studies, participants were able to assess the demand for knowledge. Figure 5 shows that 52.9% ± 19.5% answered the basic knowledge questions insufficiently while 78.3% ± 10.8% stated their need for better knowledge.

Attitude to treatment alternatives, preferences for treatment alternatives and reasons for refusal

People form their opinion or choice of treatment by their individual knowledge. Information about peoples' attitude to treatment options can give an insight about deficits in knowledge. Additionally, it would be interesting to know which treatment alternatives are preferred. If patients refuse specific treatments, the analysis of information about the reasons for refusal is essential. Table 4 summarises results of these three outcome parameters.

Figure 6 shows participants' attitude towards oral implants which was investigated in 18 studies. Three of them additionally questioned the attitude towards FPDs and RPDs as a treatment option. The mean and standard deviation of attitude towards implants were 46.8% ± 23.2%. The attitude to FPDs and RPDs were stated equally with 34.5% ± 9.2%. The results of attitude towards implants were shown to be very heterogeneous, ranging from 14.8% to 80.5%, whereas the attitude to FPDs and RPDs did not vary a lot.

Study participants in six investigations were asked about their preferences for a specific treatment option. Figure 7 shows that dental implants were preferred by 44.5% ± 26.8%, FPDs by 56.2% ± 18.9% and RPDs by 17.1% ± 11.2% of study participants.

Participants were asked in 18 of the performed studies why they would refuse the treatment for replacing a missing single tooth. High costs were most often the major reason (52.6% ± 25.4%) which can be seen in Figure 8. Secondly, possible risks and side effects (27.7% ± 15.3%) as well as fear of treatment (25.1% ± 10.0%) and subjectively less knowledge (27.6% ± 11.7%) were the following reasons for refusal. A long duration of the treatment procedure as well as time restraints of the participants were reasons in 19.4% ± 8.8%.

Discussion

Findings of Ali et al[11] and Jayaratne et al[26], who investigated online information, suggested that there is a need for improvement in the online information about oral implants. Results of Barber et al[20] showed that a clinician should accompany patient information leaflets provided by dental implant companies to give all necessary information, facilitating informed consent. Risks of complications, the relevance of smoking and periodontal disease, and failure or disadvantages were often not described in leaflets. Significant associations revealed by Strietzel[40] suggested that optimisation of pretreatment information of patients as well as during the treatment and maintenance phase would be important.

Analysis of 29 questionnaires revealed large variations of results between studies conducted in different countries and within the same country. Publications from India stated contradictory results on attitude to treatment alternatives, which was the same as studies performed in Jordan, where results about peoples' preferences of treatment were different between two cities. One cause could be differing study designs. Sample sizes varied between 109 and 10,000 study participants. Questionnaire designs were not concordant by including different questions about basic knowledge, which could lead to different results. Due to the density of publications in the last few years, Figures 3 to 8 were sorted by the place of origin. Otherwise, it would have been interesting to see differences in publications with large time intervals in between repetition. In 2011, Pommer et al[41] repeatedly performed the study by Tepper et al[8] from 8 years before, revealing slightly better results, in terms of awareness of dental implants and the increased use of different sources of information.

Table 4 Summary of 29 included studies using questionnaires – attitude to treatment alternatives, preferences for treatment alternatives and reasons for refusal.

Place of origin of study	Authors	Year	Attitude to treatment alternatives (%)			Preferences for treatment (%)			Reasons for refusal (%)
			DI	FPD	RPD	DI	FPD	RPD	Cost / Time / Risk / Fear / Knowledge
Australia (New South Wales)	Best HA[6]	1993	-	-	-	-	-	-	-
Austria									
Nationwide	Pommer B et al[28]	2011	-	-	-	-	-	-	83.0/16.0/53.0/-/-
Nationwide	Tepper G et al[39]	2003	-	-	-	-	-	-	76.0/15.0/34.0/-/-
Germany (Bremen)	Rustemeyer J and Bremerich A[32]	2007	-	-	-	-	-	-	-
India									
Nationwide	Chowdhary R et al[22]	2010	24.2	-	-	-	-	-	85.0/-/-/-/15.0
Ahmedabad	Shah RJ et al[35]	2014	45.3	-	-	-	-	-	78.5/-/-/21.5/-
Bhubaneswar & Cuttack	Satpathy AP et al[34]	2011	71.6	28.4	28.4	-	-	-	58.8/26.¼4.0/-/-
Chattisgarh	Saha A et al[33]	2013	14.8	-	-	-	-	-	35.2/14.3/10.3/21.7/-
Guntur	Suprakash B et al[37]	2013	16.0	-	-	-	-	-	27.8/15.6/11.3/18.4/-
Jaipur	Bhoomika K and Devaraj CG[21]	2015	18.4	-	-	-	-	-	75.3/-/-/-/-
Jaipur	Pragati K and Mayank K[29]	2010	29.0	-	-	-	-	-	61.1/-/19.6/-/18.7
Khammam	Ravi Kumar C et al[31]	2011	72.5	27.5	27.5	-	-	-	57.2/19.3/33.6/-/-
Songadh & Amargadh	Raj N et al[30]	2014	47.5	47.5	47.5	88.9	66.2	37.6	-
Iran (Tabriz)	Faramarzi MS et al[23]	2013	-	-	-	42.6	-	-	-
Japan (Hiroshima)	Akagawa Y et al[4]	1988	47.0	-	-	-	-	-	31/-/-/40/-
Jordan									
Amman	Mukatash GN et al[14]	2010	-	-	-	44.3	33.2	16.3	-
Irbid	Al-Dwairi ZN et al[15]	2014	-	-	-	27.3	65.3	14.7	5.3/-/6.6/14.6/-
Malaysia									
Nationwide	Kohli S et al[12]	2014	80.5	-	-	-	-	-	81.8/20.1/30.2/-/28.3
Nationwide	Kohli S et al[13]	2014	80.5	-	-	-	-	-	-
Nigeria (Ibadan)	Gbadebo OS et al[24]	2014	22.6	-	-	-	-	-	9.0/-/-/-/46.2
Norway (Nationwide)	Berge TI[7]	2000	56.7	-	-	-	-	-	M>>FF>P
Pakistan									
Karachi	Hussain M et al[25]	2015	-	-	-	-	-	-	-
Lahore	Amjad F and Aziz S[18]	2014	-	-	-	2.5	81.3	13.6	30.0/25.0/-/-/12.5
Poland (Tomaszòw Mazowiecki)	Szymanska I et al[38]	2014	-	-	-	-	-	-	-
Saudi Arabia									
Alkharj	Alqahtani F et al[16]	2015	74.4	-	-	-	-	-	51.2/-/-/29.0/-
Riyadh	Al-Johany S et al[17]	2010	-	-	-	61.5	35.2	3.3	70.7/38.8/46.7/41.4/34.3
Sudan (Khartoum)	Awooda EM et al[19]	2014	-	-	-	-	-	-	29.1/3.8/15.2/13.9/38.0
Turkey (Istanbul)	Ozcakir Tomruk C et al[27]	2014	-	-	-	-	-	-	-
USA (Rochester, MN)	Zimmer CM et al[5]	1992	47.0	-	-	-	-	-	-

This table includes 29 questionnaire studies sorted by the place of origin. Resulting relative proportions of study participants about attitude, preferences and reasons for refusal are summarised in this table. Attitude to treatment & preference for treatment: dental implants (DI), fixed partial dentures (FPD), removable partial dentures (RPD).

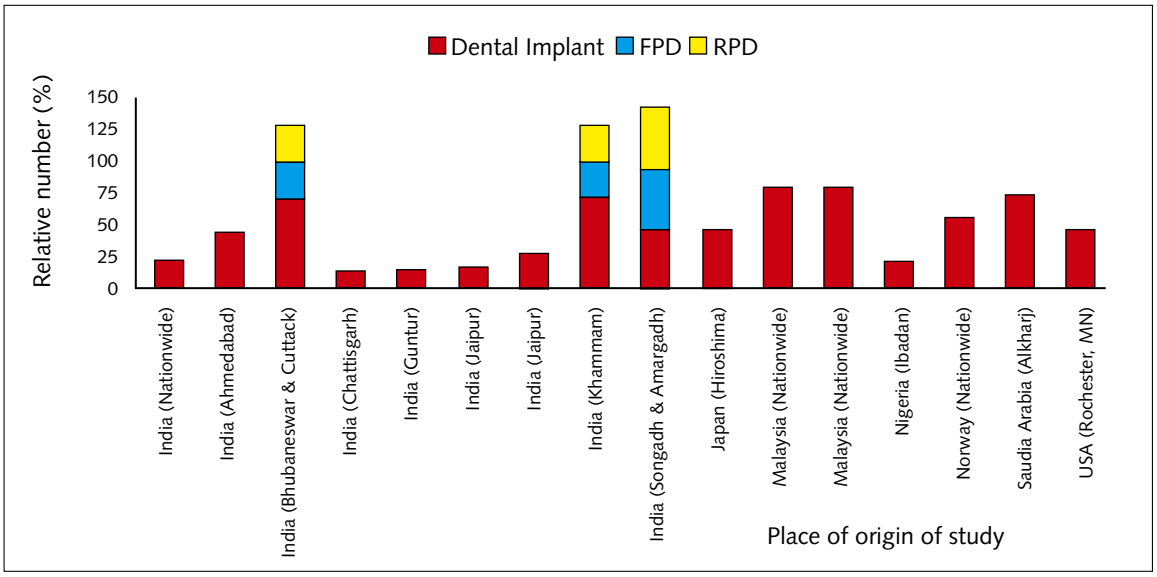

Fig 6 Attitude to treatment alternatives of missing single teeth. In 16 publications, attitude to dental implants, and three additional studies about FPDs and RPDs as treatment for a missing single tooth were investigated.

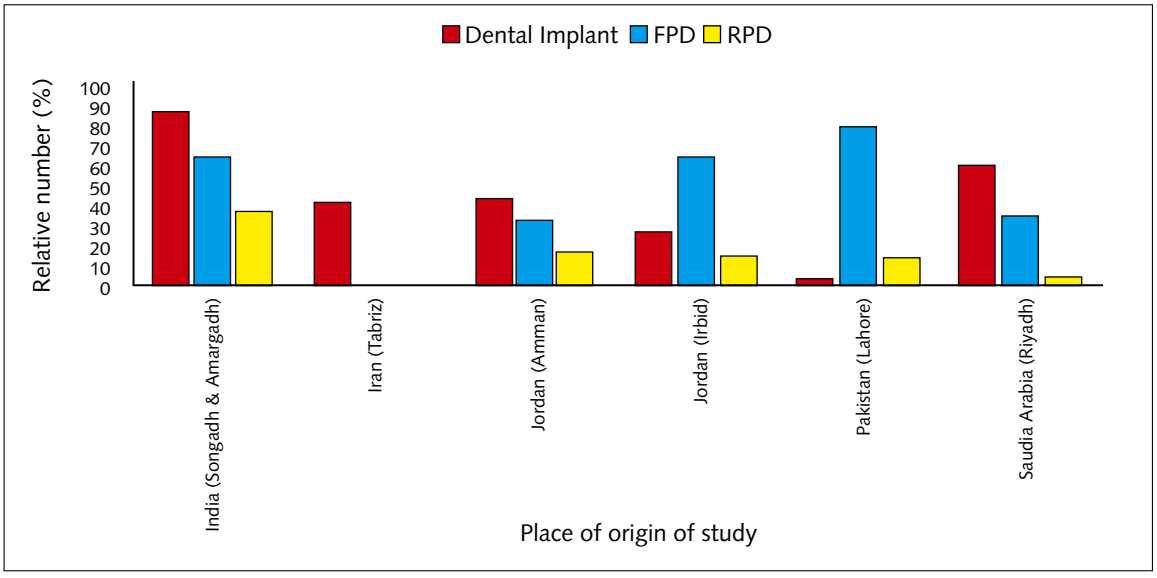

Fig 7 Preferences for treatment alternatives of missing single teeth. Only six studies contained information about preferences of treatment options of study participants. All of them have been conducted in middle and West Asia.

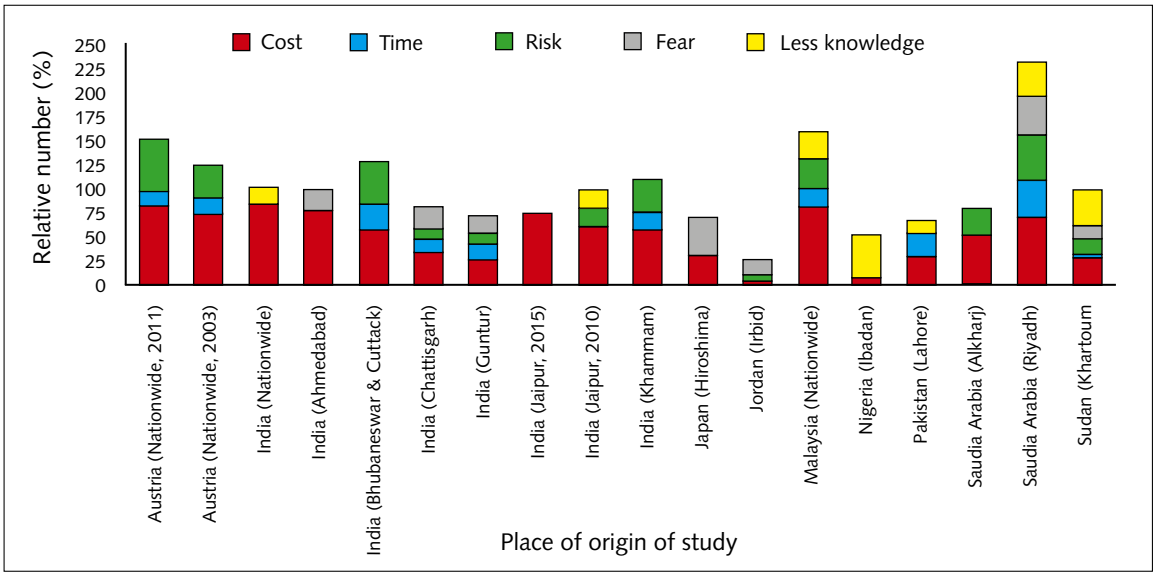

Fig 8 Reasons for refusal of treatment of missing single teeth. Eighteen included studies asked participating interviewees about their possible reason to refuse the treatment to replace a missing single tooth. Cost, time of the participants, as well as the duration of the procedure, risks and side effects, fear and the feeling of having too little knowledge about the treatment were possible options.

Selection and sampling bias

Additionally, non-randomisation of the study population lead to dissimilar age groups and education levels of the sample to be investigated. A difference in previous experience and knowledge could lead to different results. Therefore, it would be important to create balanced subgroups, at least sorted by age and education level to prevent a sampling bias. Sample sizes should be large enough to represent the public population[8]. As already mentioned, only five articles about orthodontic gap closure were among the primary search results, which had to be excluded because they did not investigate any aspects of patient information. Due to a small range of indications for treatment of missing single teeth by orthodontic gap closure, it can be difficult to perform a study about this topic. However, this finding leads to a demand for further studies.

Awareness, sources of information and knowledge

In general, awareness of FPDs and RPDs is acceptable. In more developed countries dental implant awareness reached values up to 79%. Studies performed in India, Pakistan and Nigeria show results below the mean dental implant awareness. Clinicians were by far the most important source of information for treatment alternatives of missing single teeth. The media and family and friends play important roles evenly in patient information. Only every fifth participant gained knowledge from other patients' experiences. An important finding of this review is the high deficiency level of knowledge and an even higher percentage of demand for knowledge.

Attitude to treatment alternatives, preferences for treatment alternatives and reasons for refusal

A positive attitude towards implants was higher than for FPDs and RPDs. Nevertheless, the results of this attitude varies in a wide range (14.8% to 80.5%), whereas the attitude to FPDs and RPDs did not vary a lot, which may have been caused by the low number of studies which asked about it (three), in comparison to 16 publications investigating attitude to dental implants.

Study participants who had a positive attitude to treatment alternatives for missing single teeth preferred implants and FPDs to RPDs. If treatment was refused, high cost was the major reason in every second participant. One third were afraid of the treatment or feared possible risks and side effects. Only every fifth interviewee criticised the long duration of the treatment or stated their personal time constraints.

Conclusion

Non-uniform study designs of used questionnaires could be cause for variations in resultant outcome parameters. By consideration of this systematic review, further studies can standardise methods by using key parameters and a representative study population (size and randomization). Clinicians as the major source of information for patients are responsible for improving patient education about treatment alternatives. Results revealed a high demand for knowledge of patients. The high subjective and objective need for information shows a clear challenge for national and international organisations affiliated with oral rehabilitation and dental implants such as the European Association for Osseointegration (EAO), the Academy of Osseointegration (AO) and the Foundation for Oral Rehabilitation (FOR). It is their responsibility to develop and deliver state-of-the-art information about oral implants to the public in order to enhance awareness, attitude and preference for dental implant therapy in the general population.

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Charles J. Goodacre, W. Patrick Naylor

Single implant and crown versus fixed partial denture: A cost-benefit, patient-centred analysis

Key words *cost-benefit, cost-effectiveness, fixed partial dentures, patient perceptions, single implants*

Single implants and their crowns have high survival rates that exceed the survival rates for fixed partial dentures on teeth and most but not all publications have determined single implants are more cost-effective than 3-unit fixed partial dentures. Both initial root canal treatment and retreatment are more cost-effective than tooth extraction and rehabilitation with a single implant and crown.

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The literature review process

For this analysis, the scientific literature was searched using the following terms: single implants (9,261 results); single dental implants (3,483 results); cost-benefit analysis dentistry (1,172 results); single implants cost-effectiveness (74 results); dental implants cost-effectiveness (118 results); cost-effectiveness analyses dentistry (143 results); cost-benefit dental implants (104 results); dental implant versus fixed partial denture (77 results); dental implant versus bridge (16 results); dental implant versus fixed dental prosthesis (170 results); single implant versus bridge (9 results); and single implant versus fixed partial denture (19 results).

The first two searches (single implants and single dental implants) were not pursued because of the overly general nature of the resulting articles that were identified. The abstracts for all publications identified in the other searches were read to identify those that should undergo a full-text review. During this detailed review process, additional papers were identified and added to the list. All of the resulting publications received a comprehensive review to determine their relationship to the topic of single implant versus fixed partial denture.

One of the papers discussed the 'treatment options for the replacement of missing mandibular incisors' and outlined the available options along with their indications and limitations but did not contain data comparing single implants with fixed partial dentures so it was not included in the review but was included in the reference list[1]. Other articles presented appropriate reasons for selecting an implant as the preferred treatment with references for most but not all of the stated reasons. Therefore, articles identified in their papers were added to the reading list as well as articles containing information and data that supported their unreferenced reasons. A total of 43 papers received full-text reviews in preparation for the literature review[2-44]. This literature review was divided into the following topics:

1. Introduction
2. Background Information
   a) Trends in oral rehabilitation in the United States of America
   b) Reasons for selecting an implant as the preferred treatment
   c) Factors affecting treatment choice: patient's perspective
   d) Perceived need for implants amongst individuals
   e) Sources of patient information
   f) Patient perceptions and expectations related to oral implants
   g) Providing implant treatment: practitioner confidence and barriers
3. Publication quality and patient perceptions about cost

a) Assessment of publication quality
b) Patient perceptions regarding implant treatment costs

4. Direct comparisons of single implants versus fixed partial dentures
   a) Systematic reviews
   b) Findings of the two papers specifically comparing implants and fixed partial dentures
   c) Findings of papers published after the systematic reviews
5. Cost comparisons that included additional alternative types of treatment
6. Costs associated with specific, individual types of treatment
7. Survival comparisons of teeth and implants

Introduction

Prior to the introduction of osseointegrated implants, fixed partial dentures served as the primary means of replacing single missing teeth. But the many benefits provided by an implant compared to a fixed partial denture established the single implant as the preferred treatment alternative to a fixed partial denture (FPD) in most situations.

Background information

Dental treatment trends in the US

The placement of oral implants continues to increase as evidenced by data reported in a 2010 publication based on insurance claims filed between 1992 and 2007 in the US[2]. A decline in the number of pontics was reported, indicating a decrease in the number of fixed partial dentures being provided to patients. In contrast, the only prosthodontic procedure that experienced increased usage during that reporting period was the placement of dental implants[2].

Reasons for selecting an implant as the preferred treatment

Several reasons for using single dental implants rather than a fixed partial denture have been discussed in the scientific literature. They include the following: 1) preservation of tooth structure on the teeth adjacent to the edentulous area[3,4]; 2) avoiding tooth hypersensitivity that can accompany tooth preparation[3]; 3) avoiding the potential need for root canal treatment when teeth are prepared for fixed partial dentures[3] because abutment tooth preparation was found to result in 11% of the abutment teeth requiring endodontic treatment[5]; 4) improved access for oral hygiene[3]; 5) enhanced gingival response compared to fixed partial dentures with subgingival finish lines (there were no references for the enhanced gingival response around implants but there are articles that show less than optimal response that occurs with fixed partial dentures[6-9]; and 6) fewer complications with single dental implants compared with fixed partial dentures[5,10].

In addition, survival percentages for single implants and their crowns have been very high as evidenced by a systematic literature search from The Third European Association for Osseointegration Consensus Conference in 2012[11]. This critical review presented both 5- and 10-year survival rates for both single implants and their crowns. The estimated 5-year single implant survival was 97.7%, while the 10-year estimated survival rate was 94.9%. For the implant-supported single crowns, the 5-year survival estimate was 96.3% and the 10-year survival rate was 89.9%[11].

In contrast, the long-term survival of fixed partial dentures is significantly lower. A meta-analysis of seven studies by Creugers[12] calculated a high 5-year survival rate of 95% for fixed partial dentures based on 26 included studies. However, the survival rate decreased to 90% at 10 years and even further to 74% after 15 years[12]. Scurria[13] also prepared a meta-analysis based on eight studies and determined that 13% of fixed partial dentures were missing or needed replacement at 10 years and more, 31% were removed or in need of replacement at 15 years[13]. A systematic review in 2007[14] provided pooled data showing that implants had a 5 year success rate of 95.1% and tooth-supported fixed partial dentures had a 94.0% survival after 5 years. However, the FPD survival rate declined to 87.0% after 10 years and dropped to 67.3% after 15 years. The authors were unable to identify direct comparative studies assessing the clinical performance of single implant-supported crowns and tooth-supported fixed partial dentures[14].

Factors affecting treatment choice: Patient's perspective

Factors affecting the choice of treatment for replacing a single missing tooth were evaluated in a study by Al-Quran et al[15]. Two hundred volunteers (121 females and 79 males with an age range between 19 and 67 years, and a mean age of 43.6 ± 10.4) were asked about the factors affecting their choice of treatment. The three treatment options evaluated included a single implant and crown, a fixed partial denture and a removable partial denture. One hundred and fifty of the participants received one of the three treatments, with 50 patients in each of the three treatment options. The remaining 50 individuals received no treatment and served as controls.

Avoiding damage to the adjacent natural teeth emerged as the most frequently reported overall factor affecting treatment selection, followed closely by the duration of treatment, and then by the potential 'pain and suffering' they would experience. In reviewing each of the three treatment modalities, the time required for implant treatment was not identified as a major disadvantage by most of the participants. In this 2011 study by Al-Quran, 94% of the patients who received an implant, had a good understanding of implant therapy whereas 34% of the fixed partial denture and 72% of the removable partial denture groups had no understanding of dental implant therapy[15]. It is quite possible such a lack of awareness of implant surgery would likely have an effect on the treatment choice.

Brägger et al[3] reported on the choice of treatment amongst 41 patients who received conventional 3-unit fixed partial dentures and 52 patients who received single crowns on implants. The final treatment choice was based on the preferences of the patient and clinician as it related to the need for preparation of the teeth with fixed partial dentures and the presence or absence of sufficient bone for the placement of an endosseous implant. The authors did not provide data regarding the selection process[3].

A survey[16] of 15 patients who had received single molar implants determined that the major deciding factor in treatment selection was its affordability. Such an outcome was no surprise because these patients only paid a nominal fee for their implant treatment as part of the research project. Interestingly, the authors stated that the majority of the patients would have selected another form of treatment if they had to pay for their implant treatment[16].

Anxiety related to intraoral procedures also has been identified as a major barrier to seeking implant treatment[17].

Perceived need and acceptance of implants amongst individuals

Based on a questionnaire mailed to 3,000 randomly selected individuals in Sweden[18], a 79.4% response rate was obtained, with adequate information received from 2,347 of the 2,382 subjects who returned their questionnaires. Individuals who reported they were missing teeth were asked if they wanted their missing teeth replaced with implants. Approximately 21% or 492 of the survey participants answered yes to this question. Respondents who had all their teeth were asked hypothetically what kind of treatment they would prefer if they were to lose one or two teeth and 51% opted for implants. Their subjective need for implants tended to decrease based on the state of their dentition, meaning participants with the largest number of teeth showed the highest subjective need for implants. When individuals with removable partial dentures were asked if they would rather have implants, assuming such treatment were possible, only 23% gave a positive response. For those Swedes who were edentulous in one arch, there was a 17% 'yes' response rate. However, only 8% of those who were edentulous in both jaws indicated they wanted implant-based dentures. The major reason respondents gave for not desiring implants was satisfaction with their current oral condition. Cost for treatment had some importance. The authors stated that subjective need is not equivalent to demand for treatment[18].

Another study in 2002[19] examined the perceived need for oral rehabilitation amongst 2,176 patients with 1,001 individuals from Sweden and 1,175 individuals from Denmark. Among the Swedes, 4.8% had oral implants (2.1% in the maxilla, 1.5% in the mandible and 1.2% in both jaws) and 2.5% of the Danes had undergone implant-based treatment (1.4% in the maxilla, 0.6% in the mandible and 0.5% in both jaws). Of those with missing teeth, 38% of the Swedes indicated they wanted an implant-based treatment whereas 54% of those

from Denmark desired implants. The authors stated this finding was surprising because patient fees in Denmark were higher than in Sweden, almost double the cost in Sweden for the placement of a single implant. In the previous study[18] by these authors, cited above, 21% of the respondents indicated they would like dental implants. In this study the percentage was higher, indicating the need for implants seems to have increased over time[19].

A 2003 survey in Austria[20] consisted of a 'representative sample' from 1,000 adults who were interviewed (sample size not specifically identified). Some of the 61% of those interviewed reported they would accept oral implants, if the need occurred. The acceptance rate was highest among males and those males below the age of 30 years old. It was of interest to note that 23% of those sampled decidedly rejected dental implants[20]. The authors repeated the survey in 2010[21], again with 1,000 Austrian adults, and at that time the acceptance rate for implants was 56%. Interestingly, 23% of those individuals surveyed decidedly rejected implant treatment, meaning the rejection percentage was the same as in 2003. The authors did not demonstrate an upward trend in implant acceptance. It was suggested that improved communication may lead to greater patient acceptance of implants as a treatment modality in oral rehabilitation[21].

A study of the treatment preference of 59 subjects at a university dental hospital found that 94% of the subjects selected implant treatment rather than fixed partial dentures and removable partial dentures for the replacement of missing anterior teeth and 84% for replacement of missing posterior teeth[22].

Sources of patient information

In a survey of 1,000 Austrian adults[23], 72% said they were familiar with implant treatment modalities, but they knew less about implants than other alternative treatments. Amongst the respondents, the preferred source of information was their clinician. However, 77% of those questioned indicated their clinicians did not use implant-based treatments. Forty-four percent thought implants should only be placed by specially trained doctors and over 60% thought cinicians or surgeons who provided treatment modalities involving implants were better qualified than those who did not provide such treatment. When queried about the reasons for implant failure, half attributed them to allergies and incompatibilities, the other half to poor medical care. Only 29% incriminated poor oral hygiene[23].

The authors of the Swedish survey indicated that many of the 2,347 subjects in their study were not aware of the possibility of implant treatment[18].

A stress-provoking intraoral procedure such as implant surgery can impair the ability of patients to process relevant information. In support of this effect, a study[17] involving 98 healthy subjects showed that the ability of patients to correctly understand information provided to them when they are under the stress of an anticipated treatment is limited. While patients felt they properly comprehended the supplied information, their perception was unreliable[17].

Patient perceptions and expectations related to oral implants

Interviews were conducted with 15 participants who had been part of a controlled clinical trial of immediately placed molar implants[16]. Patients were asked their opinion about the preoperative, intraoperative and postoperative phases of their treatment. The participants indicated they expected a long life span from their implants, yet it was apparent they only had minimal knowledge regarding the need for postoperative maintenance, a finding that was described by the authors as alarming[16].

Providing implant treatment: Confidence of the clinician and barriers

In a 2010 questionnaire sent to 500 general dental practitioners in Wales, 217 responses were received[24]. The survey was focused on determining the confidence level, barriers and attitudes of clinicians toward the replacement of missing teeth. Approximately 81% of the respondents indicated they were not confident enough to provide dental implants to their patients. Almost all of the respondents admitted they had poor or no university training relative to providing implant treatment. In addition, many of the clinician's highlighted the significance of financial barriers to their treatment planning imposed by the National Health Service (NHS)[24].

Publication quality

The quality of peer-reviewed 'economic evaluation' publications in dentistry was examined in a 2015 systematic review[25]. Published papers were compared as to how they rated against the Drummond Checklist (a guideline used extensively amongst health economists to ensure studies reach an acceptable standard). This checklist is recommended by the Cochrane Handbook for Systematic Reviews of Interventions. The conclusion of the review was that methodological limitations were often present in the reviewed publications. These limitations included absence of sensitivity analysis (an approach for handling variable uncertainties in economic analyses, such as examining the best and worst case scenarios and allowing one item to vary while all others are held constant), absence of discounting (a method for eliminating the effects of inflation) and insufficient information being provided on how costs and outcomes were measured and valued. In fact, 21% of the eligible studies did not discount costs and 11% provided insufficient information regarding costs and outcomes discounting. In addition, the authors reported that more than half of the published articles did not perform a sensitivity analysis[25].

In an earlier systematic literature review[26] related to economic outcomes in prosthodontics, the authors stated that measures of cost-benefit (comparing the cost of different options against anticipated benefits including physiologic and psychosocial impact), cost-effectiveness (comparing the cost with the benefit based on strong evidence of the treatment effectiveness, often used to calculate the 'cost-saved' by a particular treatment), and cost-utility (comparing cost with value as evidenced by quality of life and length of life) are the gold standards for evaluation but the feasibility of such analyses is an issue. To ensure these measures were included in publications, the authors recommended collaboration with health economists to help guide such future research[26].

Patient perceptions regarding treatment cost

In questioning a representative sample of 1000 adults in Austria, Tepper et al[20] determined that cost was an important factor when choosing amongst treatment options for tooth replacement. Interest in implants, should there be a need, was highest amongst males and interviewees below the age of 30. The interest in implant therapy increased with increased family income. However, all of those questioned considered implant treatment to be very expensive[20].

In the previously cited study[16] on 15 patients, implants were selected as the treatment option because the patients "took park in the clinical trial mainly because it offered oral implant therapy at a reduced cost". If they had to pay the regular cost for the implant treatment, the majority would have selected another treatment option[16]. This response indicates the participants considered implant treatment to be too costly.

In comparing the survey results obtained in 2003[20] with those obtained 7 years later[21], the authors found that significantly more interviewees complained about treatment costs, which were rated as the major disadvantage of oral rehabilitation by means of implants. In both the high-income and the low-income groups, implant treatment was reported to be too expensive. However, those who had first-hand experience with dental implants tended to have less of a negative opinion about costs to benefits[21].

There have been studies comparing the amount of money individuals would be willing to pay for dental implants with what they thought the actual cost of such treatment would be. In one study[20], individuals were asked to estimate the cost of a single implant without a crown, 18% responded with 750 Euros, 26% said 1000 Euros, 20% said 1500 Euros, 11% said 2000 Euros, 16% said more than 2000 Euros and 9% were undecided. Amongst those who provided the lowest estimate of 750 Euros, 75% considered this amount to be too expensive. Even in the group who had already received implants, 79% believed that oral implants were too expensive. Most of the respondents attributed the cost to the clinician (62%) while 21% felt it was the dental laboratory technician and another 15% indicated it was due to the implant manufacturers and government taxes[20].

A study of 59 individuals in Hong Kong determined participants were willing to pay 10,000 Hong Kong dollars for a single tooth replacement using an implant (1 USD = 7.8 HKD)[22].

Comparisons between single implants and fixed partial dentures

Systematic reviews

A 2012 systematic review[27] compared a single tooth implant and crown with a conventional fixed partial denture placed on teeth, based on economic considerations. Twenty-six publications were full-text reviewed. The authors determined initial costs for both treatments were similar but varied depending on geographic location. Additionally, they stated failure rates were comparable between the two treatment modalities and the long-term economic comparisons were similar. Paradoxically, in their discussion section, the authors stated the following: "The main finding of the present review is that in most of the included reports, the outcome of the implant crown was regarded as economically superior compared to the FDP"[27].

Another systematic review[28], published in 2013, examined the cost-effectiveness of dentures on implants and determined the single implant was a more cost-effective treatment compared with a 3-unit fixed partial denture. This conclusion was based on 14 studies looking at long-term costs and cost-effectiveness[28]. However, only 2 of the 14 included studies were specifically focused on comparing the cost-effectiveness of single implants versus fixed partial dentures.

Direct comparisons of implants versus fixed partial dentures

In one of the two papers[3] , which made a direct comparison between single tooth implants and fixed partial dentures (FPDs), 37 patients received 41 conventional fixed partial dentures and 53 patients received 59 single crowns on implants. Based on the Swiss system, the mean total treatment cost was 3,939 ± 766.4 Swiss francs for the fixed partial dentures and 3,218 ± 512 Swiss francs for the implant treatment. Laboratory costs were higher for the FPD group (1,527.8 ± 209 Swiss francs) than for the implant group (579.6 ± 106.9 Swiss francs). The time span from the start of treatment to completion was 3.23 ± 2.64 months for the FPD group and 5.94 ± 3.29 months for the implant group. However, the total treatment time in hours was similar (4.8 ± 0.9 h for the implant group and 5.1 ± 1.3 h for the FPD group). The authors concluded that implant treatment had a more favourable cost-effectiveness ratio than a fixed partial denture, especially in situations where there was sufficient bone and the adjacent teeth were intact or minimally restored[3].

The second paper[29], published in 2009, compared a single implant and crown with a fixed partial denture based on a model that used a 'simulation decision framework', which covered a 20-year period. Costs were determined based on a survey of 47 clinicians with the following results: 1) The fee of a fixed partial denture ranged from 1850 to 4200 Euros; 2) The cost of an implant and crown ranged from 1990 to 3950 Euros. The authors concluded that an implant appears to be the dominant 'first-line strategy' based on its lower overall costs and higher success rate. They also indicated the data in their study showed the implant strategy was acceptable in all the high-income areas of Europe, within the limitations of their model[29].

Findings of papers published after the two systematic reviews

The long-term cost-effectiveness of an implant and a 3-unit fixed partial denture was compared in 26 patients[30], 15 of whom had selected an implant and 11 who chose a fixed partial denture. The cost-effectiveness of the treatments was analysed over 3, 5, and 10 years. The implant and single crown had a higher probability of being cost-effective compared with the fixed partial denture over both the 3-year and 10-year time horizons. The 'quality adjusted tooth years' (QATYs) were slightly higher for the implant treatment and there were fewer complications. Implant treatment led to a cost saving of 584 Swiss francs primarily due to the higher initial costs of the fixed partial denture[30].

A 2014 study[31] from Korea examined the cost-effectiveness of a single dental implant and a 3-unit tooth-supported fixed partial denture from a societal perspective. The mean cost in US dollars for an intraoral implant was 1,616 in a clinic and 2,708 in a hospital whereas the fixed partial denture cost was 1,308 in a clinic and 1,805 in a hospital. Using a decision tree model to estimate cost-effectiveness over a 10-year period, the implant treatment cost 261 to 342

US dollars more than the fixed partial denture while having an average survival rate that was 10.4% higher than the fixed partial denture. It was determined that the implant would become the dominant intervention if the cost of an implant were reduced to 80% of the current cost (in U.S. dollars in 2010). In other words, a dental implant would be more effective from a societal perspective, if the cost were 20% lower[31].

■ Cost comparisons that included additional alternative types of treatment for replacement of missing single teeth

The long-term cost-effectiveness of five treatment alternatives (single implant and crown, resin bonded fixed partial denture, conventional complete coverage fixed partial denture, cantilevered fixed partial denture and autotransplantation of a tooth) for replacing a maxillary lateral incisor was investigated[32]. The costs were based on the national fee schedule in Switzerland, provided by the Swiss Dental Association. The following rankings of cost-effectiveness were presented, from most cost-effective to least cost-effective: 1) autotranplantation; 2) cantilever fixed partial denture; 3) resin bonded fixed partial denture; 4) single implant and crown; and 5) conventional complete coverage fixed partial denture. Therefore, the most cost-effective treatment was autotranplantation and the least cost-effective treatment was the conventional complete coverage fixed partial denture[32].

One 2009 paper[33] on clinical decision-making included a table containing the cost of various treatment options based on the cost as a factor of 'X'. The information related to the cost of 'X' was obtained through a survey of 100 dentists from various metropolitan areas throughout the US. Six of the 11 cost factors that were most closely related to the topic of this review are presented below:

1. Three-unit fixed partial denture cost factor was 4.0X (meaning 4 times the value of X)
2. Three-unit FPD with crown lengthening surgery = 5.1X
3. Three-unit FPD with one root canal treatment = 4.9-5.3X
4. Three-unit FPD with two root canal treatments = 6.2X
5. Implant, stock abutment and crown = 4.3X
6. Implant with sinus augmentation, stock abutment and crowns = 6.8X

The cost of maintaining single implants and their crowns was compared with the cost of maintaining teeth through periodontal care in 43 patients who had 847 teeth at the initial examination and received 119 implants[34]. It was determined that the mean cost of maintaining the implants was 10.2 Euros per year and the cost of maintaining the teeth was 2.1 Euros per year, about five times lower. The higher cost of maintaining the implants was due to the high prevalence of peri-implantitis. Indeed, the prevalence of peri-implantitis was 53.5% at the patient level and 31.1% at the implant level while the prevalence of periodontitis was 53.4% at the patient level and 7.6% at the tooth level[34].

A 2015 publication determined the most cost-effective management for oral conditions that could lead to partial or complete edentulism[35]. The available evidence indicated that root canal treatments were the most cost-effective treatment for central incisors with irreversible pulpitis and coronal lesions. When initial root canal treatments failed, retreatments were still the most cost-effective. When root canal retreatments failed, extractions and replacement with implant-supported crowns were more cost-effective than fixed partial dentures or removable partial dentures[35].

The cost-effectiveness of molar endodontic retreatment was compared with fixed partial dentures and single-tooth implants. When there was a failed endodontically treated first molar, endodontic microsurgery was the most cost-effective treatment followed by nonsurgical retreatment and crown, then extraction and a fixed partial denture, and finally extraction and a single tooth implant with a crown[36].

Based on costs specific to the state funded healthcare system in the UK, an evaluation was made of the cost-effectiveness of conventional approaches to root canal treatment versus replacement with an implant[37]. The authors concluded that root canal treatment is highly cost-effective as the first treatment option. Retreatment is also cost-effective but if retreatment were to fail, the additional cost of apical surgery could not be justified. The authors stated that implant treatment is limited to a third line intervention when re-treatment fails[37].

A 2008 article[38] reviewed the available literature regarding single implants and restored natural teeth, to recommend management strategies that influence treatment planning decisions. The authors determined that "endodontic treatment of teeth represents a feasible, practical, and economical way to preserve function" and they also stated that "implants serve as a good alternative in selected indications in which prognosis is poor"[38].

A paper by White et al[39] compared endodontic and implant treatments for the purpose of helping clinicians make treatment decisions. The authors indicated there is a need for long-term, large, clearly defined studies, with simple and clear outcome measures (such as survival in combination with defined treatment protocols that compare the clinical performance of endodontic and implant treatments)[39].

Costs associated with specific, individual types of treatment

A cost analysis based on 24 patients with ectodermal dysplasia and severe hypodontia was used to develop a model that would accurately identify the dental costs from birth through to early adulthood[40]. The analysis produced a cost range from 2,038 to 3,298 US dollars for those who only received prosthodontic treatment whereas the cost ranged from 12,038 to 41,146 US dollars for patients treated with a combination of prosthodontic, orthodontic and implant treatment[40].

The cumulative costs associated with prosthodontic treatment and maintenance of 45 young adult patients with birth defects was determined (22 patient with hypodontia/oligodontia, 22 with hypodontia/oligodontia and 5 with amelogenesis/dentinogenesis imperfecta)[41]. The initial treatment costs per replaced tooth unit were higher for implant treatments than tooth-supported treatments, but there were no significant differences in the long-term treatment costs over an 8-year time period. However, the treatments involved replacement of multiple teeth and were not related to the replacement of single missing teeth. The median costs per person associated with amelogenesis/dentinogenesis were by far the highest[41].

In 2014, an estimation of the long-term complication costs associated with single implants in periodontally healthy patients was calculated after a time period of 16 to 22 years old[42]. Fifty patients with 59 surviving implants were recalled for a clinical examination and complications data retrieved from their patient records. After a mean follow-up of 18.5 years, the cost of complications amounted to an average of 23% of the initial treatment cost ranging from 0 to 110%. There were no costs associated with 39% of the implants whereas 22% had expenses that exceeded 50% of the initial treatment fees. Eight percent of the patients experienced costs that were 75% of the initial treatment costs[42]. A 5-year prospective randomised clinical trial[43] assessed the need for surgical aftercare and prosthodontic aftercare in 93 patients with implant crowns in the anterior maxilla where bone grafting had also been performed. Surgical aftercare was required in 9% of the patients and was related to peri-implant tissue problems. The average time required for surgical aftercare was 6 min per patient whereas the prosthodontic aftercare was 54 min per patient[43]. While there was no cost analysis provided, the time required in providing aftercare did have a financial implication.

Survival comparisons of teeth and implants

A systematic review[44] conducted in 2007 compared the outcomes of the following three courses of treatment: 1) root canal treatment with single implants; 2) fixed partial dentures attached to teeth; and 3) extraction without replacement. The authors concluded that success criteria differ greatly among the various courses of treatment, preventing direct comparisons of success rates. However, survival comparisons were able to be made, making it possible to determine that root canal treatment and single implants had similar survival rates in the studies that were evaluated. In addition, both root canal treatment and single implants produce superior long-term survival compared to fixed partial dentures. Limited data suggested that tooth extraction without replacement resulted in inferior psychosocial outcomes compared to the other treatment choices[44].

Discussion

Two systematic reviews that compared single oral implants with fixed partial dentures provided differing

conclusions regarding a long-term economic comparison. One review[27] determined the economic comparisons were similar whereas the other review[28] indicated the single implant was more cost-effective. In both of the included studies[3, 29] that made direct comparisons between implants and fixed partial dentures, the single implant treatment modality was judged to be more cost-effective. There were two papers published after the above-mentioned systematic reviews. One of the publications[30] indicated the 'quality adjusted tooth years' were higher for the implant treatment and resulted in cost savings due to the higher cost of a fixed partial denture. In contrast, the other study[31] calculated a higher cost of implant treatment and suggested a 20% implant fee reduction if the dominant intervention was used. Based on this limited scientific evidence, oral implant treatment was determined to be more cost-effective in some geographic areas but not in other areas. Therefore, more scientific evidence is needed to form the basis for a definitive statement regarding which treatment modality is the most cost-effective. However, it is apparent from patient cost perceptions that oral implant therapy is judged to be expensive[20,21].

In comparing the long-term cost-effectiveness of multiple treatments for the replacement of missing single teeth, treatments other than the single implant were determined to be the most cost-effective. These treatments included autotransplantation, a cantilever fixed partial denture and a resin bonded fixed partial denture[32]. The cost of maintaining teeth through periodontal care was calculated to be five times lower than the cost of maintaining implants[34]. Root canal treatment was determined to be the most cost-effective first treatment for teeth requiring such an intervention[35, 37]. Root canal retreatments were found to be more cost-effective than extraction and replacement with a single implant[35-37]. When root canal retreatments fail, extraction and implant placement was found to be more cost-effective than a fixed partial denture in two studies[35,37], but not in another analysis[36]. A systematic review that compared root canal treatment with single implant fixed partial dentures attached to teeth, found that root canal and single implant treatments had similar survival rates that were superior to the survival rate of fixed partial dentures. Based on these studies, the preservation of natural teeth is the preferred treatment modality while oral implants provide an excellent solution should tooth retention through root canal treatment or retreatment not be successful.

For patients with congenitally missing teeth, the cost of treatment can be high, particularly when the oral rehabilitation includes orthodontic, prosthodontic and oral implant treatment modalities.

Conclusions

1. The use of single implants has increased while the use of fixed partial dentures has decreased. Reasons for this change have been related to the higher long-term survival of dental implants and factors such as tooth structure preservation.
2. There is limited perceived need for implants in many patients but the acceptance of implant therapy is greater in those patients who have a greater number of teeth.
3. Patients consider implant treatment to be expensive.
4. More scientific evidence is needed to formulate a definitive statement regarding the comparative cost-effectiveness of single oral implants and fixed partial dentures that replace one tooth. However, given the available publications, single implants appear to be more cost-effective than fixed partial dentures.
5. Retaining teeth through periodontal care and both initial root canal treatment and root canal retreatment was determined to be more cost effective than tooth extraction and rehabilitation with a single implant.
6. Oral rehabilitation for patients with congenitally missing teeth can be quite expensive when it involves multiple oral disciplines.

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Keith Horner, Andrew M. Shelley

Preoperative radiological evaluation of missing single teeth: A review

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Aims: Missing single teeth can be treated in several ways and preoperative radiological evaluation varies accordingly. The main area of controversy relates to the need for cross-sectional imaging in the context of implant treatment. In this context, the aim of the systematic component of this review was to determine whether the use of additional cross-sectional imaging has any impact on diagnostic thinking, treatment planning or outcome, compared with conventional imaging alone. An additional aim was to present information relating to diagnostic efficacy, dose of radiation, economic aspects of imaging and selection criteria.

Materials and methods: PubMed/MEDLINE, OVID/Embase and the Cochrane central register of controlled trials were searched up to and including June 2015. Studies were eligible for inclusion if they compared the impact of conventional and cross-sectional imaging when placing implants. Quality assessment of studies was performed. Synthesis was qualitative.

Results: Twelve studies were included, all of which had a 'before-after' design. Only three of these were limited to single implant treatments with none limited to immediate implants. There were methodological problems with most of the studies and results were sometimes contradictory regarding the impact of cross-sectional imaging.

Conclusions: It is tentatively suggested that cross-sectional imaging may not be required in straightforward, unchallenging, cases of missing single teeth being considered for implant treatment. Beyond this, no strong evidence exists to inform the choice of imaging. Existing guidelines on preoperative imaging for missing single teeth are not unanimous in their recommendations, either for implant or non-implant treatments.

Conflict-of-interest statement: *The authors declare that they are authors of one paper included in the systematic review part of this paper. Otherwise there are no conflicts of interest.*

■ Introduction

Treatment planning for replacement of missing single teeth requires a thorough history and clinical examination, usually supplemented by radiological examination. It is a fundamental principle of radiation protection that all clinical uses of ionising radiation must be justified in advance at the individual patient level[1]. Furthermore, some radiological modalities can be expensive, particularly those typically used in more complex treatments such as implants. Therefore, from both radiation protection and economic perspectives, it is important to use radiological diagnostic procedures only when it is appropriate to do

so. Following justification, all exposures to ionising radiation must be optimised so that patient doses are kept as low as reasonably achievable, taking into account image quality requirements[1]. The diagnostic efficacy of imaging is a key consideration and the hierarchy developed by Fryback and Thornbury[2] is widely used to assess it (Table 1). In this hierarchy, a satisfactory performance at lower levels does not mean that efficacy is guaranteed at the higher levels. For example, a technically excellent diagnostic imaging test (Level 1) may produce more accurate diagnosis (Level 2), but may not alter patient management (Level 4) or patient outcome (Level 5). Thus, the choice of imaging for patients should ideally be informed by higher level evidence which addresses impact (Levels 3 or higher).

For most of the latter half of the twentieth century, the clinician and/or surgeon had limited choices for imaging: mainly 'conventional' radiography (intraoral, panoramic and cephalometric), supplemented by possible access to conventional or computed tomography (CT) radiograph systems. Today, cone beam computed tomography (CBCT) offers easy access to cross-sectional imaging, with particular relevance to implant placement. There has, however, been concern about the potential for overuse of this modality on the grounds of radiation dose and financial costs[3].

The treatment modalities for replacement of missing single teeth range from simple to complex procedures. Imaging should be prescribed which provides adequate diagnostic efficacy at the lowest financial cost and with the least exposure to radiation. This process is aided by the availability of clinical guidelines, known as referral criteria, selection criteria or appropriateness criteria. These criteria are not protocols that must be followed for all patients, but are "a concept of good practice against which the needs of the individual patient can be considered"[4].

Selection criteria for dental radiology, when treating missing single teeth using non-implant solutions, are well established[5-7]. When planning oral endosseous implants, however, there is disagreement between the guidelines. Some suggest that cross-sectional imaging is required in all cases when implants are planned[8-11], while others suggest selected use[3,7,12-20] or offer equivocal statements[21-23]. These differences have been highlighted in recent systematic reviews[24,25]. It is notable that existing guidelines do not look specifically at the single tooth implant situation, which might present unique imaging needs and challenges, or at immediately placed implants in tooth sockets. There is, therefore, a need for systematic assessment of the relative diagnostic efficacies of conventional radiography and cross-sectional imaging, as part of implant planning, particularly at the higher levels of the Fryback and Thornbury hierarchy[2].

The broad question underlying this review was: what imaging techniques are appropriate as part of preoperative evaluation of missing single teeth? Nevertheless, the main area of controversy in preoperative radiological evaluation of missing single teeth is the appropriateness of cross-sectional imaging when planning implant placement. Consequently, the focused question addressed by this review was: does the use of additional cross-sectional imaging have any impact on diagnostic thinking, treatment planning or outcome compared with conventional imaging alone, in the preoperative evaluation of single missing teeth for implant treatment? This was addressed by a systematic review of the literature. The paper subsequently considers the preoperative radiological evaluation of missing single teeth in a wider context, including selection criteria.

■ Materials and methods

The design of this review was adapted from that used in a recently published systematic review[26], which addressed implants in the anterior mandible to support an overdenture. The research question, modified from those used previously, was: does the use of additional cross-sectional imaging have any impact on diagnostic thinking, treatment planning or outcome compared to conventional imaging alone, in the preoperative evaluation of single missing teeth for implant treatment? This matched levels 3, 4 and 5 of the hierarchy of efficacy as defined by Fryback & Thornbury[2] (Table 1). Lower level studies, concerned with technical efficacy or diagnostic accuracy efficacy, were not included. Similarly, studies which analysed only the higher level of societal efficacy were excluded.

Inclusion criteria

- Human *in vivo* studies or *in vitro* human simulation studies where implants were planned.
- Comparison between cross-sectional imaging, of any type (tomography, CBCT, CT and Magnetic Resonance Imaging [MRI]), and conventional, two-dimensional radiography prior to implant placement.
- The outcome had to be classifiable as diagnostic thinking, therapeutic efficacy or patient outcome (Table 1).
- Permissible study designs were before-after studies, randomised controlled studies or other observational study designs.
- Studies were included where the primary purpose was cross-sectional imaging for assessment prior to implant placement rather than being primarily for the construction of a computer- generated surgical guide.
- Studies in the English language or with an English language abstract.
- The following publication types were considered: peer-reviewed journals, non-peer-reviewed journals, reports, book chapters, conference abstracts, theses, informal reports and on-going studies where complete data were available.

While the review was focused on preoperative imaging of missing single teeth, previous experience[27] suggested that the volume of literature was likely to be limited and often not restricted to specific clinical situations such as single missing teeth. Consequently, an a priori decision was taken not to restrict the review to studies solely dealing with single implants.

Search strategy

This replicated the previously performed strategy[27] exactly, but with the endpoint date extended from February 2013 to June 2015. Three bibliographic databases, PubMed/MEDLINE, OVID/Embase and the Cochrane central register of controlled trials were searched. Each allowed different search terms. The reference sections of relevant studies identified in the search of bibliographic databases were handsearched, and the references of clinical guideline publications listed in the reference sections of two recent reviews[24,26], were similarly handsearched.

Study selection

After removal of duplicates, two authors (KH and AMS) independently screened publications. First, titles and then abstracts were screened to exclude studies that were irrelevant. Finally, full texts of remaining publications were reviewed for eligibility. In cases where there was disagreement between the authors, or where either expressed doubt about whether the inclusion criteria were fully satisfied, a third reviewer (AMG) was involved.

Data extraction

Detailed assessment of each full paper was carried out independently by two reviewers (KH and AMS). Disagreements were resolved by subsequent discussion. Reviewers were not blinded to authors, institution or study results during the study selection process, as there was existing familiarity with most studies and blinding was not seen as essential[27]. The data extraction form developed by Shelley et al[26] was used.

Quality assessment

All included studies could be classified as having a 'before-after' design. Quality assessment was carried out by two reviewers (AMS and KH) independently, using the tool used by Shelley et al[26], which is an adaptation of a previous design[28]. This tool summarises overall quality assessment using a visual analogue scale. After independent assessment, the two reviewers met to compare quality assessments and came to an agreement. Any disagreement was resolved by the involvement of a third reviewer. To limit the risk of bias in the quality assessment, where any of the authors of the current review were listed as an author of included publications, quality assessment was performed independently by two reviewers (KH, AMS and, if required, one or two alternative reviewers).

Synthesis

Tables were constructed of study characteristics, outcomes and quality assessment. For each included

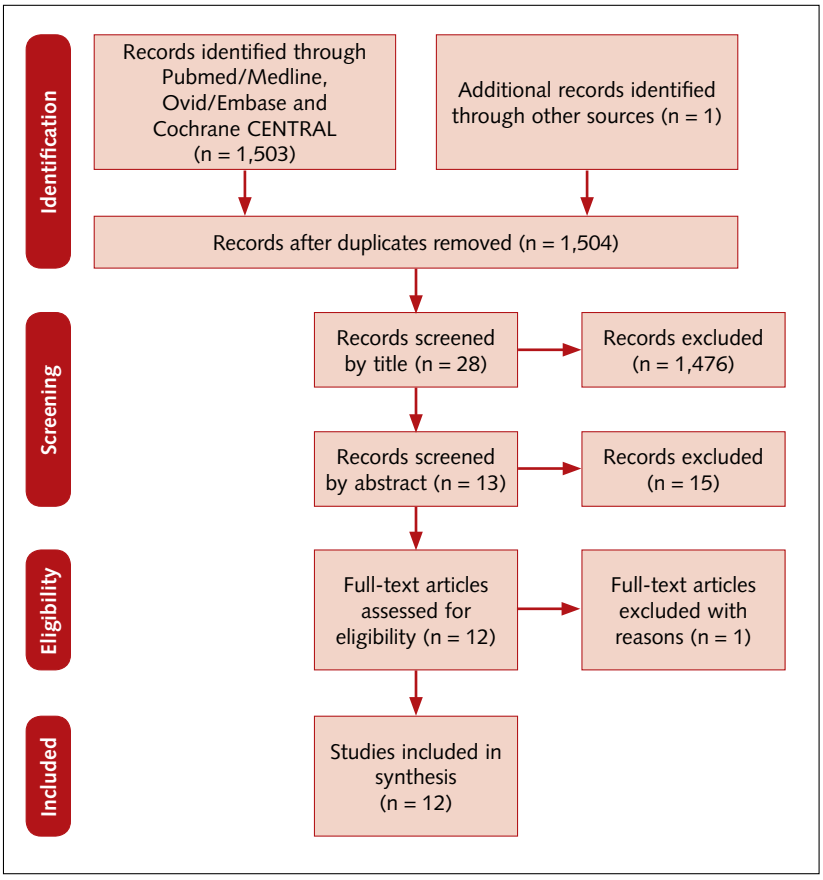

Fig 1 PRISMA[29] flow chart showing the results of searches and study selection.

study, the two authors agreed on whether or not the availability of cross-sectional imaging led to a change in diagnostic thinking, treatment planning or outcome. Pooled quantitative analysis was not possible because of the small number of identified studies and their heterogeneity. Analysis, therefore, was qualitative only.

■ Results

Figure 1 shows the flow of publications identified through the searches. Twelve articles were included and underwent data extraction and quality assessment[30-41]. The authors of the current review were listed authors of one included study[41]. Of the twelve included studies, only three were studies limited to implants which were planned for single missing teeth[31,34,37]. At least three other studies included some cases of implants replacing single missing teeth, or could reasonably be assumed to have done so, but the data relating to these could not be extracted for separate analysis[32,33,38]. No studies differentiated between immediate, early or delayed implant cases. All 12 included studies were judged to be at Level 4 of Fryback and Thornbury's hierarchy of diagnostic efficacy[2], although one[37] stated that their study was at Level 3 (diagnostic thinking efficacy), although in our view, the design matched the definition of Level 4 listed in Table 1. Another study[41] had an element that arguably could have been judged as Level 5, as the authors recorded perforations when performing osteotomy for implants in an anthropomorphic phantom. A pragmatic decision was made to evaluate this study with the others, as studies of therapeutic efficacy.

Table 2 shows the subjective quality assessments for the studies using the visual analogue scale. The quality of the studies was judged as variable but was frequently low. The reasons for these low ratings were many, but typical problems included single observer studies[31,32,35,38] , the results of which are unlikely to be translatable, and combining observations of multiple observers into average scores[33,37], which does not reflect real clinical practice. Sample sizes were sometimes very small[30,36]. Although some studies used selection criteria to narrow the focus onto particular patient and case types, notably Frei et al[32], who excluded challenging cases, other studies included study subjects that were of mixed difficulty[33,38,40]. Low quality scores were often related to vague or incomplete reporting of methods[40]. In some cases, the 'after' cross-sectional imaging was viewed without simultaneous availability of conventional radiographs[34,37] or clinical information, which limits the relevance to clinical practice. Finally, patient selection bias may also have been a problem[35,38].

Table 3 shows the main study characteristics of the twelve publications. There was a range of cross-sectional imaging, with spiral tomography being used in four studies[31-34] and CT in one study[30]. All other studies used CBCT; all studies published after 2011 did so. Panoramic radiographs were always used as conventional 'before' imaging, although intraoral radiography was added to panoramic imaging in some studies[31,33,35,40], while Shelley et al[41] added transymphyseal (lateral anterior mandible) radiographs[42].

Table 4 summarises the outcomes of the studies according to whether cross-sectional imaging had an

Table 1 The hierarchical model of efficacy of diagnostic imaging, according to Fryback and Thornbury[2], with some typical measures of analysis.

Efficacy level	Measures of analysis
Level 1: Technical efficacy	Resolution of line pairs Linear and angular measurement accuracy Contrast detail resolution Grey scale reproduction of true density differences Severity of artefacts
Level 2: Diagnostic accuracy efficacy	Sensitivity and specificity Positive and negative predictive values ROC curve areas
Level 3: Diagnostic thinking efficacy	Proportion of cases in a series in which image judged to be 'helpful' Difference in clinicians' subjective estimated diagnosis probabilities pre- and post-imaging in a case series
Level 4: Therapeutic efficacy	Proportion of cases in a series for which image judged to be 'helpful' in planning treatment Proportion of cases in which pre-imaging treatment plans were changed after imaging
Level 5: Patient outcome efficacy	Proportion of patients improved with the imaging test compared to without the imaging test Morbidity avoided by using imaging Change in oral health-related quality of life (OHRQoL) resulting from using imaging
Level 6: Societal efficacy	Benefit-cost analysis from a societal standpoint Cost-effectiveness analysis from a societal standpoint

impact on aspects of therapeutic efficacy. The impact of cross-sectional imaging on the selection of implant size (width and length) was addressed in eight studies. All reported some changes, although this was in the minority of cases for most studies[32,33,38,39]. In one of these, the availability of cross-sectional images changed the selected implant size in less than 4% of cases[32]. One study looked at multiple implant systems and cross-sectional imaging availability led to a change in implant size to varying degrees depending on the system used[37]. Only two studies reported a change in selected implant dimensions for a majority of cases[31,34]. In terms of trends looking at whether a change of implant dimensions (i.e. narrower/ wider and shorter/longer) were associated with the availability of cross-sectional imaging, no trends in any direction were seen in three studies[31,32,33], all of which used spiral tomography systems. A trend associated with shorter implant size when using cross-sectional images was seen in two studies[37,39]. Also there was a trend towards a narrower implant size being used in three studies[37,38,41], although this was only for challenging cases in the latter study[41]. One study, however, reported a trend in terms of longer and wider implants being selected[34].

Table 2 Subjective quality assessments on a visual analogue scale. Green suggests high quality and red suggests low quality.

Study	Quality assessment
Reddy et al[30]	✓
Schropp et al[31]	✓
Frei et al[32]	✓
Diniz et al[33]	✓
Fortin et al[34]	✓
Schropp et al[35]	✓
Baciut et al[36]	✓
Correa et al[37]	✓
Guerrero et al[39]	✓
Guerrero et al[40]	✓
Mello et al[38]	✓
Shelley et al[41]	✓

Those studies looking at the confidence of operators[30,36,39] reported an improvement with the availability of cross-sectional imaging. For all other outcomes measured in the included studies, there was either no measurable change or equivocal findings when cross-sectional imaging was available, with the exception of two studies[39,41]. Guerrero et al[39]

Table 3 Characteristics of the included studies; OPG: orthopantomograph.

Reference	Country Setting	No. of implants placed [No. of patients treated]	No. of evaluators	Site	'Before' imaging	'After' imaging	Summary of aim(s) of study
Reddy et al[30]	Not stated but probably USA	>10 [10]	4	Not stated	Panoramic	Medical multi-slice CT	For ten subjects the treatment was planned using panoramic images alone and panoramic plus CT images, and the aim of the study was to determine the validity of both examinations and the confidence of the investigators in treatment planning with these images
Schropp et al[31]	Hospital Denmark	46 [46]	1	All sites	Panoramic and periapical	Spiral tomography (Scanora)	The aim of this study was to evaluate the efficacy of conventional cross-sectional tomographic examination as an adjunct to panoramic and periapical examination in the prediction of the appropriate implant size (length and width) for treatment with single tooth implants
Frei et al[32]	Not stated but probably Switzerland	77 [50]	1	Posterior mandible	Panoramic	Spiral tomography (Cranex Tome)	To investigate whether cross-sectional imaging influences the planning and therapy of standard implant cases in the posterior mandible
Diniz et al[33]	Not stated but probably Brazil	113 [29]	2	All sites	Panoramic and periapical	Spiral tomography (Cranex Tome)	To investigate variation in the pre-surgical treatment planning after using conventional spiral tomography in addition to conventional radiographic exams
Schropp et al[34]	Hospital Denmark	121 [121]	3	All sites	Panoramic	Spiral tomography (Scanora)	To compare panoramic and conventional cross-sectional tomography for preoperative selection of implant size. The aim of the study was to evaluate in how many cases did the planned dimensions differ
Fortin et al[35]	Hospital France	301 [128]	1	Posterior maxilla	Intraoral or panoramic	CBCT (Newtom)	To determine the degree to which residual bone was underestimated on panoramics compared to CBCT To determine the degree to which the necessity for sinus grafting was overestimated on panoramics compared to CBCT
Baciut et al[36]	Hospital Romania	16 [13]	6	Posterior maxilla	Panoramic	Cone beam CT (Newtom 3G)	To compare clinical validity of panoramic and CBCT in preoperative planning of implants in combination with sinus grafting procedures
Correa et al[37]	Hospital Brazil	103 [71]	3	Upper premolar and lower molar	Digital panoramic (Cranex D)	CBCT (iCat)	To compare implant length and width planned with panoramic and CBCT views in four implant systems
Mello et al[38]	Hospital Brazil	95 [27]	1	All sites	Panoramic (Cranex Tome)	CBCT (iCat)	To investigate the impact of CBCT on implant planning and predication of final implant size
Guerrero et al[39]	Hospital Peru	619 [105]	4	All sites	Panoramic (OPG or Cranex Tome)	CBCT (Scanora or iCat)	To compare planning of implant placement based on panoramic and CBCT images To study the impact of the image data set on treatment planning
Guerrero et al[40]	Hospital Peru	365 [108]	5	All sites	Intraoral or panoramic	CBCT (iCat)	To determine the efficacy of prediction of the need for bone grafting and perioperative complications
Shelley et al[41]	Private Dental Practice UK	64 [4] (patient simulations)	8	Anterior mandible	Intraoral (transymphyseal) and panoramic	CBCT (3D Accuitomo)	To evaluate the impact of CBCT imaging when placing implants in the anterior edentulous mandible using a before-after study design

Table 4 Summary of the outcomes of the included studies according to whether cross-sectional imaging had an impact on aspects of treatment planning*.

	Selection of implant size	Surgical confidence	Necessity for bone grafting or other surgical procedures	Prediction of graft volume	Change in treatment plan	Mean implant length	Prediction of complications	Assessment of sinus morphology	Choice of treatment	Timing of treatment	Image quality	Perforation of lingual plate	Assessment of surgical difficulty
Reddy et al[30]		Improved				No significant difference							
Schropp et al[31]	Change in majority of cases. No trends												
Frei et al[32]	Change in small minority of cases. No trends				No difference in 96.1%								
Diniz et al[33]	Change in minority of cases. No trends		Equivocal										
Schropp et al[34]	Change in majority of cases. Trend to longer and wider implants												
Fortin et al[35]			Reduced using X-sectional										
Baciut et al[36]		Improved	No difference	No difference			No difference	No difference	No difference				
Correa et al[37]	Change in minority of cases. Trend to shorter and narrower implants												
Mello et al [38]	Change in minority of cases. Trend to narrower implants												
Guerrero et al[39]	Change in minority of cases. Trend of shorter and narrower implants in posterior regions	Improved									Improved		
Guerrero et al[40]			Equivocal				Equivocal						
Shelley et al[41]	Trend to narrower implants in "challenging" cases		No difference									No difference	More difficult

* In studies which suggested a difference after the availability of cross-sectional imaging, the results are highlighted in pink. In cases where no difference after cross-sectional imaging was found the results are highlighted in blue. Equivocal results are highlighted in grey.

reported an increase in subjective image quality for CBCT, compared with panoramic radiographs, while Shelley et al[41] found that challenging cases were perceived as more difficult after cross-sectional imaging was viewed.

■ Discussion

This systematic review demonstrated limited evidence for the efficacy of cross-sectional imaging when planning implant treatment for missing single teeth. Only three studies, with some shared authorship, specifically dealt with this clinical context and should be considered in some depth[31,34,37]. The two earlier studies used spiral tomography, although the widely available method of cross-sectional imaging is currently CBCT. There are differences in image quality between tomography and CBCT and the results of these studies may not be automatically transferable in terms of the contemporary situation. The results of these studies have some methodological limitations in terms of their wider applicability; one was a single observer study[31] with a consequently high risk of bias due to potential individual idiosyncrasies, while another used mean values of three observers[34]. The most recent study, in contrast, presented data for individual observers[37]. One methodological feature of two of these studies[34,37] is that they considered selection of implants based either on panoramic radiographs alone or cross-sectional images alone. This is different from the clinical situation, in which all available images would be used together with the findings of the clinical examination. This point was recognised by the authors, who emphasised that their studies were aimed at understanding the relative contributions of different images to treatment planning rather than to identifying selection criteria.

Schropp et al[31], in a study of 46 implant sites, found that the availability of cross-sectional images led to a change in either selected implant length or width in 70% of cases and concluded that preoperative cross-sectional imaging was indicated for single implant treatments. Length was altered more than width, with a slight tendency towards selecting longer and narrower implants. Putting aside the issue of this being a single-surgeon study, there are other potential criticisms. Magnification factors for the radiographs and tomograms were assumed rather than controlled using a reference object. This potentially introduced a systematic error. The implant dimensions actually used at surgery were compared with those planned using conventional radiography alone or with the addition of tomography and found significantly greater agreement with surgery, for the latter. However, it should be noted that the choice of implant size at surgery was determined by the surgeon and was changed in a few cases even when tomography was available. It could be argued therefore, that the imaging was not of primary importance when the surgical findings were pre-eminent in selecting implant dimensions.

Schropp et al[34] found differences in the selection of implant size based on tomography or panoramic images in the overwhelming majority of cases. The impact on choice of length and width agreed broadly with the results of their previous study[31]. With cross-sectional imaging there was a tendency to choose longer implants overall, although shorter implants were selected in a smaller proportion of cases. The findings for implant width are less clear. Overall data showed a fairly even split between selecting wider or narrower implants when using tomograms, but the authors also reported a marked tendency to select narrower implants in both maxillary and mandibular anterior regions (in 53% and 44% of cases, respectively), when tomography was used. However it is not stated, in what proportion of these cases was a wider implant chosen. Furthermore, the authors did not provide details of absolute implant size differences between imaging methods and presented only qualitative changes (i.e. shorter, longer, wider and narrower). They did, however, demonstrate that the impact of basing selection of implant size on tomographs or panoramic images differed according to the implant system used. In the study where a system with fewer available implant size options was used, where in this case the Straumann system was adopted, the impact of the imaging technique was less.

The study of Correa et al[37] has the advantage of a larger sample size of patients and implant sites. The cross-sectional imaging method selected was CBCT, which provides greater contemporary relevance. This study considered implant dimensions planned using three image types: conventional panoramic

radiographs, panoramic images reconstructed from CBCT data and cross-sectional images reconstructed from CBCT data. They reported that the majority of the implants changed to a smaller size, in either width or length, when the planning was made using CBCT cross-sectional images and that the length was changed more often than the width. The authors state that results for width were in agreement with the results of Schropp et al[34], which were different for length, since the earlier study reported a shift towards longer implants, where tomographic images were available, with no trend in either direction, for diameter. The reasons for the difference between studies cannot be answered with any confidence. It may reflect any one, or a combination of factors, including a change in imaging modality, differences between observers or differences in case selection. For example, one study was limited to posterior teeth[37] while the other had a large proportion of maxillary anterior teeth[34].

If the inclusion criteria for this review had been strictly limited to studies where implants for missing single teeth could be considered in isolation, these three studies[31,34,37] would have been the only ones considered. A decision was made to include a broader range of studies in the expectation that even a more comprehensive strategy would not identify a large body of literature. The question that must be asked however is, how different is implant planning and treatment for a single missing tooth compared with multiple implant cases? The answer must be very little in terms of the jaw anatomy, although it seems reasonable to assume that the presence of teeth next to the space might limit ridge resorption after extraction compared with a wider edentulous space. It is also possible that the roots of adjacent teeth may impinge on a potential osteotomy site for single implant placement. Significant differences might be encountered, however, in the imaging. The presence of adjacent teeth may preclude the use of some imaging options (e.g. lateral views) because of superimposition. If teeth adjacent to the single missing tooth space are heavily restored, with root fillings and metal posts, then the artefact may make image quality poor with CBCT or CT. Overall, it seemed reasonable to keep the inclusion criteria quite wide, so long as these potential weaknesses were borne in mind.

When all included studies are considered, it is worth highlighting the variability in the methodology, some of which had a major impact on the quality assessment. None can be considered as having a sufficiently faultless design in providing strong evidence. Some studies included a clearly insufficient number of observers making image assessments[33,35,38]. Some studies, such as Mello et al[38] had implant cases that were well distributed around the jaws, however other studies gave no detail of the distribution[30,33], while others were skewed to certain regions or highly specific in their design[32,40,42]. As some studies show differences in outcomes according to anatomical site[31], it is important not to extrapolate results as being generally applicable throughout the oral cavity. Surgical validation of the image-based implant planning was sometimes used[30,32,38], although not strictly required for a before-after study design, it does offer an independent standard against which choices based on imaging can be compared. Nonetheless, it is of particular interest that in these studies there were cases of the surgically selected implant being different to that chosen by either conventional or cross-sectional imaging[32,38]. It also raises questions about the role and importance of preoperative imaging when final decisions about implant size are made at the time of implant placement.

It was hard to identify any clear message from the studies regarding the impact of cross-sectional images on treatment planning (Table 4). As far as implant dimensions are concerned, most studies report that the availability of cross-sectional images leads to a change in planned implant size, although the recent study of Guererro et al[39] stands out in showing this for only a minority of a large sample of implants, mainly in the posterior parts of the jaws, with a tendency towards selecting shorter and narrower implants when CBCT was available. Only the studies of Schropp et al[31,34] report a change in implant size for the majority of cases when cross-sectional images are used. In both of these studies, the cross-sectional imaging technique was conventional tomography. In terms of any trends towards changes in implant dimensions, some studies show none, either for implant length or width while the others give conflicting findings (Table 4).

In these studies, the importance of selection of implant size alone may be questioned. It is clearly

possible to place the same size of implant in either a favourable or unfavourable position. Differences in implant size selection alone, therefore, should not necessarily be interpreted as justification for three-dimensional imaging. The study of Shelley et al[41] stands out from the others in that it was a laboratory study using anthropomorphic phantoms and extended the scope of the work to include both Fryback and Thornbury's Level 4 and Level 5 (outcome efficacy), in the form of recording perforations of the lingual surface of the mandible, when placing implants in the parasymphyseal region. A critical aspect of successful implant treatment is optimal position in relation to the three dimensions. Failure to achieve this can lead to significant problems, ranging from damage to adjacent teeth, through to permanent nerve damage or significant haemorrhage. Their study showed that in 'regular' cases CBCT had no impact on implant selection or the incidence of cortical perforation, but that in 'challenging' cases there was a trend to selecting narrower implants. Differences in cortical perforations before and after the availability of three-dimensional imaging were not statistically significant. As it is probably unrealistic to anticipate well-designed randomised controlled trials addressing the impact of cross-sectional imaging on patient outcomes, this type of laboratory study may be the best research design available. It is interesting that there is some evidence for the effect of case difficulty on the impact of cross-sectional imaging in a previous clinical study, in which the eligibility criteria excluded complex cases[32] and cross-sectional imaging had almost no impact on treatment planning.

It appears that cross-sectional imaging improves the confidence of surgeons when planning implant treatment[30,36,39]. Shelley et al[41] demonstrated that the availability of CBCT images leads to a perception of higher surgical difficulty and this can perhaps be considered as an aspect of surgical confidence. Nevertheless, surgical confidence is only acceptable as evidence for the need for cross-sectional imaging, if it translates into patient benefits, whether those are indirect, such as through shorter operating times, or by direct improvement in patient outcomes. Evidence of this type from randomised controlled trials at Level 5 of Fryback and Thornbury's hierarchy does not exist however.

Five studies included the necessity for surgical bone grafting as an outcome measure[33,35,36,40,41]. None of the studies unequivocally demonstrated a difference after cross-sectional imaging was available. Whilst the study of Fortin et al[35] suggested that the availability of CBCT imaging reduced the need for sinus augmentation surgery, the three assessors in the 'before' part of the study were different from the single assessor in the 'after' part of the study. The difference in the two parts of the study, therefore, may have represented a difference in practice between the assessors rather than the effect of the availability of different image types. It is notable that Baciut et al[36] found almost perfect concordance between treatment choices (prediction of graft volume, prediction of complications, assessment of sinus morphology, choice of treatment or of timing of treatment), made using panoramic radiography and CBCT but, paradoxically and inexplicably, concluded that cross-sectional imaging "should be recommended in all cases for sinus lift". The findings of Guerrero et al[40] suggest that availability of CBCT increases the sensitivity of presurgical assessment of the necessity for bone grafting or the prediction of several potential complications (fenestrations, dehiscence, membrane perforations and wrong angulations), although by combining all of these in the statistical analysis, it is impossible to determine whether all factors were equally affected.

Only one study considered the perception of image quality[39] and found, perhaps unsurprisingly, that CBCT images were perceived as better quality than panoramic images alone. Nevertheless, there is a level of image quality above which the image becomes clinically useful and, it can be presumed, there is a leve of image quality above which no additional clinical usefulness is obtained. Difference in image quality, therefore, does not necessarily lead to a difference in clinical usefulness or a benefit to the patient. This cannot, therefore, be considered as evidence supporting the need for cross-sectional imaging.

Other treatments for the missing single tooth

Although this systematic review was focused on the issue of cross-sectional imaging in the context of

Table 5 Scope and limitations of the radiographic imaging techniques available to clinicians as part of the preoperative evaluation of single missing teeth, including diagnosis of pathosis within the edentulous space and of adjacent teeth. Usefulness is indicated by +, ++ or +++, according to potential value. No useful role is shown by -.

	Intraoral radiograph	Panoramic radiograph	Lateral radiograph†	Conventional tomogram	CBCT*	CT*
Measurements:						
Mesio-distal	++	++	-	-	+++	+++
Supero-inferior	++	++	-/+	++	+++	+++
Bucco-lingual	-	-	-/+	++	+++	+++
Bone external morphology	-	-	+	+	+++	+++
Bone internal morphology	++	+	-	-	+/+++	+/++
Bone density	+	+	-	-	-/++	+++
Anatomical structures and boundaries	++	++	-	+	++/+++	+/+++
Tooth-related pathosis:						
Dental caries	++	+	-	-	-	-
Periodontal bone levels	++	+	-	-	++/+++	-/+
Periapical inflammation	++	+	-	-	++/+++	-/+
Root fracture	++	-	-	-	++	-

* Variation in the efficacy for the CBCT reflects wide variation between image quality of different equipment and according to exposures used.

†This includes both the lateral cephalogram and the transymphyseal radiograph.

treatment using an implant, pre-treatment radiological assessment of single missing teeth goes beyond this method of treatment. There are four principal treatments for missing single teeth apart from an implant-supported crown: mucosal-supported denture, tooth-supported denture, adhesive bridge and conventional bridge. There is a variety of radiological examinations available to the clinician. This breadth of treatment options means that most of the imaging options available to clinicians can have a role to play, either alone or in combination. It is beyond the remit of this paper to review comprehensively the scope and limitations of all the imaging techniques which can be found in contemporary textbooks and some review publications[7,17], but Table 5 gives a summary of the diagnostic capabilities of the principal radiograph imaging methods. It should be noted that the scope of all imaging methods rely on a meticulous technique. For CBCT in particular, there is also wide variation in its capabilities, which reflect variations in technical efficacy[43,44].

One factor of particular relevance to the single missing tooth situation and both CBCT and CT is artefact related to metallic objects[45]. This phenomenon results in streaks in the plane of the radiograph beam, which radiate from the object, leading to loss of anatomical information. This may be particularly evident where two metallic objects are fairly close together. If the teeth on either side of a single missing tooth space contain root fillings or metal posts, this can significantly reduce the diagnostic value of the CBCT/CT examination. Metal artefact reduction algorithms are of limited or no value because they mask the artefact rather than restore missing anatomical information[46-48]; this phenomenon is not seen with conventional tomograms.

Radiation aspects

The justification process for selecting radiological techniques requires consideration of the likely benefits of radiograph examination against the risks. In diagnostic radiology, the risks are of somatic stochastic effects, i.e. deleterious effects on the irradiated individual that have a specific probability of occurring. The only somatic stochastic risk is of cancer. Tissue effects (formerly deterministic effects) have threshold doses that would normally be impossible to exceed by dental imaging, therefore can be reasonably ignored. As described in a recent review[49], cancers of various types have been associated with oro-facial radiology, including those of the salivary

Table 6 Effective doses for dental radiological examinations. The data represent a summary of review publications[3,17,49-51]. All doses in mSv. The field of view subdivisions for CBCT vary according to authors' definitions, but are broadly equivalent.

Radiological examination	Effective dose (mSv)	References
Intraoral radiograph	< 0.002	3
	< 0.002	17
	0.003-0.022	49
Panoramic radiograph	0.003-0.024	3
	0.003-0.024	17
	0.003-0.038	49
Lateral cephalogram	< 0.006	3
	< 0.006	17
	0.002-0.014	49
Conventional tomogram	0.047-0.088	17
CBCT (dentoalveolar)	0.011-0.674* (median 0.061)	3
	0.019-0.674*	17
	0.011-0.214	49
	0.005-0.652 (mean adult 0.084)	50
	0.010-0.197 (median 0.028)	51
CBCT medium FOV	0.018-0.674	49
	0.009-0.560 (mean adult 0.177)	50
	0.004-0.674 (median 0.070)	51
CBCT (craniofacial)	0.030-1.073 (median 0.087)	3
	0.030-1.073	17
	0.030-1.025	49
	0.046-1.073 (mean adult 0.212)	50
	0.009-1.073 (median 0.114)	51
CT	0.280 -1.410	3
	0.280 -1.410	17
	0.250-1.410	49

* Harris et al[17]: the dentoalveolar field of view encompassed the medium field of view.

glands, thyroid and brain, as well as the leukaemias. Risk of cancer related to exposure to radiographs is age-dependent, being two to three times higher for children than adults and steadily falling with advancing years. The risk of fatal cancer is estimated at 5% per sievert[1]. In other words, if one million people receive 1mSv of an effective dose, 50 might develop a fatal cancer.

An effective dose is the tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body. It is widely used because it takes account of the specific organs and tissues through which the radiation passes and is directly related to cancer risk. Effective doses associated with dental radiographic examinations have been reviewed on several occasions, both specifically or as part of guideline documents, although recent reviews have tended to focus on CBCT alone[3,17,49-51]. Table 6 provides a summary of data from these publications. Wide ranges are seen for most radiographic examinations, as the effective dose is influenced by so many variables. For example, while a localised radiographic examination, for example a periapical radiograph, may use a fixed set of exposure factors, the resultant effective dose will differ according to anatomical location in the jaws because of the different tissues irradiated. Thus it is essential to recognise that there is no single dose for a particular radiographic examination. A comparison such as "a CBCT scan is equivalent in dose to four panoramic radiographs" is nonsense unless the precise details of the equipment are known and dose measurements have been made. Effective doses in children are not necessarily the same as adult doses for the same examination; indeed, they may be higher than for adults even if lower exposure factors are used because of the different volume of the patient that is irradiated and the relative differences in the position of some organs, for example the thyroid gland[17,50,52].

In the context of preoperative radiological management of missing single teeth, the higher dose levels of CT have meant that, understandably, clinicians may have been reluctant to use it. Conventional tomograms, however, offer a relatively low dose and are suitable to single implant cases. CBCT systems vary considerably, but some offer limited fields of view e.g. 4 or 5 cm in height and diameter. Generally, a smaller CBCT field of view is associated with a smaller dose than larger fields[3], therefore for practitioners performing single implants it is easier to justify CBCT than it is to justify CT[3]. An effort should always be made to reduce the dose associated with the radiological examination to a level that is as low as reasonably practicable and diagnostically acceptable. All available imaging modalities must have the exposure factors (tube current-exposure time product, mAs and operating potential kV) appropriately set. Additionally, other factors are important in terms of dose reduction and these are set out in Table 7.

The need for correct setting of mAs and kV are common during optimisation of all radiograph systems. It is important to be aware that, for digital imaging systems, adequate image quality can be achieved over a wide exposure range. Manufactur-

ers often advise higher exposure factors than are necessary because this flatters the image quality of their equipment. For CBCT, there is substantial evidence that exposure factors can be reduced from the manufacturers' recommended values for a range of equipment, in the context of implant planning[53-58]. Optimisation of exposure factors is best performed with the assistance of a medical physics expert rather than a trial and error approach for turning down the exposures. Due to the generally higher doses used with CBCT than conventional imaging, optimisation is of particular importance[3] and both Harris et al[17] and Hidalgo Rivas et al[59] have described low-dose protocols for CBCT, the former in the context of implant planning.

Table 7 The main factors, other than exposure factors (tube current-exposure time product, mAs and operating potential, kV), that favour a lower radiation dose in dental radiological examinations.

Radiological examination	Factors favouring a lower dose
Intraoral radiograph	Fast film (F-speed) or digital detector Rectangular collimation Paralleling technique
Panoramic radiograph	Fast film/screen combination or digital system Field size limitation
Lateral cephalogram	Fast film/screen combination or digital system Field size limitation
Conventional tomogram	Fast film/screen combination or digital system As few 'cuts' as possible
CBCT	Field size limitation Largest voxel size consistent with clinical needs
CT	Request 'low dose protocol' (e.g. mAs < 100) Slice thickness 1 mm Pitch 1 to 1.5 Suggested window width: 1250; level 250

Financial costs

Although the justification process is one of balancing radiation-associated risk against benefit, in the real world, financial costs also have an influence. In a public healthcare system with finite resources, increased expenditure on a new diagnostic or therapeutic technique will leave less resource for others. In a purely private system, patients or insurance companies may pay for the intervention recommended by the clinician, but will be expecting some clinical benefit from that payment.

Economic evaluation of diagnostic methods in oral health care, including imaging techniques, has an extremely limited literature, as shown in a recent systematic review by Christell et al[60]. They identified 12 studies, of which only two are relevant to the current review. To these can be added one subsequently published study[61].

Scaf et al 62 compared radiation doses and financial costs of film-based tomography and CT scanning. The economic component in this US-based study was rudimentary and consisted of a simple survey of examination costs; this revealed that CT was the more expensive option. As film-based tomography is increasingly of historical interest and the study is 20 years old, there is nothing of current value in this study. Furthermore, as Christell et al[60] point out, simply measuring expenditures is not a substitute for well conducted original costing, that involves measuring quantities of resources required to deliver the intervention. Two studies[61,63] are of interest in that they included cost analyses. Christell et al[63] compared 'conventional' radiographic examination (panoramic and intraoral radiographs) with additional CBCT examination in different healthcare systems in three countries, in the context of evaluation of ectopic canines. The other study[61] was a randomised controlled trial of CBCT in the management of mandibular third molars and included a cost analysis. Both studies showed that costs were higher when CBCT was added to the imaging, although Christell et al[63] found significant variations between countries in terms of costs, emphasising that cost analyses are not easily transferable.

Cost analysis is only part of a complete economic evaluation. The costs have to be considered against the benefits. Christell et al[60] point out that benefits must be considered against the hierarchy of diagnostic efficacy by Fryback and Thornbury[2]. The highest level of assessment considers Level 5 (outcome efficacy) using a randomised-controlled trial design with concurrent Level 6 (economic evaluation). Petersen et al[61] found that cross-sectional imaging in the form of CBCT did not change the resources used in relation to mandibular third molar surgery. There was, unfortunately, an absence of literature of this quality, in the context of the current systematic review related to implants.

Selection criteria for preoperative radiological evaluation

A patient requiring treatment for a missing single tooth would do so as part of comprehensive oral care, with the possible exception of treatment using an implant where onward referral to a specialist is made. Selection criteria for oral radiography for a new adult patient have been described in various guidelines[5,6,7], all of which have undergone multiple editions over the years. All agree that no radiographic examination is indicated unless a full history and clinical examination has been taken and that posterior bitewing radiography and selected periapical radiographs are appropriate for dentate or partially dentate patients. In the context of the current review, examination of these guideline documents did not show any specific guidance on radiographs when planning partial dentures. There was, however, agreement that periapical radiography of potential abutment teeth was indicated when a bridge is planned.

When a mucosal-supported denture is planned for restoration of a missing single tooth, there is no apparent justification to radiograph the edentulous space in the absence of clinical signs or symptoms. While this seems obvious, it should be noted that the ADA guidelines[6] give an equivocal message, saying that "prescription of radiographs is appropriate as part of the initial assessment of edentulous areas for possible prosthetic treatment", but do not explain why this should be. They conclude, however, with this recommendation: "an individualized radiographic examination, based on clinical signs, symptoms, and treatment plan is recommended", the wording of which suggests that absence of signs and symptoms would preclude radiography.

Where a tooth-supported denture is planned, the ADA guidelines are unequivocal in recommending intraoral radiography of abutments, whereas other guidelines do not suggest this. The rationale for radiography of denture abutments is presumably the same as that for potential bridge abutments. The recommendation to radiograph potential bridge abutment teeth, regardless of clinical signs or symptoms of disease, appears to be based on the evidence of increased incidence of periapical inflammatory pathosis in heavily restored, crowned and endodontically treated teeth[64-72]. There is also evidence that greater restoration depth is associated with a higher frequency of periapical inflammatory disease[64], as is inadequacy of the restoration[66-70]. In one study, 19% of non-root filled crowned teeth showed evidence of periapical periodontitis[65]. If a potential bridge abutment tooth has been endodontically treated, has a large restoration or the restoration is inadequate on clinical examination or on bitewing radiography, then a periapical radiograph can be justified based on the evidence. In a situation of an unrestored, clinically healthy, potential bridge abutment tooth, there is no apparent evidence to justify a radiographic examination. It should be noted that panoramic radiography has inferior diagnostic accuracy efficacy to periapical radiography[73].

The role of cross-sectional imaging, in particular CBCT, for non-implant related purposes, remains a developing field of research. However, several guidelines exist, which was reviewed by Horner et al[25], and one other has subsequently appeared[20]. While none has specifically focused on preoperative evaluation of missing single teeth, there is broad agreement that CBCT should be used in situations where conventional radiography fails to answer the diagnostic question; in other words, it should be seen as a second line of diagnosis. Table 8 provides a summary of guidelines for preoperative radiological evaluation of missing single teeth when non-implant treatment is planned.

Where an implant treatment is chosen for a single tooth space, the clinician is seeking information on bone dimensions, shape, density, the positions of relevant important anatomy and the presence of pathosis at and immediately adjacent to the proposed site of implant placement. Clinical examination followed by conventional radiographic examination (intraoral and, in many cases, panoramic radiographs) may be adequate for these needs. The use of a reference object of known dimensions, such as a ball bearing, in the plane of the dental arch will assist in measurement[15]. The decision to supplement conventional radiography with cross-sectional imaging should be made after conventional radiography has been evaluated. This may avoid unnecessary cross-sectional imaging, avoiding the associated radiation dose and financial cost. As the current sys-

Table 8 Suggested guidelines for preoperative radiological evaluation of missing single teeth (non-implant-based treatments). This assumes that normal selection criteria[5,6,7] for dental radiography of a new patient have been followed.

Treatment under consideration	Recommended imaging	Cross-sectional imaging
Mucosal-supported denture	None	Consider small field-of-view* CBCT: If radiographs give a negative finding when there are contradictory positive clinical signs and symptoms. In cases where radiographs provide information which is equivocal or inadequate for planning treatment, In cases where cross-sectional imaging is likely to alter the management or prognosis of the tooth
Tooth-supported denture	None may be needed If there are clinical concerns, periapical radiographs of abutment teeth	
Resin-retained bridge	None may be needed If there are clinical concerns, periapical radiograph of abutment teeth.	
Conventional bridge	Periapical radiographs of abutment teeth	

* small field of view CBCT implies a diameter < 5cm

tematic review failed to identify any clear selection criteria for cross-sectional imaging, existing opinion/consensus-based guidelines recommending selected use should be considered.

As described in the introduction, available guidelines fall into two categories, those recommending the use of cross-sectional imaging for all proposed implant sites[8-11] and those recommending selected use[3,7,12-20]. Those favouring a selected approach are in broad agreement, regarding the situations in which cross-sectional imaging may be indicated (Table 9), although it should be noted that some of these situations would not be satisfactorily imaged using conventional tomography and require the use of either CBCT or CT.

The position statements of the AAOMR and the FGDP(UK) selection criteria in dental radiography mention the experience of the implant practitioner as a factor in image selection and, the FGDP(UK) document states that three-dimensional imaging increases surgical confidence for less experienced operators[7,11]. Studies[30,36,39] confirm increased surgical confidence when three- dimensional imaging is available and in one questionnaire study, inexperienced operators were more likely to prescribe three- dimensional images[75]. It would appear to be the common sense position that some inexperienced operators may benefit from increased surgical confidence when three-dimensional imaging is available preoperatively. Nonetheless, evidence that increased surgical confidence leads to an improvement in patient outcome is lacking.

Postoperative radiological evaluation

It was not the remit of this review to consider choices relating to post-implant review imaging, therefore only brief comments are included here. When selecting the appropriate imaging modality for review, most guideline documents emphasise that under normal circumstances the use of cross-sectional imaging should not be the standard[11,12,20]. In the case of CBCT or multislice CT, artefact immediately around implants may mimic failure of osseointegration and also obscure bony detail more distant to the implant[20]. Furthermore, very thin bone, such as that which may be present buccally over an implant surface, may not be visible, although this will depend on the resolution of the system and any artefact due to patient movement, amongst other factors. Cross-sectional imaging after implant placement may be indicated when there are complications, such as suspected perforations of the bony cortices, implant mobility, suspected involvement of neurovascular structures, osteomyelitis, maxillary sinus complications[11,12,15,16,17] or complications after bone grafting[15,16]. Under normal circumstances, intraoral radiography, performed using meticulous technique with film/sensor/imaging plate holders and a beam-aiming device are appropriate[7,11]. For a single tooth implant, positioning of an intraoral radiograph should be straightforward and a panoramic radiograph, with its inherently inferior detail, should not normally be used.

In terms of the frequency of review imaging, guideline documents frequently give no advice. One guideline document states that "postoperative

Table 9 Situations in which cross-sectional imaging may be of value when planning implants, according to current guideline documents which provide detailed criteria. As different terminology is used in different guidelines, the authors have grouped and rephrased these appropriately. Indications not relevant to single tooth situations (e.g. zygomatic implants) have been omitted.

Situations in which cross-sectional imaging may be of value when planning implants	References
When clinical and conventional radiographic examination have failed to demonstrate anatomical boundaries/ structures adequately	7,12,15,17,20
History and clinical examination with a significant deviation from standard anatomy	12,15
In clinical borderline situations where there appears to be limited bone height and/or bone width available for successful implant treatment	12,16,17,20
Highly aesthetic zone	16
When computer-aided implant planning is to be used	7,15,16,17
When surgical navigation is to be used	15,16
When the maxillary sinus has a possible influence on implant restoration in the posterior maxilla (e.g. sinusitis)	7,15,17
Pre-bone grafting, including sinus augmentation and bone defects* Post-bone grafting*	12,16,17, 20
History of pathosis or suspected pathosis of the jaws requiring further clarification after conventional radiography	15,16
Cases in the A or C categories of the SAC (straightforward, advanced and complex) classification+ "can generally be regarded as identical with the recommendation for the use of CBCT in the preoperative assessment".	20
If there is a considerable risk of harm from the surgical intervention when performed following only plain film imaging	20

* Post-bone grafting only mentioned as the standard for all cases by Benavides et al[16], while AWMF[15] state cases of dubious success or complication after augmentation.

\+ Dawson and Chen[74]

review protocols appear to be the subjective opinion of authors"[7]. This document advises that a radiograph is appropriate at baseline and after 12 months, but that an ongoing review interval of 1, 3 and up to 5 years is suggested. It seems likely that suggestions on appropriate radiographic review intervals have emerged secondary to guidance on the periodicity of clinical review intervals. One guideline document suggests that clinical recall appointments are recommended within 6 months of restoration and at least annually thereafter, without explicit recommendation that this frequency also applies to radiographs, yet it also suggests that radiographic appearance is one consideration in evaluating implants at recall[22]. No evidence is cited to support these recommendations. Clearly, however, clinical signs of pathosis, such as increased probing depth, bleeding, exudate and mobility are criteria to justify a radiographic examination.

A widely used criterion for success of an implant is that radiographic marginal bone loss at surfaces facing the implant should be less than 1.0 mm in the first year of function and that subsequent annual bone loss should not exceed 0.2 mm[76]. It is notable that publications describing bone loss after implant placement use submillimetre measurements. For example, a recent systematic review and meta-analysis reported that mean marginal peri-implant bone loss around single-implant prostheses was 0.58 mm (95% CI: 0.37 to 0.80 mm)[77]. It is important to recognise that submillimetre dimensions are the product of averaging multiple measurements and that the latter are very unlikely to have these levels of precision and reliability when applied to individual patients and implants. Although some research studies, using meticulous radiographic and measurement methods, report intra- and inter-observer variability in measurements far lower than 1 mm[78], others have shown relatively high measurement error[79] meaning 'real world' accuracy and precision in a typical dental office will be less. Thus, clinicians should be cautious in interpreting the clinical significance of submillimetre measurements of marginal bone from radiographs.

The implications in the difficulty of obtaining precise measurements of bone levels on radiographs, may be that it is pointless to take review radiographs at very frequent intervals in everyday clinical practice, in the absence of clinical signs or symptoms and that a more logical approach could be adopted, such as:

1. Baseline radiograph at the fitting of the prosthesis.
2. Radiograph after 1 year. If bone loss is < 1 mm, then re-radiograph after 5 years. The rationale for 5 years is that if there is bone loss of 0.2 mm per year, it would be measurable with acceptable precision. If there is evidence of stabilisation of bone levels at this 5 year point, future radiographic examination would be indicated only if there were clinical signs, symptoms or other specific concerns.
3. If bone loss at the 1 year point is > 1 mm, then radiograph again after a further 12 months (i.e. at the 2 year point). If the 2 year radiograph shows further measurable bone loss then consider ongoing annual radiographic examination until there is evidence of stabilisation of bone loss to acceptable levels.

Of course, a radiograph might be taken at any time point if there is a clinically evident problem.

Conclusions

The systematic review failed to provide convincing evidence to answer the question: does the use of additional cross-sectional imaging have any impact on diagnostic thinking, treatment planning or outcome compared with conventional imaging alone, in the preoperative evaluation of single missing teeth for implant treatment? All included studies had methodological limitations and results were sometimes contradictory. It can be suggested in cases that are identified by an experienced clinician as being straightforward on clinical examination and on the conventional radiographs, there may be no need for cross-sectional imaging. This is in line with a previous recommendation[12]. Consequently, guidelines based on a consensus of experts suggesting selection criteria for cross-sectional imaging are of considerable value.

When all potential treatments for missing single teeth are considered, imaging choices are not based on robust research evidence in the form of randomised controlled trials or economic evaluations. For non-implant treatments, there is broad agreement amongst guidelines, about the need for intraoral periapical radiography of potential bridge abutment teeth, mainly based upon evidence from radiographic clinical surveys. An exception to this may be the clinically healthy, unrestored abutment tooth.

Overall, this review has highlighted that, in terms of preoperative radiological evaluation of missing single teeth, much of what we do lacks a solid basis in the research evidence. It is therefore appropriate for the surgeon to use imaging wisely according to the individual patient's needs, taking into account the history and findings on the clinical examination, radiation dose, financial costs and after reflecting on personal surgical skill and experience.

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The impact of immediately placed and restored single-tooth implants on hard and soft tissues in the anterior maxilla

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Key words *immediate implant placement, immediate implant restoration, peri-implant tissue remodelling, single-tooth replacement*

Aim: The purpose of this literature review is to systematically evaluate the impact of immediate implant placement and restoration (IIPR) on hard and soft tissues and to identify clinical parameters which influence the outcome.

Materials and methods: An electronic search of the PubMed database was performed from January 2000 to September 2015. A further hand search was conducted in selected journals and only abstracts published in English were considered for review. Human clinical trials with at least 10 participants and which reported hard and soft tissue outcomes were assessed. Randomised controlled trials (RCT), prospective, prospective comparative and retrospective studies were considered. The effects of the following clinical parameters on hard and soft tissue outcomes were analysed: type of implant, primary stability, gingival biotype, flapless surgery, tooth extraction, spatial arrangement of the implant, socket grafting, the gap between implant surface and alveolar wall and the loading protocol.

Results: 17 studies (four RCT, six prospective, two comparative prospective, three controlled cohort and two retrospective studies) were included with 626 censored IIPR in 609 patients. A total of 411(65.56 %) implants were placed flapless vs 215 implants after raising a mucoperiosteal flap. Five studies defined raising a mucoperiostal flap as a mandatory part of the surgical protocol. The mean of the remaining gap in between the implant surface and the alveolar wall, the so-called "jump space", was reported for 170 implants ranging from 1.38 mm to 2.25 mm. Two hundred and one implant sites were not grafted, 405 were grafted, mostly with bone substitutes; for 20 no information was available. For 419 implants, a minimum insertion torque of ≥ 32 Ncm or an ISQ value of ≥ 60 was reached; for 53 implants an insertion torque of 25 Ncm was accepted. The implants were mostly placed palatinally of the jaw bone. The vertical position of the platform was reported either to be 0.5 to 1.0 mm below the vestibular bone crest or 3 to 4 mm apical to the adjacent cementoenamel junction of the neighbouring tooth. Post-insertion healing with a non-functional occlusion occurred for 97.8% of the implants. The final single crowns were inserted 3 to 6 months after implant placement. The IIPR resulted in a high success (97.96 %) and survival rate (98.25%) after a mean follow-up period of 31.2 months. The soft-tissue biotype was evaluated in 379 (60.5%) sites as thick. The mean crestal bone and the mean interproximal mucosa level changes were less than 1 mm compared to the baseline. The midfacial periimplant mucosal level change was less than 0.95 mm. This level was reached for both thin and thick soft-tissue biotypes, without a significant difference. Only in one study did the thin biotypes show a significantly higher recession.

Conclusion: The systematic review revealed promising results for immediately placed and immediately restored implants (IIPR) in the anterior maxilla. The possible options of flapless surgery and absence of grafting of the socket allows a minimal surgical intervention. However, a strict patient selection seemed mandatory for all included clinical trials.

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■ Introduction

The use of single-tooth implants for the treatment of single tooth loss is steadily increasing. With a few exceptions in the molar region, only one implant is inserted for anchoring a single crown. The conventional loading protocol consists of several months of healing after implant insertion, without any load application. It aims to avoid micromovements between the implant and the bone, enabling a predictable osseointegration. However, this delayed loading protocol implies additional surgery for exposing the implant. During healing the crown may either be out of occlusion or in functional occlusion and contributes at the day of implant placement to a satisfactory aesthetic result. Additionally, immediately implant-anchored temporary single crowns provide a satisfactory aesthetic result. The undisputed increased patient comfort by minimal invasiveness, shortened treatment time and cost reduction render the IIPR approach popular among clinicians.

To keep the micromovements at the implant-bone interface sufficiently low during healing, a high primary stability of the implant is imperative. An immediate rigid connection between multiple implants to ensure immobilisation is not available at a single-tooth gap. The primary stability of an implant is known to depend on many factors, which include the anatomical site, the protocol of the osteotomy, the implant dimensions (length and diameter) and the macro- and micro-design of the endosseous implant surface.

A special feature of immediately restored implants is the immediate correct shaping of the peri-implant soft tissue at the already healed alveolar ridge, by the correctly shaped morphology of the abutment and/or the cervical portion of the temporary single crown. In the case of a fresh extraction wound, this temporary crown supports the existing dentogingival complex and seals the wound. The aesthetic outcomes are mainly dependent on the stability or the remodelling of soft and hard peri-implant tissue. The impact of immediate placement and loading of single implants on surrounding hard and soft tissues is especially relevant in the aesthetic zone of the maxilla. The search strategy of available literature was therefore focused on immediately placed and restored single implants.

Following tooth extraction in the anterior maxilla, the clinician is often faced with the dilemma of whether to place the implant immediately or at varying post-extraction time intervals.

Immediate implant placement in the aesthetic zone was first advocated with advantages including preserving the alveolar bone, decreasing treatment time and providing superior aesthetics[1]. This concept developed from a two-stage submerged protocol into immediate implant placement and restoration therapy (IIPR)[2]. The rationale for this one-stage therapy was to preserve the original hard and soft tissue architecture with a suitably fabricated provisional abutment and crown. This technique was also thought to be of particular relevance in the thin highly scalloped gingival biotype, where hard and soft tissue recession are more likely[3]. This approach offers social and psychological (shorter treatment time), functional (correct placement permitting axial loads) and aesthetic (tissue preservation) advantages[4].

The literature appears to be inconclusive regarding the best method to preserve crestal tissues following the loss of a single tooth in the aesthetic zone.

Following tooth removal the extraction socket is subject to physiological remodelling. Clinical studies involving subtraction radiography, study casts and linear radiographs have demonstrated major alveolar bone loss over 1 year, with up to 50% reduction

in the orofacial dimension, following tooth extraction[5]. Two thirds of this change occur during the first 3 months. This is also in agreement with an animal study which showed vertical bone loss on the buccal and lingual crest, with greater changes on the buccal crest, translating into a net loss of bucco-palatal bone after 8 weeks[6].

Due to marked post-extraction reductions in alveolar dimensions, ridge preservation techniques have emerged, however they provide limited capacity to prevent remodelling of the original alveolar bone[7]. Fickl et al[7] evaluated four such preservation techniques in a dog model. All treatment groups suffered from vertical and horizontal bone loss. Furthermore, it was demonstrated that overbuilding of the buccal plate failed to prevent resorption or a more effective preservation technique. Hence ridge preservation techniques were unable to halt the physiological changes which take place post-extraction.

Both human[8] and animal studies[9] have demonstrated that the sole placement of an implant in an extraction socket is insufficient to prevent bone. These experiments concluded that hard tissue alterations still occur despite the placement of an implant, although to a lesser extent when a low-turnover bone substitute is used in the peri-implant defect[10].

Immediate implant placement and restoration procedures require careful selection of patients, with appropriate assessment of hard and soft tissues and accurate implant positioning in all three dimensions[3,11]. Since the placement of the implant is more challenging in post-extraction sockets, clinicians may decide to insert the implant 4 to 8 weeks later[12], with possible tissue loss, which may compromise the final aesthetic result or dictate additional hard and soft tissue augmentation techniques. The main purpose of the present review is to explore the impact of immediate single implant placement and restoration on surrounding hard and soft tissue.

Materials and methods

Participants

Patients requiring an immediate single tooth implant and restoration in the anterior aesthetic zone.

Intervention

Immediate implant placement and immediate restoration with a single crown.

Outcome

Implant survival/success, soft and hard tissue behaviour. For the purpose of this review, the anterior maxilla was chosen as the incisor, canine and premolar areas. Immediate implant placement is defined as placement of an implant immediately post-extraction, and immediate restoration is defined as placement of a dental restoration within 48 h after implant placement. The loading protocol was further defined as immediate occlusal and non-occlusal depending on whether or not the restoration was in contact with the antagonistic teeth.

Search strategy

An electronic search of MEDLINE (PubMed) was conducted from January 2000 until September 2015 using the following search terms: 'immediate' AND 'implant' AND 'placement' AND 'single' AND 'maxilla' AND 'anterior'. In addition, a manual search of the following journals was performed from 2000 to 2015: International Journal of Oral and Maxillofacial Implants, Clinical Oral Implant Research, Clinical Implant Dentistry and Related Research, International Journal of Periodontics and Restorative Dentistry, European Journal of Oral Implantology, Journal of Prosthetic Dentistry, Journal of Periodontology and Journal of Clinical Periodontology.

Study selection

Only clinical studies which met the following inclusion criteria were permissible in this review:

1. prospective RCT's, prospective cohort studies, retrospective studies, comparative studies and case series with a minimum of 10 participants;
2. follow-up of at least 12 months;
3. immediate single tooth replacement in the anterior maxilla including incisors, canines and premolar regions;
4. co-reporting of objective soft and hard tissue outcomes;

5. clearly stated restorative protocol and material selection;
6. reports describing the three-dimensional positioning of the implant;
7. restorations delivered within 48 h of implant placement;
8. defined success criteria e.g. according to Smith and Zarb[13] or Adell et al[14];
9. publication is in English.

Studies which included multiple interventions like ridge splitting, sinus grafting, soft and hard tissue grafting, other then filling the horizontal defect distance with bone or bone substitute, were omitted.

Of the 95 articles, 59 were selected for review of abstracts. Of the 37 articles determined for further review, only 17 articles were included for final analysis. Figure 1 describes the workflow in achieving the final choice of articles for analysis. The main reasons for omission include:

- failure to report on hard and/or soft tissue outcomes;
- mean follow up of less than 1 year;
- implants placed in healed sites;
- multiple interventions;
- multiple surgical protocols without linked differentiation of results;
- splinted implants;
- implants placed in partially dentate regions;
- case presentation;
- less than 10 patients;
- no immediate restoration.

Data extraction

Data were extracted independently of the 17 studies which were included for final analysis.

Survival of implants was defined as the number of implants still in situ at the follow-up period and was expressed as a cumulative survival rate.

The mucosal biotype was described as thin or thick according to the translucency of the periodontal probe through the free gingival margin or by direct measurement.

The papillary morphology was recorded in either a millimetre scale, percentage fill or scored according to the papilla index[15]. The papilla index proposed by Jemt[15] allowed for assessment of the interproximal papilla adjacent to single tooth restorations. The following values were used to describe the degree of papillary fill:

- Index 0 = complete absence of papilla;
- Index 1 = less than half of the papilla is present;
- Index 2 = greater than half but still not to the level of the contact point;
- Index 3 = the papilla fills the entire proximal space and represents the ideal contour;
- Index 4 = the papilla is hyperplastic.

The horizontal defect distance which arises from the placement of an implant immediately into an extraction socket is the distance measured from the outer surface of a defined point of the implant to the inner wall of the cortical plate. In addition to recording this distance, the eventual use of a graft material and the type of graft material was also noted.

Assessment of study quality

Following the selection of eligible papers for review, a quality checklist devised by the Dutch Cochrane Collaboration was utilised to assess study design. The checklist was modified to include a quality assessment process for retrospective studies. This quality checklist in Table 1 describes the quality assessment for randomised case series and retrospective studies. The areas of assessment included randomisation (if appropriate), patient and site characteristics, patient selection, intervention, evaluation method, outcome and follow-up. The study was considered appropriate for inclusion if the randomised studies scored at least 8 pluses and the case series and retrospective studies scored at least 7 pluses.

Statistical analysis

Given the huge heterogeneity amongst the articles, in terms of the variables which affect hard and soft tissue outcomes, the results were analysed with descriptive statistics since no meta-analysis was possible.

Results

A total of 17 studies[4, 16-31] reporting hard and soft tissue outcomes of maxillary single tooth IIPR were

Table 1 Modified quality assessment check list for randomised case series and retrospective studies (unmodified checklist devised by Dutch Cochrane Collaboration).

	Quality assessment of randomised controlled trials	Quality assessment of case series/ retrospective studies
Randomisation	Were adequate methods used for randomisation?	N/A
Patient and site characteristics	Were patient characteristics well described for both groups? Were site characteristics well described for both groups? Were there no disparities between patient and site characteristics between groups?	Were patient characteristics well described? Were site characteristics well described?
Patient selection	Were the inclusion and exclusion criteria well described and the same for both groups? Did the study report on consecutively treated patients?	Were the inclusion and exclusion criteria well described? Did the study report on consecutively treated patients?
Intervention	Were interventions for both groups clearly described? Were all patients of the same group treated according to the same interventions?	Was the intervention clearly described? Were all patients treated according to the same intervention?
Evaluation method	Was blinding used to assess the outcome? Were adequate methods used to assess the outcome? Were reproducibility data reported on the outcome variable(s)?	Was the outcome assessed by an investigator who had not been involved in the treatment? Were adequate methods used to assess the outcome? Were reproducibility data reported on the outcome variable(s)?
Outcome and follow-up	Was the outcome clearly described? Was an intention-to-treat analysis performed and was there a low risk of selective loss to follow-up	Was the outcome clearly described? Was the response rate acceptable and was the number of patients lost to follow-up clearly described?

included in the present systematic review for final analysis. Of the 17 studies, four were RCTs, six were prospective, two were comparative prospective, three were controlled cohort and two were retrospective studies. A summary of these studies are included in Tables 2 to 4.

The four randomised controlled studies had test and control groups to compare i) implants placed in extraction sockets with matching abutments vs implants placed in the socket with mismatching abutments (platform-switched)[4,22]; ii) Implants placed in extraction sockets with final abutments vs implants placed in extraction sockets requiring several abutment changes[20]; iii) immediate implant placement and restoration vs immediate loading in a healed site[31].

There was one prospective comparative study[18] which compared IIPR versus implants placed in post-extraction sockets, and implants which were submerged with a delayed restorative protocol. A retrospective study[21] compared IIPR with grafting and non-grafting of the horizontal defect distance, defined as the space between the outer rim of the implant and the inner wall of the socket.

There were additional studies which did not satisfy the quality checklist. The reasons for exclusion are summarised below.

Reasons for exclusion

Cooper et al[32]

There was a 5-year follow-up study of Cooper et al[25] describing the same clinical trial at a later follow-up.

De Bruyn et al[33]

This was a 5-year follow-up study of the co-author of Cooper et al[25] and was not included for the reasons described above.

Table 2 Enrollment and survival/success rate.

Author name	Year of publication	Journal	Follow-up period (months)	Mean follow-up (months)	Type of study	No. of patients with immediate placed and restored implants	Region	No. of total placed implants	No. of immediate placed and restored implants	Failures of implants	Survival rate (CSR %)	Succes rate (%)	Used criteria for success
Kan et al[16]	2003	IJOMI	12	12	Prospective	35	Ant Max (13-23)	35	35	0	100	100	Smith/ Zarb
Kan et al[17]	2011	IJOMI	96	48	Prospective	35	Ant Max (13-23)	35	35	0	100	100	Smith/ Zarb
De Rouck et al[18]	2009	COIR	12	12	Prospective comparative	49 (24 IP / 25 DP)	Ant Max (15-25)	49	24	1	96	96	Smith/ Zarb
De Rouck et al[19]	2008	JCP	12	12	Prospective	30	Ant Max (15-25)	30	30	1	97	97	Smith/ Zarb
Canullo et al[4]	2009	COIR	NR	25	RCT	22	Ant Max (15-25)	22 (11 PS / 11NS)	22	0	100	NR	NR
Degidi et al[20]	2013	CIDRR	24	24	RCT	68 (35 control / 33 test)	Ant Max (13-23)	68	53 (24 test / 29 control)	0	100	NR	NR
Spinato et al[21]	2012	ID	NR	32	Retrospective	41	Ant Max (15-25)	45	45	0	100	NR	NR
Pieri et al[22]	2011	IJOMI	12	12	RCT	38	Ant Max (pre-m)	40 (20 PS / 20 NS)	38 (19 PS / 19 NS)	1	94.7	94.7	Smith/ Zarb
Cosyn et al[23]	2011	JCP	36	36	Prospective	25	Ant Max (15-25)	25	25	1	96	96	Smith/ Zarb
Berberi et al[24]	2014	J Cont. D. Pract	36	NR	Prospective	20	Ant Max (14-24)	20	20	0	100	100	NR
Cooper et al[25]	2014	IJOMI	60	NR	Prospective comparative	104 (45 Ext / 49 HS)	Ant Max (15-25)	113 (55 Ext / 58 HS)	55	3 (Ext) 1 (HS)	94.55 (Ext) 98.28 (HS)	NR	Smith/ Zarb
Ross et al[26]	2014	IJOMI	60	NR	Retrospective	47	Ant Max (12-22)	30 flap 17 flapless	47	0	100	NR	NR
Calvo-Guirado et al[27]	2015	COIR	36	NR	Controlled cohort study	53	Ant Max (15-25)	71	71	0	100	NR	NR
Bruno et al[28]	2014	J Prost Dent	12	NR	Controlled cohort study	23	Ant Max (15-25)	36	31 (17 one year follow up)	0	100	NR	NR
Grandi et al[29]	2013	EJOI	12	NR	Controlled cohort study	50 (25 IP / 25 DP)	Ant Max (15-25)	50	25	2 (8%)	92	NR	NR
Malchiodi et al[30]	2013	CIDRR	36	NR	Prospective	58	Ant Max (13-23)	64	64	0	100	100	Albrektsson
Slagter et al[31]	2015	J Clin Period.	12	NR	RCT	40 (20 IP / 20 DP)	Ant Max (13-23)	40	20	0	100	NR	NR
			Mean: 31.2			**Σ = 609**		**Σ = 790**	**Σ = 626 (Ext)**	**Σ = 9 (Ext)**	**Mean = 98.25 % (Ext)**	**Mean: 97.96**	

NR: Not reported; PS: Platform switched; NS: Non platform switched; HS: placement healed site; Ext: placement fresh extraction socket; IP: immediate placement, DP: delayed placement.

Block et al[34]

This was a randomised controlled study comparing IIPR with placement of an implant in a healed socket 4 months later. A total of 76 patients were originally included in the study with 21 lost to follow-up. This represents a significant risk for selection bias. A fixed reference guide stent was fabricated for hard and soft tissue measurements prior to extraction and at varying time points after the definitive restoration. Despite this, the baseline was the time of definitive crown delivery and subsequently measured every 6 months up to 2 years. It was unclear whether any significant soft and hard tissue remodelling had occurred prior to this newly adopted baseline, which may have resulted in an underestimation of soft and hard tissue values. The papilla height values were not available for assessment. The outcome measurements were unclear and not adequately described. A mean follow-up time could not be deduced. A survival rate was neither documented nor clearly defined in the results.

Mijiritsky et al[35]

There was significant study design heterogeneity. Not all patients were treated according to the same surgical protocol and different implant designs were used (Xive, MIS and Frialit 2). Site characteristics were unclear as there was no mention of gingival biotype, horizontal defect dimension and placement of implant relative to the facial crest of bone. A non-standardised radiograph technique was used without clear explanation of reference points. The soft tissue outcomes were not measurable as data were not provided. Due to the inadequate evaluation method the outcomes remained unclear.

Hui et al[36]

This prospective study compared immediate restorations in healed sites versus in extraction sockets. The site characteristics were lacking with no documentation of biotype, horizontal defect dimensions and placement protocol relative to the facial osseous crest. All patients in the immediate placement group were not treated according to the same time interval to finalise the permanent restoration. The timing of definitive crown delivery varied from 2 weeks to 3 months after implant placement. These variables may have influenced the final hard and soft tissue outcomes. It was also unclear whether the provisional crowns were placed in occlusal or non-occlusal loading. The response rate over a 12-month period was unacceptable, with half of the original participants lost to follow-up. No reason was given for dropouts and only seven belonged to the immediate group. This results in a risk of selection bias.

Cornelini et al[37]

This study analysed immediate implant placement and restoration in 22 patients in the maxillae and the mandible. While the number of implants placed in the premolar, incisor and canine sites were documented, the locations were not stated. Hence, the data for the mandible and maxillae were pooled, making it impossible to analyse results for the maxillae.

The article failed to document the type of permanent restoration or the mean delivery time of the definitive prosthesis. The site characteristics were not adequately described. There was no mention of the gingival biotype, the peri-implant defect dimensions and the presence or absence of facial bone defects following extraction was not clear. The study claimed that three-wall defects were included, provided the dehiscence defect did not exceed 3 mm. Not all patients were treated according to the same surgical protocol. Some patients underwent a full-thickness flap reflection via an intrasulcular incision, while others received a full-thickness flap with mesial and distal releasing incisions. It was unclear whether the provisional crown was subject to occlusal or non-occlusal loading. Bone remodelling was assessed by non-standardised radiographs and the soft tissue margin was recorded relative to a straight line, which joined the zenith points of the adjacent teeth. These recordings were performed at surgery and at 12-month follow-up. The open flap surgery could have caused recession of the adjacent tissues, affecting the reference line and actual midfacial gingival recession values.

Canullo and Rasperini[38]

The aim of the study was to assess the hard and soft tissue outcomes of IIPR in the anterior aesthetic zone, after a mean follow-up of 22 months. A further aim of the study was to assess the impact of utilising a platform switching implant and its effect on clinical parameters. Baseline measurements were

defined from placement of the final prosthesis which was 3 months after implant placement. The actual bone loss and soft tissue measurements may have been over-rated for this very reason, due to unaccounted potential tissue loss. This may have biased the results and is the reason why the soft tissue results showed an increase in both midfacial mucosal level and papilla heights for the mean follow-up of the study. Although the descriptions of patient and site characteristics were adequate, the methodology used to assess the gingival biotype was not described. It was unclear whether an objective assessment via the transparency of a periodontal probe through the gingiva or a subjective visual assessment was carried out. Only nine patients were included, while the inclusion criteria asked for 10.

Brown and Payne[39]
This study compared a novel implant design with an inbuilt 12 degree angulation for IIPR in the anterior maxillary zone. Not all patients were treated according to the same surgical intervention. A facial plate dehiscence of 3 mm was accepted, necessitating adjunctive augmentation therapy. It was not clear from the study how many received this therapy. Adjunctive augmentation techniques other than filling of the "jump space" were reasons for exclusion. The selected baseline was 8 weeks after implant placement and patients were followed for 52 weeks from the time of surgery. This resulted in a follow-up period of less than 1 year from baseline, which did not satisfy the defined inclusion criteria. The site characteristics lacked a description of the gingival biotype and it was impossible to deduce the actual three-dimensional positioning of the implants.

Cabello et al[40]
The aim of this study was to analyse a flapless IIPR relative to the gingival biotype in the anterior zone of the maxilla (limited to the intercanine area).

Not all patients were treated according to the same surgical technique, with some patients receiving bone level implants and others mucosal level implants. These implants were placed with different three-dimensional placement techniques. There were additional confounding variables and significant heterogeneity in the study design.

Rieder et al[41]
The follow-up period of 4 months does not meet the inclusion criteria.

Berberi et al[42]
The distribution of delayed or immediately loaded implants was not reported.

Cecchinato et al[43]
It concerned implants with delayed loading.

Felice et al[44]
The follow-up period of 4 months does not meet the inclusion criteria.

Noelken et al[45]
Thirteen patients received a single crown and three patients received a partial restoration. The results pooled both prosthetic restoration types.

Covani et al[46]
It concerned implants with delayed loading.

den Hartog et al[47]
All implants were placed in healed sites.

Region

All implants were placed in the anterior aesthetic zone (from tooth locations 15 to 25), with one study analysing the IIPP of an implant in the maxillary premolar region[22].

Survival and success rate

The review included 626 censored IIPR in 609 patients, with a success rate of 97.96% and a survival rate of 98.25%, after a mean follow-up period of 31.2 months (Table 2).

Types of implants

A total of eight different implant systems were utilised in these studies (Table 3). The implants had a tapered and/or a straight body configuration, with a moderately roughened surface and an internal connection.

Gingival biotype

The gingival biotypes were assessed as thick or thin according to the visibility of the periodontal probe through the gingival tissues. Only one of the studies[21] measured the thickness of the gingiva directly with the aid of an endodontic file. The soft-tissue biotype was evaluated as thick in 379 (60.5%) sites (Table 3).

Socket grafting

Socket grafting consisted of the placement of graft material in the peri-implant space, between the outer surface of the implant and the inner wall of the facial socket wall.

Two hundred and one implants sites were not grafted, 405 were grafted mostly with bone substitutes and 20 were not reported (Table 3). The majority of the studies utilised deproteinized bovine bone material (DBBM) or a mixture with autogenous bone (Table 3). The size of that space, which was reported for 170 implants, ranged from 1.38 mm to 2.25 mm.

Loading protocol and time to definitive restoration

Nearly all of the implants (97.8 %) healed with non-functional occlusion; Bruno et al[28] fabricated temporary crowns with functional occlusion. The final single crowns were inserted between 3 and 6 months after implant placement.

Implant position

Only two studies[18,25] did not include specific three-dimensional placement parameters. All 15 residual studies placed the implant palatally, with an interproximal space between implants and teeth. The vertical position of the implant shoulders were reported as either 0.5 to 1.0 mm below the vestibular bone crest or 3 to 4 mm apical to the adjacent cemento-enamel junction.

Flapless vs flap raising

Flapless placement applied to 411 (65.56 %) implants, while 215 implants were placed after raising a mucoperiosteal flap. Five studies defined a mucoperiostal flap as a mandatory part of the surgical protocol.

Antibiotics

Only one study[18] did not stipulate an antibiotic regimen, while the other 16 studies used preoperative and postoperative antibiotics. The documented choice of antibiotics was a broad-spectrum antibiotic such as amoxicillin, augmentin and clindamycin. The doses are listed in Table 3.

Insertion torque

For 419 implants, a minimum insertion torque of 32 Ncm or an ISQ value of 60 were mandatory, while for 53 implants, a minimum insertion torque of 25 Ncm was allowed.

Interproximal mucosa level

The mean reduction of interproximal mucosa level was less than 1 mm compared to the baseline (Table 4).

Midfacial peri-implant mucosal level

The midfacial peri-implant mucosal level change was less than 0.95 mm (Table 4). This level was for thin and thick soft-tissue biotype, without a significant difference, however in one study the thin biotype showed a significantly increased recession.

Crestal bone loss

The crestal bone loss was radiographically measured using a long-cone paralleling technique at various intervals relative to a baseline measurement. The mean crestal bone resorption was less than 1 mm compared to the baseline (Table 4).

Discussion

The main purpose of this review was to assess the impact of immediate single-tooth placement and restoration on hard and soft tissue outcomes, and to

Table 3 Treatment protocol.

Author name	Year of publication	Journal	Type of implant	Implant shape (tapered/ straight)	Type of implant connection	Antibiotics (pre/post)	Type of antibiotic	Implant position
Kan et al[16]	2003	IJOMI	Nobel Biocare	Tapered	Internal	Post	Amoxicillin 500 mg	Palatal
Kan et al [17]	2011	IJOMI	Nobel Biocare	Tapered	Internal	Post	Amoxicillin 500 mg	Palatal
De Rouck et al[18]	2009	COIR	Nobel Biocare	Tapered	Internal	NR	NR	NR
De Rouck et al[19]	2008	JCP	Nobel Biocare	Tapered	Internal	Pre/post	Amoxicillin	Palatal
Canullo et al[4]	2009	COIR	Global	Tapered	Internal	Pre/post	Amoxicillin	Palatal
Degidi et al[20]	2013	CIDRR	Ankylos	Tapered	Internal	Pre/post	Amoxicillin	Palatal
Spinato et al[21]	2012	ID	Screw Vent	Tapered	Internal	Pre/post	NR	Palatal
Pieri et al[22]	2011	IJOMI	Biospark	Tapered	Internal/ morse taper	Pre/post	Augmentin	Palatal
Cosyn et al[23]	2011	JCP	Nobel Biocare	Tapered	Internal	Pre/post	Amoxicillin	Palatal
Berberi et al[24]	2014	J Cont. D. Pract	Astra	Tapered	Internal	Pre/post	Amoxicillin	0.5 mm below crestal bone level
Cooper et al[25]	2014	IJOMI	Astra	Tapered	Internal	Pre/post	NR	NR
Ross et al[26]	2014	IJOMI	Nobel Biocare	NR	NR	Pre/post	Amoxicillin / clindamycin	3 - 4 mm apical to the adjacent cemento-enamel junction
Calvo-Guirado et al[27]	2015	COIR	MIS Implants	NR	Internal	Post	Amoxicillin 875 mg	Bone crest level
Bruno et al[28]	2014	J Prost Dent	Nobel Biocare	Tapered / straight	Internal	NR	Amoxicillin 1000 mg	0.5 - 1.0 mm below the interproximal bone crest
Grandi et al[29]	2013	EJOI	JDentalCare	tapered	Internal	Pre	Amoxicillin 1000 mg	0.5 - 1.0 mm below the vestibular bone crest
Malchiodi et al[30]	2013	CIDRR	NR	NR	NR	Pre/post	Amoxicillin 3000 mg	Most coronal part of the alveolar crest
Slagter et al[31]	2015	J Clin Period.	Nobel Biocare	Tapered	Internal	Pre	Amoxicillin 500 mg	3 mm apical to most apical aspect of prosp. clinical crown

NR: Not reported; PS: platform switched, NS: non platform switched; PIS: Jemt Papilla Index Score; HS: placement healed site; Ext: placement fresh extraction socket; IT: insertion torque; IIPR: immediate implant placement and restoration; ILHS: immediate loading healed site.

identify critical clinical parameters which influence success. From a total of 95 articles, only 17 met the inclusion criteria. There was a scarcity of data involving both hard and soft tissue outcomes and many of the studies were underpowered, thus with a high risk of bias. In a recent Cochrane Database of Systematic Reviews[48], a similar finding was observed and the authors concluded that there was insufficient evidence to recommend either an immediate or a delayed approach.

Randomised controlled trials assessing immediate implant placement versus delayed placement have found no statistical difference in the survival and success between these two treatment modalities[49,50]. This systematic review showed a mean survival rate of 98.40% over a mean follow-up

Insertion torque (Ncm)	Biotype thick	Biotype thin	Flap elevation vs flapless	Socket grafting	Grafting material	Jump space (mm)	Immed. rest. Therapy	Loading protocol non-functional / functional	Definitive restoration (months)
NR	14	21	Without flap reflection	No	--	NR	IIPR	Non-functional	5
NR	14	21	Without flap reflection	No	--	NR	IIPR	Non-functional	5
IT > 35	Normal to thick-flat	0	Minimal mucoperi-osteal flap	Yes	DBBM	NR	IIPR	Non-functional	6
IT > 35	Normal to thick-flat	0	Minimal mucoperi-osteal flap	Yes	DBBM	(0-4) mean 1.38	IIPR	Non-functional	6
IT 32 - 45	11	11	Without raising a flap	Yes > 1mm	Bioss Col-lagen	NR	IIPR	Non-functional	2
IT > 25 Ncm / ISQ > 60	30	23	Flapless	No	--	1.97	IIPR	Non-functional	6
IT > 35	45	0	Flapless	Yes (22), no (23)	DBBM (D)	2.25 (G) 2.03 (NG)	IIPR	Non-functional	6
IT > 40	Thick	0	Flapless	Yes	Mixture A & D	NR	IIPR	Non-functional	4
IT > 35	Normal-thick	0	Minimal mucoperi-osteal flap	Yes	DBBM	1.38	IIPR	Non-functional	6
IT > 32	NR	NR	Limited flap design	NR	NR	NR	IIPR	Non-functional	NR
IT < 55	NR	NR	15 flap (Ext), 40 flapless (Ext)	No	--	NR	IIPR & ILHS	Non-functional	3
IT > 35 Ncm	36	11	30 flap, 17 flapless	Yes	Cortical allograft (Puros)	NR	IIPP	Non-functional	3
ISQ > 60	32	21	Flap	NR	NR	NR	IIPP	Non-functional	NR
IT > 35 Ncm / ISQ > 65	NR	NR	Flapless	Yes	DBBM (D)	1.5	IIPP	Functional	6
IT 72.2 Ncm (average)	NR	NR	Flapless	Yes	DBBM	NR	IIPR & ILHS	Non-functional	4
NR	64	Exclud-ed	Flapless	Yes	Autol. bonechips	NR	IIPP	Non-functional	6
NR	16	4	Flapless	Yes	Autol. Bonechips & DBBM	NR	IIPR & ILHS	Non-functional	3
Number of implants	**Σ = 379**	**Σ = 112**	**Σ = 411 flap-less / Σ = 215 flap (65.56 % flapless)**	**Σ = 201 non grafted (= 32.11 %)**		**Σ = 170**		**Σ = 609 non-func. / Σ = 17 func. (97.28 % non-func.)**	

period of 23.7 months. These results were identical to a recent systematic review[51] which found the survival of immediate implants to be 98.4% over 2 years.

The success rate was not reported in nine studies (Table 2). In a review[52], the authors concluded that there is a scarcity of data and there were limitations in aesthetically relevant and reproducible parameters. Some studies have also relied on patient-based satisfaction criteria, which have been shown to result in high levels of satisfaction, despite obvious discrepancies in crown height, owing to increased recession and incomplete papilla formation[53]. In an attempt to address this limitation in reporting, indices have been developed to score the papilla level[15], and the so-called pink esthetic score (PES)[54].

Table 4 Hard and soft tissue behaviour.

Author name	Year of publication	Inter-proximal mucosa level IML mesial (mean/mm)	Inter-proximal mucosa level IML distal (mean/mm)	Midfacial peri-implant mucosal level (mean/mm)	Midfacial periimplant mucosal level MML thin biotype (mean/mm)	Midfacial periimplant mucosal level MML thick biotype (mean/mm)	Midfacial periimplant mucosal level (MML range / mm)	Crestal bone loss / gain (mean / mm)	Crestal bone loss / gain mesial (mean/ mm)	Crestal bone loss / gain distal (mean/ mm)
Kan et al[16]	2003	-0.53	-0.39	-0.55	NR	NR	NR	-0.24	-0.26	-0.22
Kan et al[17]	2011	-0.22	-0.21	-1.13	-1.5	-0.56	0–3	-0.67	-0.72	-0.62
De Rouck et al[18]	2009	-0.44	-0.31	-0.41	NR	-0.41	NR	-0.82	-0,92	-0,72
De Rouck et al[19]	2008	-0.41	-0.31	-0.53	NR	-0.53	NR	-0.88	-0,98	-0,78
Canullo et al[4]	2009	0.0 (PS), -0.94 (NS)	+0.14(PS), -1.0 (NS)	+0.18 (PS), -0.45 (NS)	+0.4 (PS), -0.5 (NS)	0.0 (PS), -0.4 (NS)	NR	-0.1 (PS), -0.21 (NS)	NR	NR
Degidi et al[20]	2014	-0.08 (test), -0.01 (control)	-0.1 (test), 0.03 (control)	-0.35 (test), -0.59 (control)	-0.41 (test), -0.64 (control)	-0.31 (test), -0.56 (control)	0–0.95	-0.96 (test), -0.97 (control)	-0.65 (test), -0.62 (control)	-0.77 (test), -0.68 (control)
Spinato et al[21]	2012	NR	NR	-0.4mm (G), -0.35 (NG)	NR	-0.4 (G), -0.35 (NG)	NR	-0.94 (G), -0.9(NG)	NR	NR
Pieri et al[22]	2011	-0.24 (PS), -0.33 (NS)	-0.33 (PS), -0.28 (NS)	-0.61 (PS), -0.73 (NS)	NR	-0.61 (PS), -0.73 (NS)	NR	-0.19 (PS), -0.49 (NS)	NR	NR
Cosyn et al[23]	2011	-0.05	-0.08	-0.34	NR	-0.34	NR	-1.0	-1.13	-0.86
Berberi et al[24]	2014	NR	NR	NR	NR	NR	NR	-0.265	-0.24	-0.29
Cooper et al[25]	2014	*-0.13 (Ext), 0.39 (HS)	*-0.21 (Ext), 0.50 (HS)	*0.06 (Ext), 0.42 (HS)	NR	NR	*-2.0–+2.0	+0.43 (Ext), +0.38 (HS)	NR	NR
Ross et al[26]	2014	NR	NR	0.30	> 2.0	0.30	0.08–0.82	NR	NR	NR
Calvo-Guirado et al[27]	2015	NR	NR	NR	NR	NR	NR	**ICBL -0.86	-0.09	-0.11
Bruno et al[28]	2014	17.6%, PIS score 3	23.5 %, PIS score 3	NR	NR	NR	NR	0	NR	NR
Grandi et al[29]	2013	82.6 % (mesial and distal), PIS score 3	82.6 % (mesial and distal) PIS score 3	52.1 % ideal (no recession)	NR	NR	0.0–2.0	-0.71	NR	NR
Malchiodi et al[30]	2013	-0.6	-0.8	46.9% no recession	NR	NR	0.0–2.5	-0.8, **ICBL +0.2	-0.7	-0,9
Slagter et al[31]	2015	-0.89, PIS 2.35	-1.00, PIS 2.45	-0.95	NR	NR	- 0.95 ± 0.62	NR	-0.75	- 0.70

* Baseline: time of definitive crown placement.

** ICBL: distance between the interproximal crestal apex and and the contact point with adjacent teeth at the moment of tooth extraction.

NR: Not reported; PS: platform switched; NS: non platform switched; PIS: Jemt Papilla Index Score; HS: placement healed site; Ext: placement fresh extraction socket.

In order to obtain a predictable and a very good aesthetic result, careful patient selection and treatment planning seems to be needed, with assessment of key diagnostic indicators[18,55]. The proper placement of the implant in the three dimensions of space is considered to be a key clinical parameter for achieving good aesthetics[56]. Buser et al[11] described these spatial relationships relative to comfort and danger zones. It was considered safe if an implant was placed 1 mm palatal to the cervical emergence profile of the adjacent teeth, with a mesiodistal clearance of 1.5 mm and an apicocoronal position 1 mm apical to the CEJ of the adjacent teeth. Grunder et al[56] also considered it to be of particular relevance if there was at least 2 mm of bone buccal to the implant. This was to compensate for the possible re-establishment in the biological width, which was approximately 1.5 mm in both the vertical and horizontal position. Funato et al[57] has further illustrated the placement requirements of an implant, with importance given to the implant being prosthetically driven, ensuring it engages the palatal socket wall, and is ideally placed just lingual to the incisal plane.

Type of implant

The implants used in the included studies were broadly defined according to their shape, surface characteristics and interface connection. All of the implants had a solid tapered or straight and threaded design, with a moderately roughened surface and internal connection. There are arguments in favour of the use of a tapered implant design in extraction sockets, owing to the shape of this implant design better matching socket anatomy and facilitating placement[58]. The benefit of a tapered design to achieve high primary and secondary stability has been demonstrated[59]. All of the studies in the present review used a standard tapered and threaded design with two studies adopting a progressive thread pattern[20,31].

One of the features which was constant throughout the reviewed literature, was the use of a moderately rough surface. The advantage of a roughened surface vs a machined one is the ability to achieve more rapid osseointegration and secondary stability[60].

The implant interfaces utilised in the analysed studies consisted of internal connections with matching and mismatching abutments. The latter has been commonly referred to as platform switching and has recently gained popularity through claims of superior postoperative crestal bone preservation. The beneficial effects of limiting crestal bone loss with platform switching implants has been confirmed in a recent systematic review and meta-analysis[61].

The studies by Canullo et al[4] and Pieriet al[22] represented randomised controlled studies comparing matching and mismatching abutments. In both of these studies the bone level preservation tended to be improved in the platform switching group compared with the non-switching groups. However, the peri-implant soft tissue levels had different outcomes with the two studies. Pieri et al[22] demonstrated no statistical difference in the recession of the midfacial gingiva and papillae, with almost identical results at the 12-month follow up. This may have been influenced by the placement of implants in patients with thick gingival biotypes only. In contrast, the study by Canullo et al[4] included 11 participants with thin biotypes and 11 with thick biotypes. In the thin biotype group, the platform switching groups mean midfacial recession value was almost 1 mm better. When we analyse the thick biotype subgroup, the difference in recession is 0.4 mm. Hence, it appears that the platform switching concept may be of particular relevance in the thin gingival biotype groups.

Gingival biotype

Recent studies have considered the presence of a thick gingival biotype to be crucial for immediate implant placement procedures[55]. In three of the included studies, only patients with thick gingival biotypes were enrolled, as thin gingival biotypes were considered to carry high aesthetic risks with IIPR[19,21,23].

While the mucosal biotype had a negative influence on midfacial gingival levels, it failed to influence crestal bone loss and regeneration of papillae. In both thick and thin gingival biotypes, the amounts of crestal bone loss and papilla regeneration were about the same and independent of biotype. The papillae were the only soft tissue parameters which improved with time, despite continued crestal bone loss. In two

studies[21,23], a continuous trend for papilla regeneration occurred even after more than 12 months, while two other studies[4,20] demonstrated stable papillae after 2 and 6 months, respectively. This was independent of the choice of a matching or mismatching abutment, although the platform switching concept resulted in greater papilla regeneration. This finding is also in contrast to other published data which have demonstrated that the papilla will only reach a stable state after 1.5 years[15,62]. In a study by Romeo et al[63], it was shown that the presence of a papilla statistically correlated with thick gingival biotypes over a follow-up period of 12 months. In contrast, Canullo et al[4] found no relationship between biotype and papilla, and Kan et al[17] demonstrated progressive regeneration of the papilla, irrespective of biotype. The failure to establish a relationship between papilla level and biotype also corresponded with the findings of a recent study by Cordaro et al[64]. However, they did conclude that thin gingival biotypes resulted in statistically increased levels of midfacial recession when compared to thick gingival biotypes. These findings were also confirmed by results of a 4-year follow-up study by Kan at al[17]. In comparison, the studies by Canullo et al[4] and Degidi et al[20] did not demonstrate a relationship between thin gingival biotype and increased recession. In the study by Canullo et al[4], the single most important influencing factor for improved peri-implant soft tissue profile was the use of a platform switching implant-abutment-joint. Although more recession occurred with thin gingival biotypes and in particular with the use of matching abutments, this was found to be statistically insignificant. The study by Degidi et al[20] also failed to provide a relationship between the midfacial recession and biotype. Degidi et al[20] found that the non-removal of abutments and the "one abutment at one time concept", resulted in preservation of horizontal bone overlying the platform switching component of the implant. The removal of abutments (control) resulted in loss of the horizontal dimension of the bone and increased midfacial recession.

There is limited evidence to support or refute the stability of the midfacial gingival recession despite the recommendation for thick gingival biotypes with IIPP[65]. In particular, the present review failed to demonstrate a difference between thick and thin biotypes. The stability of the midfacial gingiva and papilla has been attributed to the fabrication of an immediate anatomically contoured provisional[16,18], and the presence of bone adjacent to the natural tooth[66]. The study by De Rouck et al[18] compared IIPR versus IIP and healing abutments, in patients with thick gingival biotypes. It was found that IIPR resulted in superior aesthetic results and that failure to instantly provisionalise caused a two to three times greater recession. The prosthetic therapy was shown to be the single most influencing factor favouring soft tissue stability. In the latter investigation, a relationship between biotype and marginal bone levels could not be shown, with both thick and thin biotypes behaving similarly. This was also reported by Cordaro et al[64], although the technique for assessing bone loss utilised a non-standardised long cone paralleling technique, and therefore the results should be interpreted with caution. The greatest rate of marginal bone loss was shown to occur in the first 6 months and continued after 12 months, with a range between 0.7 mm and 1.0 mm, despite the difference in biotypes.

Spatial implant placement

The studies which described the three-dimensional placement of immediate post-extraction implants dictated palatal placement, engaging bone beyond the apex and ensuring an interproximal space of 1 to 2 mm. When placing implants into extraction sockets, it is important to control the axial inclination, to prevent contact with the thin facial plate of the bone. Implants which have been placed buccally have been associated with negative aesthetic outcomes[67]. In the same study, it was found that implants with a buccal shoulder position showed three times more recession than those that were placed with a palatal shoulder. Chen et al[10] investigated this in a prospective study, analysing the effects of axial implant placement and resultant peri-implant defects on aesthetic outcomes. The peri-implant defect was measured in a horizontal and vertical dimension at placement and at re-entry after 6 months of healing. The horizontal defect dimension (HDD) was measured from the outer bevel of the implant to the inner wall of the buccal plate. This distance was shown to significantly influence the aesthetic outcome when the

HDD measured 1.1 ± 0.3 mm, and the implant was placed buccally. Ten implants (33%) were scored as aesthetic failures, with midfacial recessions ranging between 1 mm and 3 mm. Implants which were buccally placed represented 70% of the aesthetic failures and the remaining 30% belonged to the implants with a palatal placement of 2.3 ± 0.6 mm. Interestingly, three out of four implants with initial dehiscence defects, also resulted in an unsatisfactory recession, 6 months after implant placement. This finding is also in agreement with a study by Kan et al[68], who investigated the morphology of facial osseous defects and their effects on mucosal recessions with IIP. The morphology of the facial defects were characterised as V-, U- and ultra U (UU)-shaped, based on osseous probing. A V defect is one where the defect can only be probed on the buccal; a U defect is one which extends to the mesial and distal aspect of the failing tooth; a UU defect is one where the defect extends to the mesial and distal aspects of the neighbouring teeth. The incidence of the recession was found to occur in 100% of cases with UU morphology, 42.7% of cases with U morphology and 8.3% of cases with V-shaped defects. The study also found that there was no statistical relationship between biotype and the incidence of recession greater than 1.5 mm after 1 year.

The vertical or apico-coronal placement of the implant varied from 0.5 mm supracrestal, equicrestal and up to 2 mm subcrestal placement. The 2 mm subcrestal placement was recommended by Degidi et al[20], together with the platform switching concept. De Rouck et al[19] recommended the placement of the implant 1 mm subcrestally and utilised matching abutments. This placement methodology resulted in the greatest amount of bone loss in studies with 12-month follow-up, but had no significant influence in midfacial recession outcomes. The equicrestal placement protocol was recommended by Canullo et al[4] and resulted in superior bone level outcomes compared to subcrestal placement methodologies. This study also analysed the difference in matching and mismatching abutments in thin and thick biotypes. In these groups, the midfacial recession and crestal bone loss was primarily influenced by the choice of prosthetic protocol and not by the biotype. The midfacial gingival position was superior with an equicrestal and platform switching concept, compared to a subcrestal placement with platform switching. The only study which specified a supracrestal placement was by Pieri et al[22]. This study served to analyse the difference between switching and non-switching abutments in patients with thick gingival biotypes. The supracrestal placement with a platform-switching concept resulted in better marginal bone levels than for the subcrestal switching placement reported by Degidi et al[20]. Pieri et al[22] failed to establish such a relationship. It is important to note that they were dealing with single-tooth premolar sites which exhibited thick gingival biotypes.

It would appear from this systematic review that, where possible, an equicrestal placement should be maintained and if an implant needs to be placed further down to ensure stability, a platform switching implant should be considered. The use of equicrestal implants with platform switching also resulted in the best aesthetic and hard tissue outcome, irrespective of biotype.

Antibiotics

In nearly all of the included studies, antibiotics were taken either, preoperatively and postoperatively or postoperatively only. The choice was always a broad-spectrum antibiotic.

Socket grafting and gap size between implant and alveolar wall

When placing implants in extraction sockets, a space will usually remain between the implant and the inner wall of the facial plate of the bone. This defect can be managed with or without a graft and with a varying choice of filling materials. An experimental study by Araújo et al[69] demonstrated the benefits of grafting such 1 to 2 mm gaps, with immediate implant placement in the mandibles of dogs. The benefits of grafting were illustrated with the establishment of a thicker buccal bone, and maintaining the level of buccal bone close to baseline crestal positions. In contrast, the non-grafted sites resulted in a significantly apical and thinner buccal bone crest. The study by Caneva et al[70] failed to demonstrate the same beneficial effects in preserving vertical crestal bone level, since a similar magnitude of bone loss in grafted and non-grafted sites was observed. One of

the distinguishing features in this study was the very small baseline defect width, consisting of 0.5 mm. The merits of grafting a small site and in particular less than 1 mm has been questioned[19].

A human 7-year prospective study served to analyse the relationship between baseline horizontal defect depths (HDD) grafted with DBBM and its effects on hard and soft tissue outcomes[71]. The bone levels were examined via CBCT and revealed that when the buccal bone was absent, 1 mm greater recession occurred. The mean HDD for this group without buccal bone was 1.3 mm, and when buccal bone was maintained, the mean HDD was 1.6 mm. This was not statistically significant and the study failed to establish a relationship between the morphology of the defects at baseline and bone dimensions at the 7-year follow up. It would appear from this study and that of Chen et al[10], that grafting of the horizontal "jump space" alone is not adequate in preventing vertical soft and hard tissue loss.

The need for bone graft materials in the remaining gaps has been questioned[8,72], and their ability to limit vertical crestal bone loss is unsubstantiated[4,10,18,19,21,22,71,73,74]. Although there may be some merits for increasing the horizontal dimension of bone[10,67,69] or providing a scaffold for hard and soft tissue development[69,75], the current systematic review has failed to conclusively provide evidence in support of this method. Other factors such as the palatal placement of the implant and correct axial alignment[4,10] appear to be more important than just simply treating the HDD with bone substitute.

Conclusion

Within the limitations of this systematic review, it revealed excellent results for immediately placed and immediately restored single implants (IIPR) in the anterior maxilla. The possible choice for flapless surgery and a lack of grafting procedure of the socket enables minimally invasive surgery. However strict patient selection was used for all included clinical trials.

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Timing of single implant placement and long-term observation of marginal bone levels

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Key words *dental implant, long-term, marginal bone level, outcome, review, timing*

Aim: To assess the outcome of immediate or early placement of implants after tooth extraction supporting a single-tooth restoration with focus on the marginal bone level and its stability over time.
Material and methods: An electronic literature search without time restrictions was conducted of the Medline/PubMed database accompanied by a handsearch. Clinical human studies reporting on peri-implant marginal bone level (BL) and/or changes in bone level (BLC) and with a follow-up period of at least 12 months were selected for the present review.
Results: The search strategy resulted in 816 articles and 115 relevant publications were included for full-text analysis. Only few randomised controlled trials exist comparing immediate or early implant placement with placement in healed bone (the conventional protocol). Summarising the results from prospective studies, it was found that the mean marginal bone loss around immediately or early placed implants from baseline (at implant placement or placement of restoration) to the latest follow-up visit (between 1 and 10 years) was less than 1.5 mm.
Conclusion: The current literature indicates that immediate or early placement of single-tooth implants after tooth extraction may be a viable treatment with long-term survival rates and marginal bone level conditions matching those for implants placed conventionally in healed bone ridges.

■ Introduction

Peri-implantitis can affect the supporting soft and hard tissues around an oral endosseous implant and is characterised by bleeding and/or suppuration on probing and marginal bone loss. Poor oral hygiene, misfit between implant components and remnants of cement in the marginal sulcus are some of the contributors to peri-implantitis, which may compromise the survival of the implant and overall success of treatment[1]. Inappropriate loading conditions have been blamed for causing loss of peri-implant bone however the level of evidence is weak and does not indicate that overload per se can lead to peri-implant bone loss[2]. In contrast, in the presence of peri-implant inflammation, excessive mechanical occlusal load seems to aggravate the plaque-induced tissue breakdown[3], which in the worst case may lead to total loss of osseointegration.

A myriad of treatment concepts for implant-based prosthodontic rehabilitation has been suggested and it is imperative to clarify if the protocol, for example the timing of treatment, has an impact on marginal bone loss or gain after implant placement as well as the long-term marginal bone level.

The conventional protocol for treatment with intra-oral implants proposed by Brånemark[4] dictates a time interval of 3 to 6 months between extraction of a tooth and placement of the implant allowing soft tissue and bone healing at the extraction site. Furthermore, the protocol advocates a waiting period of at least 3 months before loading the inserted implant.

Two strategies have been followed to challenge the original protocol in order to reduce the treatment time. One alternative is to insert the implant immediately or soon after tooth extraction (termed immediate/early implant placement). Another alternative is to restore the implant (with or without occlusal loading) immediately or soon after placement (termed immediate/early restoration or loading). The strategies combined could minimise the overall treatment time dramatically. Ultimately, a patient may have one or more teeth extracted and will leave the dental office the same day with a single or multi-unit implant-supported restoration. This new protocol has been termed immediate or early replacement in the literature[5,6].

The reduction in treatment time is mainly due to fewer interventions and visits at the clinic and may be appealing for both the surgeon/clinician and patient in terms of increased effectiveness and satisfaction, and lower expenses. However, it is important to emphasise that this new approach should not be associated with a higher risk and more complications compared with the conventional protocol or require a disproportionate amount of extra training or special skills.

It has been speculated if placement of implants in fresh extraction sockets (immediate placement protocol) may also be beneficial from a biologic point of view. It is widely accepted that height and width (buccolingual) alterations in the alveolar ridge occur after tooth extraction and that most of these changes will occur within the first 3 months of socket healing[7]. These physiological dimensional changes may have a negative impact on the subsequent implant placement. By placing the implant immediately or early after tooth extraction and therefor before the narrowing and loss of bone ridge height has taken place, it might be easier to ensure proper positioning (apicocoronal and buccolingual) and angulation, which is indeed important for the functional and aesthetic outcome of implant-supported prosthodontics. Another potential advantage of preserving the bone walls would be that ridge augmentation is needed to a lesser extent.

Even though the immediate implant placement concept seems appealing, one could imagine some critical factors associated with it. Are we in fact sure that bone height around the implant can be preserved by immediate placement? Presence of periodontal or periapical/endodontic infections may interfere with healing and survival of the implant. The socket anatomy may influence the potential for obtaining primary implant stability, for example it appears reasonable to assume that a missing buccal bone plate or a molar extraction site would be more challenging. Furthermore, the surgical and prosthetic protocols may play a role. Flapless surgery has been suggested as an attempt to avoid bone resorption that may occur due to exposure of the underlying bone after raising a surgical flap[8]. It is also relevant to consider if immediate or early loading of an implant placed in a fresh extraction socket would be detrimental for the healing process or if this approach on the contrary may be beneficial.

Several studies have reported that successful outcomes are achievable when implants are inserted immediately after tooth extraction, with similar survival rates in comparison to implants inserted in healed sites, while other studies have found higher failure rates[9,10].

This systematic review was conducted to assess the outcome of immediate or early placement of implants after tooth extraction, supporting a single-tooth restoration, with focus on the long-term marginal bone level.

Material and Methods

Search strategies

An electronic literature search of the Medline/PubMed database, without time restrictions, was conducted and was completed on March 17, 2015. The following terms were used in the search strategy:
("Dental implant" OR "Oral implant" OR "Dental implantation" OR "Oral implantation" OR "Tooth implant" OR "Tooth implantation" OR "Dental

implants" OR "Oral implants" OR "Tooth implants") AND ("Single implant" OR "Single-tooth" OR "Single tooth" OR "Single-crown" OR "Single crown" OR "Single restoration" OR "Single implants" OR "Single-teeth" OR "Single teeth" OR "Single-crowns" OR "Single crowns" OR "Single restorations") AND ("Fresh extraction socket" OR "Fresh-socket" OR "Immediate placement" OR "Immediate insertion" OR "Immediate installation" OR "Immediate implant" OR "Immediate implants" OR "Immediately placed" OR "Immediately inserted" OR "Immediately installed" OR "Immediate-delayed placement" OR "Immediate-delayed insertion" OR "Immediate-delayed installation" OR "Immediate-delayed implant" OR "Immediate-delayed implants" OR "Immediate-delayed placed" OR "Immediate-delayed inserted" OR "Immediate-delayed installed" OR "Delayed-immediate placement" OR "Delayed-immediate insertion" OR "Delayed-immediate installation" OR "Delayed-immediate implant" OR "Delayed-immediate implants" OR "Delayed-immediately placed" OR "Delayed-immediately inserted" OR "Delayed-immediately installed" OR "Early placement" OR "Early insertion" OR "Early installation" OR "Early implant" OR "Early implants" OR "Early placed" OR "Early inserted" OR "Early installed" OR "Delayed placement" OR "Delayed insertion" OR "Delayed installation" OR "Delayed implant" OR "Delayed implants" OR "Delayed placed" OR "Delayed inserted" OR "Delayed installed" NOT ("animal" OR "animals" OR "dog" OR "dogs" OR "pig" OR "pigs" OR "in vitro" OR "cadaver" OR "case report").

Furthermore, the reference list of 16 recent and relevant reviews[9-24] was manually searched.

Study selection

Titles and abstracts of the identified publications were screened by the authors and full-text articles were obtained for all potentially relevant studies.

Clinical studies were included in this systematic review, while the following criteria for exclusion were applied: case reports, technical reports, animal studies, *in vitro* studies and review papers. In addition, to be eligible for inclusion, publications must be published in English, include at least 10 implants in the test group (immediate or early implants), have a follow-up period of at least 12 months and report on peri-implant marginal bone level (BL) and/or changes in bone level (BLC). In studies including both single and multiple implant restorations, data on BL and BLC had to be reported separately for the single-tooth restorations. Similarly, in studies evaluating different timing protocols for implant placement, publications were excluded if data reporting did not differentiate amongst the protocols.

The following study information and treatment outcomes were extracted for randomised clinical trials (RCTs) and prospective controlled clinical trials (CCTs): author and publication year, follow-up period, implant placement protocol(s), number of patients and implants, implant survival rate, BL and/or BLC, implant site, loading protocol, implant system and tissue augmentation. Furthermore, for studies reporting on the buccal bone level assessed by cone beam computed tomography (CBCT), the same information was obtained for RCTs, CCTs and prospective clinical studies without a control group (PCTs).

Definitions

Various terms have been suggested in the literature with regard to defining the time of implant placement after tooth extraction. In the present review, the terms used in the included publications were presented in the text and tables, and in the tables, the actual interval between tooth extraction and implant placement was stated if mentioned by the author. The term immediate referred to implant placement in fresh extraction sockets (on the same day as tooth extraction).The terms early or delayed-immediate referred to implants placed up to 8 weeks after extraction. The terms delayed or late implants, or healed sites referred to placement after a healing period of at least 2 months.

Marginal bone level (BL) in radiographs (periapical and CBCT) was defined as the distance from implant shoulder/platform to the first visible bone-to-implant contact (BIC). A positive value indicates a BL located apical to the shoulder and vice versa. A positive value for marginal bone level change (BLC) indicated a bone gain. A negative value for BLC indicated a bone loss.

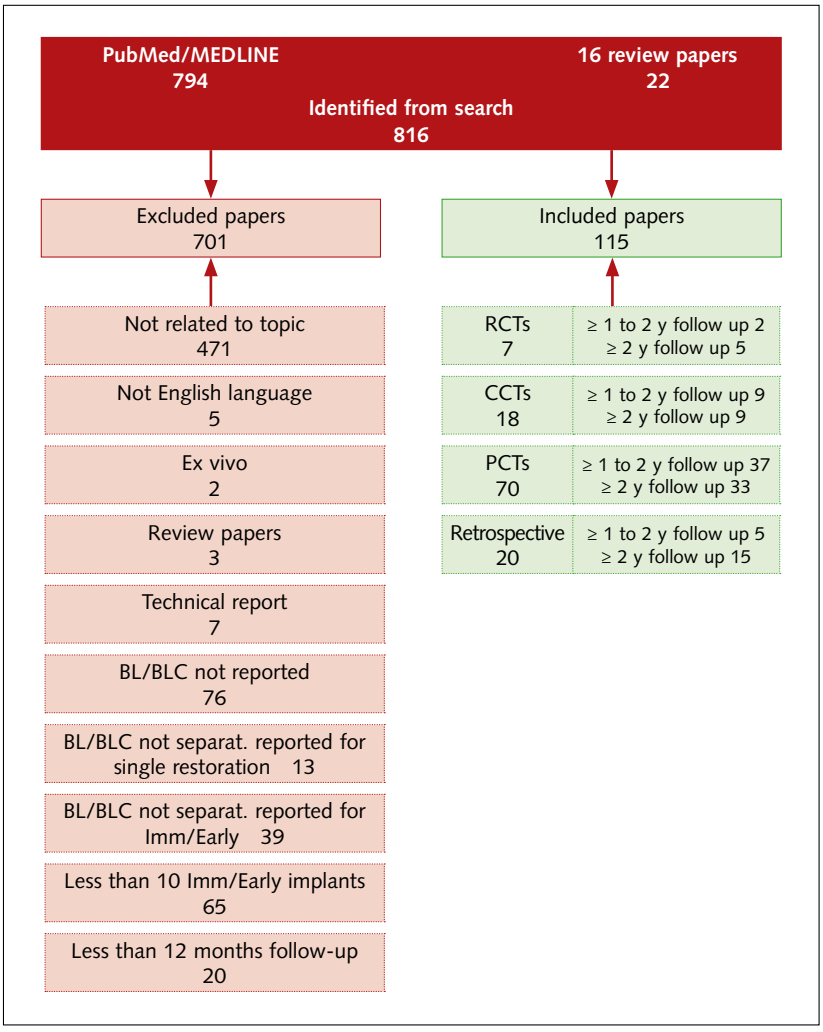

Fig 1 Study search strategy.

Results

Literature search

The PubMed/Medline search resulted in 794 potential articles and screening of the 16 review papers identified an additional 22 possible articles. Titles and abstracts (and full-texts in case the authors were in doubt if the inclusion criteria were fulfilled) were screened and 701 of the total 816 articles were excluded: 471 unrelated to the topic, five not in the English language, two *ex vivo*, three review papers, seven technical reports, 76 not reporting BL or BLC values, 13 not reporting BL/BLC separately for single-tooth restorations, 39 not reporting BL/BLC separately for immediate or early placed implants, 65 including less than 10 implants in the test group and 20 with a follow-up period of less than 12 months. Thus, 115 relevant publications were included for full-text analysis (Fig 1).

Description of studies

Forty-five studies had an observation period of 1 year, seven studies a follow-up between 1 and 2 years, and 63 studies a follow-up period of 2 years or more. Seven publications with an RCT design were identified; six of them with a follow-up period ≥ 2 years, however, four papers were from the same author group and dealt with the same study population. Eighteen publications reported on CCTs with one or more control groups, of which half had a follow-up period ≥ 2 years. Seventy studies were PCTs, i.e. without a control group (33 with a follow-up ≥ 2 years, 37 with a follow-up of 1 to < 2 years). Additionally, 20 retrospective studies (15 with an observation period ≥ 2 years, five with an observation period of 1 to < 2 years) were identified (Fig 1). The latter group of studies was not considered in detail in the following review of data. Ninety of the 95 prospective, clinical studies retrieved through the present search strategy reported on the interproximal bone level in intraoral, periapical radiographs, while five reported on the buccal bone level analysed by CBCT.

Publications from six RCTs are displayed in Table 1 while one RCT reporting on the buccal bone level analysed by CBCT is displayed in Table 2. Three articles by Schropp et al[25-27] compared the interproximal marginal bone level of implants placed early (also termed delayed-immediately) with that of delayed-placed implants at 2 and 5 years, respectively, after implant placement, and after 10 years these groups were compared with a late group comprising of implants placed approximately 1.5 years after tooth extraction in the premolar or molar regions. From crown delivery to 10-year follow-up, no changes in mean BL for the early group, a minor bone loss of 0.2 mm for the delayed group, and a minor bone gain of 0.2 mm for the late group were found. No statistically significant differences in mean BL values at 10 years were seen amongst the groups. Since the groups were not equally represented with implants in the incisor and molar regions, the authors carried out a separate analysis for implants replacing a premolar[28] and also found for this region alone

Table 1 RCTs reporting on interproximal bone level (BL) or bone level change (BLC) with a minimum mean follow-up period of 12 months.

Author/ year	Follow-up	Test group No. of patients / implants Protocol SR, BL and/or BLC	Control group(s) N of patients / implants Protocol SR, BL and/or BLC	Implant site	Loading protocol	Implant system	Augmentation
Schropp et al 2014[27]*	9.7 years	22/22 early (approximately 10 days after extraction) SR: 92% BLC: 0.00 mm; L: 1.15 mm NS difference in BL between groups	22/22 delayed (approximately 3 months after extraction) SR: 95% BLC: -0.23 mm; BL: 1.53 mm 19/19 late (approximately 1.5 years after extraction) SR: 100% BLC: 0.17 mm (gain) BL: 1.42 mm	Anterior and premolar for early/delayed Premolar and molar for late Maxilla/mandible	After 3 months	3i Parallel-walled Osseotite	Autogenous bone at dehiscences and fenestrations
Schropp and Isidor 2008[25]*	5 years	23/23 early (approximately 10 days after extraction) SR: 91%; BLC: -0.6 mm; BL: 1.2 mm NS difference in BL between groups	22/22 delayed (approximately 3 months after extraction) SR: 95% BLC: -0.8 mm BL: 1.5 mm	Anterior and premolar Maxilla/mandible	After 3 months	3i Parallel-walled Osseotite	Autogenous bone at dehiscences and fenestrations
Schropp et al 2005[26]*	2 years after implant placement	23/23 delayed-immediate (approximately 10 days after extraction) SR: 91% BLC: -0.8 mm; BL: 1.4 mm NS difference in BL between groups	23/23 delayed (approximately 3 months after extraction) SR: 96% BLC: -0.7 mm BL: 1.6 mm	Anterior and premolar Maxilla/mandible	After 3 months	3i Parallel-walled Osseotite	Autogenous bone at dehiscences and fenestrations
Palat-tella et al 2008[29]	2 years	8/9 immediate (in fresh extraction sockets) SR: 100%; BLC: -0.54 mm NS difference between groups	8/9 early (8 weeks after tooth extraction) SR: 100%; BLC: -0.46 mm	Anterior maxilla	Immediate restoration (non-occlusal loading)	Straumann TE implants	NM
Block et al 2009[30]	18 to 24 months	26/26 immediate (in fresh extraction sockets) SR: 85%; BL: 0.09 mm mesially, 0.18 mm distally NS difference in BL between groups	29/29 delayed (16 weeks after tooth extraction) SR: 97% BL: 0.32 mm mesially, 0.32 mm distally	Anterior and premolar maxilla	Immediate restoration	3i Straight wall, roughened surface	Human mineralised bone graft in gaps Grafting of extraction sites in delayed group
Linde-boom et al 2006[32]	1 year	25/25 immediate (in periapically infected extraction sites) SR: 92% BLC: -0.49 mm mesially, -0.53 mm distally NS difference between groups	25/25 delayed (12 weeks after tooth extraction) SR: 100% BLC: -0.52 mm mesially, -0.52 mm distally	Anterior and premolar maxilla	Loading after 6 months	Frialit-2 Synchro	Buccal bone augmentation in all cases (34 chin and 16 mandibular ramus bone grafts)

SR: survival rate; NM: not mentioned, NS; not statistically significant.

For BLC, a positive value means gain and a negative value means a loss. For BL a positive value means the BL was positioned apically to the implant shoulder/platform.

* The three studies reported from the same study population.

Table 2 Clinical studies reporting on buccal bone level (BL) or BL change (BLC) with a minimum mean follow-up period of 12 months.

Author/year Study type	Follow-up	Test group N of patients / implants Protocol, SR, BL and/or BLC	Control group(s) N of patients / implants Protocol, SR, BL and/or BLC	Implant site	Loading protocol	Implant system	Augmentation
Schropp et al 2015[28] RCT	9.7 years	22/22 early (on average 10 days after tooth extraction) SR: 92% BL: 2.39 mm NS difference in BL amongst groups	22/22 delayed (3 months after tooth extraction) SR: 95% BL: 2.22 mm 19/19 late(1.5 years after tooth extraction) SR: 100% BL: 1.85 mm	Anterior and premolar for early/ delayed Premolar and molar for late Maxilla/mandible	After 3 months	3i Parallel-walled Osseotite	Autogenous bone at dehiscences and fenestrations
Miyamoto and Obama 2011[40] CCT	28.2 months Range 6 to 57 months	Overall 18 patients in the three groups 7 implants immediate SR: NM BLC: -3.25 mm SS difference in BLC between Imm and D1 ($P<0.05$) NS difference between D2 and Imm or D1	16 implants delayed (D1) SR: NM BLC -0.13 mm 8 implants delayed (D2) SR: NM BLC: -0.70 mm	Anterior maxilla	Immediately placed abutments with non-occlusal loading	3i Osseotite / NobelBiocare Nobel Replace	Imm: autogenous bone D1: non-resorbable membrane and xenograft D2: resorbable membrane and xenograft
Raes et al 2013b[41] CCT	1 year	12/12 immediate SR: NM BL 0.16 mm (range 0-0.6) NS difference in BL at 1-year between groups	14/14 healed sites SR: NM BL: 0.20 mm (range 0-0.8)	Anterior and premolar maxilla	Immediate loading	Astra Tech OsseoSpeed	No augmentation
Benic et al 2012[43] PCT	7 years	24/24 immediate SR: 100% BL 5.2 mm at 7-year Almost no buccal bone detected in approximately one third of implants In two-thirds, the buccal bone plate covered the entire surface		Anterior and premolar Maxilla and mandible	Delayed loading	Straumann	Xenogenic bone graft and resorbable membrane
Buser et al 2013[55] PCT	7 years Range 5 to 9 years	4¼1 early (4 to 8 weeks after tooth extraction) SR: 100% BL not reported! Mean thickness of the facial bone wall of 2.2 mm		Anterior and premolar maxilla	Delayed loading	Straumann	Xenograft, autogenous bone, resorbable membrane

SR: survival rate; NM: not mentioned; NS: not statistically significant; SS: statistically significant; RCT: Randomized controlled trial; CCT: Controlled clinical trial; PCT: Prospective clinical trial (without control).

For BLC a positive value means a gain and a negative value means a loss.

For BL a positive value means BL was positioned apically to the implant shoulder/platform.

no significant difference in interproximal BL among the groups (early: 2.29 mm, delayed: 1.61 mm, late: 2.16 mm; $P = 0.56$). The three other RCTs[29-31] evaluated the patients at 1 year, 1.5 to 2 years or 2 years, respectively, after implant placement. All implants in these studies had replaced anterior/premolar teeth in the maxilla. Palattella et al[29] compared immediate implants with implants placed 8 weeks after tooth extraction (early); Block et al[30] compared immediate implants with implants placed 16 weeks after extraction (delayed); and Lindeboom et al[32] compared implants placed in periapically infected extraction sockets (immediate) with implants placed 12 weeks after extraction. For those RCTs, a mean marginal bone loss of 0.5 mm interproximally was found, or the BL was situated less than 0.5 mm apically to the implant shoulder, during the most recent control visit, irrespective of timing protocol; no statistically significant differences existed between test and control groups.

The trend for the CCTs comparing immediate or early placement with delayed or late placement, or immediate with early placement (Table 3) was the same as that for RCTs. Statistically significant differences between test and control groups were noted in only three out of 16 papers[33-35]. Cooper et al[33] demonstrated marginal bone gain at immediate implants and bone loss at implants placed in healed bone (statistically significant difference in BLC), resulting in a non-significant difference in bone levels between the groups at 1 year. This was the only CCT where the mean bone level was situated more than 1 mm apical to the implant shoulder, which was at immediate implants. Vandeweghe et al[35] found a significant difference in bone loss (0.4 mm; $P = 0.016$) between immediate and delayed implants in favour of the former timing, while Carini et al[34] found a significant difference in bone loss (0.15 mm; $P = 0.016$) between immediate and early implants, also in favour of the former timing. The maximum mean bone loss was 1 mm during the observation period, except in two studies[35,36], that revealed a bone loss of 1.6 and 1.3 mm, respectively, for implants placed in healed bone. A bone gain interproximal to immediate implants was observed in several studies (Table 3).

Thirty-one PCTs with a follow-up ≥ 2 years reported on the interproximal bone level (Table 4). All studies were dealing with immediately placed implants except one study[37] where the implants were placed early (4 to 8 weeks after tooth extraction). Summarising the results, it was found that the mean marginal bone loss from baseline (typically at implant placement or placement of restoration) to the latest follow-up visit was less than 1.5 mm. Two-thirds of the studies had an observation period of 3 years or more. Seven studies reported the absolute marginal bone level (BL) measured as the distance between implant shoulder/neck and BIC. The maximum mean BL was 1.5 mm except in one study where mean BL was 1.5 and 1.7 mm for two groups[38]. In a study evaluating 116 implants, BL after 6 to 9 years was > 3.5 mm for 20% and 66%, respectively, of immediate implants with or without a connective tissue graft[39].

The five prospective clinical studies reporting on the buccal bone level analysed by CBCT are listed in Table 2. Schropp et al[28] presented data of the buccal bone level in patients from the same RCT included in Table 1. Ten years after implant placement, the bone level was situated more apically in the early group compared with the delayed and late groups, however, the statistical tests revealed no significant differences amongst the groups. When analysing the premolar implants (represented in all three groups) separately, there was similarly no significant difference in BL amongst groups (early: 2.11 mm, delayed: 1.95 mm, late: 2.01 mm; $P = 0.85$). In a CCT by Miyamoto and Obama[40], more buccal bone loss was found at immediate implants (BLC: -3.25 mm) than at delayed implants augmented with a xenograft and a non-resorbable membrane (BLC: -0.13 mm; statistically significant difference), or a resorbable membrane (BLC: -0.70 mm; No statistically significant difference), during the observation period (28 months on average). Raes et al[41] found no statistically significant difference in bone level buccal to immediate implants compared with implants placed in healed bone at 1-year follow-up.

Survival rates were high for implants irrespective of whether they were placed according to the immediate/early or conventional protocol. In one RCT[30], four out of 26 immediate implants placed in the maxillary anterior or premolar regions had failed after 2 years corresponding to a survival rate

Table 3 Prospective clinical studies with control group(s) (CCT) reporting on mean interproximal bone level (BL) or bone level change (BLC) with a a minimum mean follow-up period of 12 months.

Author/year	Follow-up	Test group N of patients / implants Protocol SR, BL and/or BLC	Control group(s) N of patients / implants Protocol SR, BL and/or BLC	Implant site	Loading protocol	Implant system	Augmentation
Gotfredsen 2012[56]*	10 years	10/10 early (4 weeks after extraction) SR: 100% BLC: -0.64 mm All: During the 10-year interval, 1 patient lost more than 1.5 mm of marginal bone, three patients lost 1.0 to 1.4 mm, and 16 lost less than 1.0 mm NS difference in BLC between groups	10/10 delayed (more than 12 weeks after extraction) SR: 100%; BLC: -0.86 mm	Anterior and premolar maxilla in early Maxillary incisors in delayed	After 6 months	Astra Tech ST	Non-resorbable membranes
Gotfredsen 2004[57]*	5 years	10/10 early (4 weeks after extraction) SR: 100% BLC: -0.34 mm NS difference in BLC between groups	10/10 delayed (more than 12 weeks after extraction) SR: 100% BLC: -0.26 mm	Anterior and premolar maxilla in early Maxillary incisors in delayed	After 6 months	Astra Tech ST	Non-resorbable membranes
Berberi et al 2014b[58]	5 years	Overall 42 implants in 36 patients, 22 immediate implants SR: 91% BLC: -0.21 mm	20 implants in healed sockets SR: 100% BLC: -0.19 mm	Anterior and premolar maxilla	Immediate loading	Astra Tech / Dentsply	Autogenous bone graft in gaps
Cooper et al 2014[59]**	5 years	55/55 immediate SR: 95% BLC: 2.06 mm (gain), bone gain in nearly all cases BL: 0.43 mm NS difference in BL between groups	58/58 healed sites SR: 98% BLC: 0.1 mm (gain), gain or no marginal bone change in 59%, marginal bone loss greater than 0.5 mm in only 21.6% BL: 0.38 mm	Anterior and premolar maxilla	Immediate restoration (non-occlusal loading)	Dentsply (Astra Tech) OsseoSpeed	No augmentation
De Bruyn et al 2013[60]**	3 years	55/55 immediate SR: 95% BLC: 1.56 mm (gain) BL: 0.7 mm	58/58 healed sites SR: 98% BLC: -0.40 mm BL: 0.77 mm	Anterior and premolar maxilla	Immediate restoration (non-occlusal loading)	Astra Tech OsseoSpeed	No augmentation
Merli et al 2012[61]	3 years	Overall 60 patients in the two groups 29 immediate implants SR: 100% BL: 0.2 mm more coronally (better) in immediate group than in healed group NS difference between groups	40 implants in healed sites SR: 100%	Anterior and posterior maxilla and mandible	Immediate or early non-occlusal loading (randomized)	Element (Thommen Medical)	Anorganic bovine bone in gaps
Vandeweghe et al 2013[35]	26 months Range 8 to 44 months	Overall 38 patients in the two groups 23 immediate implants SR: 100% BLC: -0.88 mm SS difference between groups (P = 0.016)	20 delayed implants SR: 100% BLC: -1.28 mm	Anterior and posterior maxilla, mandibular molars	Immediate loading	Southern Implants	No augmentation
Tsirlis 2005[62]	24 months	Overall 38 patients in the two groups 28 immediate implants SR: 100% BLC: -0.75 mm	15 delayed (N = 4) or late (N = 11) SR: 100% BLC: -0.875 mm	Anterior maxilla	Immediate loading	3i NT Osseotite or Friatec Frialit-2	GBR (grafting and membranes)

Aguirre-Zorzano et al 2011[63]	93.3 weeks (test) 91.4 weeks (control)	Overall 56 patients in the two groups 56 immediate implants SR: 98.7% BLC -0.4 mm NS difference in bone loss between groups Both groups: < 1 mm bone loss at 67 implants (no bone loss at 36 and a small bone gain in some cases)	22 implants in healed sites SR: 100% BLC: -0.1 mm	Between the second premolars Maxilla/mandible	Immediate restoration	Astra Tech	GBR
Atieh et al 2013[42]	1 year	12/12 immediate SR: 66.7% BLC: 0.41 mm (gain) NS difference in BLC between groups	12/12 delayed (minimum 4 months post-extraction) SR: 83.3% BLC: 0.04 mm (gain)	Mandibular molars	Immediate restoration	MAX Southern Implants	NM
Cooper et al 2010[33]***	12 months	55/55 immediate SR: 94.5% BLC: 1.30 mm (gain) BL: 1.18 mm SS difference in BLC between groups ($P < 0.05$) NS difference in BL between groups	58/58 healed sites SR: 98.3% BLC: -0.40 BL: 0.81 mm	Between the second premolars maxilla	Immediate restoration	Astra Tech OsseoSpeed	No augmentation
Raes et al 2013a[64]***	1 year	16/16 immediate SR: 94% BLC: 1.05 mm (gain) BL: 0.85 mm	23/23 healed sites SR: 100% BLC: -0.18 mm BL: 0.65 mm 9/9 grafted sites (implants placed 4 to 5 months after grafting) SR: 100% BLC: 0.27 mm (gain) BL: 0.56 mm	Anterior and premolar maxilla	Immediate loading	Astra Tech OsseoSpeed	No augmentation
Grandi et al 2013[65]	12 months	25/25 immediate SR: 92% BLC: -0.71 mm NS difference in BLC between groups	25/25 delayed SR: 96% BLC: -0.60 mm	Anterior and premolar maxilla	Immediate restoration	JDEvolution Tapered implants	Anorganic bovine bone in gaps
Luongo et al 2014[66]	1 year	Overall 46 patients in the two groups 10 immediate implants SR: 100% BLC: -0.22 mm	47 implants healed sites SR: 97.9% BLC: -0.35 mm	Anterior and posterior maxilla and mandible	Immediate loading	MegaGen Implant AnyRidge	Biphasic calcium phosphate granules in gaps
Carini et al 2014[34]	12 months	Overall 10 patients in the two groups 7/7 immediate SR: 90% BLC: -0.12 mm SS difference in BLC between groups ($P = 0.016$)	8/8 Early (4 to 8 weeks after tooth extraction) SR: 100% BLC: -0.275 mm	Anterior and premolar maxilla and mandible	Immediate restoration (non-occlusal loading)	Phibo TSA Advance	Autologous and alloplastic bone in gaps, resorbable membranes
Kan et al 2007[36]	12 months	19/23 immediate SR: 100% BLC: 1.0 mm (gain) BL: 0.2 mm	12/15 healed sites SR: 100% BLC: -1.6 mm BL: -0.1 mm (coronal to ref-line)	Anterior and first premolar maxilla	Immediate restoration	Nobel Biocare NobelPerfect	Autogenous bone and xenograft

SR: survival rate; NM: not mentioned; NS: not statistically significant; SS: statistically significant.
For BLC a positive value means a gain and a negative value means a loss.
For BL a positive value means BL is positioned apically to the implant shoulder/platform, and vice versa.
* The two studies were reported from the same study population; **The two studies were reported from the same study population; ***The patients from the Raes et al study were apparently part of those from the multi-center study by Cooper et al.

Table 4 Prospective clinical studies without control group(s) (PCT), reporting on interproximal bone level (BL) or BL change (BLC) with a minimum mean follow-up period of 2 years.

Author/year	Number of implants	BL or BLC	Follow-up	SR
Barone et al 2014[67]	30	BLC: -1.0 mm / -0.9 mm (two groups)	2 years	100%
Berberi et al 2014a[68]	20	BLC: -0.27 mm	3 years	100%
Berberi et al 2014c[69]	40	BLC: statistically significant bone loss (no values reported)	5 years	100%
Bianchi and Sanfilippo 2004[39]	116	BL > 3.5 mm: 20% of implants for test (connective tissue graft) and 66% of implants for control	6 to 9 years	100%
Buser et al 2011[37]	20	BLC: -0.18 mm	3 years	100%
Calvo-Guirado et al 2014a[70]	71	BLC: -0.86 mm	3 years	100%
Calvo-Guirado et al 2014b[71]	86	BLC: -1.01 mm	10 years	97.1%
Calvo-Guirado et al 2011[72]	64	BLC: -0.97 mm	5 years	97.1%
Canullo et al 2010[73]	25	BLC: -0.55 mm / -0.34 mm (two groups)	3 years	100%
Canullo et al 2009[74]	22	BLC: -0.30 mm / -1.19 mm (two groups)	25 months	100%
Chen et al 2007[75]	26	BLC: -1.00 to -1.30 mm (three groups)	4 years	100%
Cosyn et al 2011[76]	30	BLC: -1.13 mm (mesially) /-0.86 mm (distally)	3 years	96.0%
Covani et al 2014[77]	47	BLC: -1.08 mm	5 years	95.7%
Covani et al 2012[78]	159	Maximum BL was 1.50 mm in 98% of implants	10 years	91.8%
Covani et al 2004[79]	163	BL at or coronal to the first implant thread in 91% of implants	4 years	97.0%
Crespi et al 2009[80]	64	BLC: -0.78 mm / -0.73 mm (two groups)	24 months	100%
Crespi et al 2010[81]	30	BLC: -0.82 mm / -0.86 mm (two groups)	24 months	100%
Crespi et al 2008[82]	40	BLC: -1.02 mm / -1.16 mm (two groups)	24 months	100%
Groisman et al 2003[83]	92	Maximum BLC was 2.0 mm for all implants	2 years	93.5%
Guarnieri et al 2015[84]	21	BLC: -0.83 mm BL: 0.94 mm	5 years	95.2%
Kahnberg 2009[85]	40	BLC: -0.13 mm mesially / -0.19 mm (distally)	2 years	100%
Kan et al 2011[86]	35	BLC: -0.72 mm (mesially), -0.63 mm (distally)	4 years	100%
Kolinski et al 2014[87]*	60	BLC: 0.30 mm (gain)	3 years	98.3%
Malchiodi et al 2013[88]	64	BLC < 1.00 mm loss in 95% of implants BL: 0.80 mm	3 years	100%
McAllister et al 2012[89]*	60	BLC: -0.10 mm	2 years	98.3%
Migliorati et al 2013[90]	47	BLC: -0.06 mm / -0.17 mm (two groups)	2 years	100%
Mijiritsky et al 2009[91]	24	BLC: -0.90 mm	40 months	95.8%
Prosper et al 2010[92]	120	BL: 1.31 mm / 1.01 mm (two groups)	5 years	96.7%
Prosper et al 2003[93]	111	BL: 0.70 to 0.80 mm / 0.73 to 0.80 (two groups)	4 years	97.3%
Shibly et al 2010[94]	60	BLC: 1.19 mm (gain) / 1.00 mm (gain) (two groups)	24 months	95.0%
Truninger et al 2011[38]	29	BL: 1.54 mm / 1.57 mm (mesially), 1.69 mm / 1.59 mm (distally) (two groups)	3 years	100%

SR: survival rate
For the BLC a positive value means a gain and a negative value means a loss.
For the BL a positive value means the BL is positioned apically to the implant shoulder/platform.
* same study population

of 85% and a CCT[42] demonstrated a survival rate of 67% for 12 immediate implants and 83% for 12 delayed implants replacing molars in the mandible after 1 year. All other studies (Tables 1 to 4) demonstrated survival rates higher than 90% for immediate/early implants and approximately 80% of the studies showed a survival rate of 95% or higher. In comparison, all studies with a control group (except the CCT by Atieh et al) showed survival rates of 95% or higher for delayed/late implants.

Discussion

The marginal bone level around an implant is one important criterion for the success of treatment. Loss of marginal bone following implant placement will not only possess a risk of implant failure, but also reduce the chance of achieving an optimal aesthetic outcome[36], which in turn may affect patient satisfaction.

The present systematic review focused on long-term observation of the peri-implant bone level after placing single-tooth implants immediately in fresh extraction sockets or early after removal of the tooth. After scrutinising the literature for studies reporting on the peri-implant bone level at least 1 year after implant placement, it was revealed that only few RCTs exist, comparing immediate or early implant placement with placement in healed bone (the conventional protocol). An additional 18 prospective studies assessing a test group (immediate or early) together with a control group (delayed or late placement) were found.

Based on those studies that have monitored the marginal bone level around implants from 1 to 10 years in periapical radiographs, it could be concluded that the bone level or changes in bone level over time at the interproximal aspects differed only slightly between the alternative and conventional timing protocols, and no statistically significant differences were found for the majority of the studies. The buccal bone level was assessed by CBCT in a few trials. In an RCT, the bone level at early placed implants was positioned 2.4 mm apically to the implant shoulder at 10 years[28], which did not differ significantly from the buccal bone level for delayed/late implants. In a PCT[43], the buccal bone level at immediate implants was 5.2 mm from the implant shoulder at the 7-year follow-up, and almost no buccal bone was detected in approximately one-third of the implants, while a bone loss of 3.25 mm for seven immediate implants, 28 months after implant placement, was revealed in a CCT[40].

Even though no substantial differences in bone level or survival rate were found among the implant placement protocols, it should be noted that out of the 22 studies that compared the interproximal bone level between test and control groups, the survival rate was higher for the delayed/late implants than for the immediate/early implants in 14 studies while the latter outmatched the control group in only one study. In this context, it must be emphasised that data for the marginal bone level should only be reported for implants surviving through the whole observation period, and even when this is the case, selection bias cannot be ruled out when comparing groups.

Several studies have shown that determination of the marginal peri-implant bone level in periapical radiographs is reliable[44-47]. Two studies found a significant linear correlation between histomorphometric and radiographic parameters[44,45]. However, to be able to trust bone level measurements it is imperative that the periapical radiographs are recorded with optimal and standardised projections so that bone levels of the same implant can be compared at different time points. For example, a marginal bone gain observed over time when comparing two radiographs may be due to remodelling, but could merely be a radiological phenomenon (different projection angles applied in the two radiographs). In studies evaluating bone levels radiographically, it is therefore important that the radiographic technique is well-described. In most of the papers included in this review, it was reported whether the periapical radiographs were obtained with the paralleling technique and/or standardised. It is, however, relevant to discuss how parallelism and standardisation are best achieved. For the clinician, it can be difficult to figure out the angulation of the implant in the buccolingual plane after its insertion. Thus, even though a film holder with an aiming device is used, in some cases the central beam of the radiograph will not aim perpendicular to the long axis of the implant. Fortunately, it is easy to detect if parallelism has been obtained by assessing the sharpness of the implant threads. If the threads are blurred at one or both sides of the implant, the Right blur-raise beam/Left blur-lower beam (RB-RB/LB-LB) rule[48] can be applied to correct non-parallelism. Obtaining sharp implant threads in all images is also a simple way to standardise the projection angle so that reliable comparisons among them can be made. This has the advantage that fabrication of a bite-block attached to the film holder can be avoided.

One major drawback of intraoral, periapical radiography is that this radiographic technique only

displays the bone level mesially and distally to the implant. To radiographically detect the bone level at the buccal and oral aspects of the implant, it is necessary to apply a technique which can produce cross-sectional sections of the jaw. For that purpose, CBCT is a valuable tool. Corpas et al[44] found statistically significant correlations in the depth of bone defects adjacent to implants between CBCT and histological sections ($r = 0.61$, $P < 0.01$). However, CBCT images yielded a bone defect depth underestimation of 1.2 mm on average, compared with the histological data. In a comparison of CBCT and periapical images in measurements of the interproximal bone levels, no significant differences between the modalities were observed in one study[28], whereas Raes et al[41] found a low accuracy of CBCT ($r = 0.325$, $P = 0.019$) when assessing the bone level at implants placed in extraction sockets or in healed bone (BL was 0.70 mm in periapical images vs 0.23 mm in CBCT).

CBCT seems to be helpful in the evaluation of the peri-implant bone in the bucco-oral plane, however, it must be emphasized that besides higher radiation doses and higher expenses[49,50], this modality is also associated with challenges regarding image quality. The presence of metal objects or other materials with a high atomic number in the region of interest will inevitably cause beam-hardening artefacts in a CBCT image[51], and in turn may affect the image quality. Likewise, motion artefacts in CBCT are a well-known phenomenon because this image modality is associated with a longer exposure time compared with for example fan beam CT scanning[52]. Artefacts often appear as black and white stripes and have previously been shown to impair the visibility of the peri-implant bone and preclude accurate assessment of the bone level[44,53]. Due to the inherent disadvantages of current CBCT equipment, the authors suggest that this modality should not be used as a standard when monitoring the hard tissues around an oral implant.

When the marginal bone around implants is evaluated in longitudinal studies, data on bone level changes (loss or gain) during the observation period are usually reported. In contrast, relatively few papers report on the absolute bone levels at different follow-up visits. It seems relevant to know the marginal bone level expressed as the distance between a well-defined reference point (e.g. the implant shoulder/platform) and the first visible BIC, since this variable is more informative regarding implant prognosis than bone level changes. For example, bone gain at one implant placed in a fresh extraction socket (with BIC positioned apically to the implant shoulder at baseline), and bone loss at another implant placed in healed bone (with BIC positioned at or coronally to the implant shoulder at baseline) may result in a BIC positioned at the same level at the end of the follow-up period for both cases. It was also noted that publications most often only report mean (or median) values for the BL or BLC. It would be useful if, additionally, the implant cases were divided into subgroups, with respect to BL or BLC and frequencies calculated since specification merely of the average BL/BLC might conceal serious problems for some of the implants.

The choice of surgical and prosthetic protocols in relation to implant treatment and the immediate/early implant placement approach, specifically, may affect implant survival and the peri-implant marginal bone level. Information about implant system, supplementary tissue augmentation procedures as well as loading protocol was stated in Tables 1 to 3 for the RCTs, CCTs and studies reporting on the buccal bone level, which illustrated a high heterogeneity among the studies in this respect.

Unfortunately, no consensus has been reached in the classification or terminology in relation to timing protocols in implant treatment. For example, immediate implant placement has been called 'immediate' or 'post-extraction implants' or 'placement in fresh extraction sockets'. Early placement has also been called 'early implants' or 'immediate-delayed' or 'delayed-immediate placement', and further deferred placement after tooth extraction has been termed 'delayed' or 'late' (with varying definitions) or 'placement in healed bone'. To facilitate reading and comparison of outcomes from different studies, it would be practical if researchers use the same terms when defining the time between tooth extraction and implant placement. Thus, development of a simple classification system based on clear and exhaustive (all time points for implant placement are covered) definitions would be appreciated. Hämmerle et al[54] proposed a classification based on soft and hard tissue healing parameters: Type 1- implant placement immediately following tooth extraction and as part

of the same surgical procedure, Type 2- complete soft tissue coverage (typically 4 to 8 weeks), Type 3 - substantial clinical and /or radiographic bone fill of the socket (typically 12 to 16 weeks), Type 4 - healed site (typically > 16 weeks). This classification is in our opinion sensible and useful since it considers variations in the subjects' healing capacity.

Due to the limited number of existing RCTs on the topic of this review, it was decided to include prospective studies with (CCTs) or without a control group (PCTs), in order to base our conclusions on more study populations. However, one must recognise that most prospective studies have set several exclusion criteria (e.g. lack of or thin facial bone wall, post-extraction infection, need of GBR procedures, large peri-implant infrabony defects) when enrolling patients for post-extraction or early implants. Therefore, data from non-randomised studies should be interpreted critically with attention to the clinical setup. This fact also indicates that not all clinical cases are suitable for the immediate placement approach, and it is advocated a careful patient selection in the treatment planning phase should be followed. Since a significant number of prospective studies (RCTs, CCTs and PCTs) were available from the search, it was decided to exclude data extraction from retrospective studies that are considered to have a lower level of evidence.

Conclusion

This systematic review of the current literature indicates that immediate or early placement of single-tooth implants after tooth extraction may be a viable treatment with long-term survival rates and marginal bone level conditions, matching those for implants placed conventionally in healed bone ridges. However, interpretation of the results must be made with caution as only few RCTs and prospective, controlled clinical studies with a follow-up of 5 years or more are available. The authors advocate that careful patient selection for post-extraction implant placement is made and that a strict treatment protocol for the surgical and prosthetic procedures is followed. Furthermore, publications on this topic should report mean values, as well as frequencies and ranges for the absolute marginal bone levels, in addition to only bone level changes over time. Data on marginal bone level should only be provided for surviving implants, and survival rates should always be reported. Even then, if more implants are lost in one of the groups, there will be a risk of selection bias in follow-up studies.

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Bone augmentation for single tooth implants: A review of the literature

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Key words *bone augmentation, bone graft, review, single implants*

Aim: To analyse data on bone augmentation at single-tooth implants with regard to the type of graft materials, the stability of grafts over time, reported time span towards implant placement, implant survival rates, implant marginal bone maintenance and possible complications.

Material and methods: A literature review resulted in 585 titles after exclusion of duplicates. Analyses of article titles and abstracts reduced the number to 93 studies, which were subsequently full-text analysed. After the final selection, a total of 24 studies were included, of which 13 reported on single implants and horizontal/vertical augmentation (onlay), 10 focused on single implants and sinus augmentation (inlay), and one study presented the outcome of single implants and distraction osteogenesis.

Results: All bone materials, i.e. autografts, allografts, xenografts, and alloplasts, were used with comparable satisfactory results, allowing for placement of 7 to 10 mm-long implants. Stability of bone graft volume over time was sparsely documented. Some onlay autografts tended to resorb early i.e. prior to implant placement, but minor bone resorption was also seen for other grafts over time. A continuous but small bone resorption of inlay autografts and alloplasts was seen over time for the few sites recorded. A staged approach predominated for the onlay grafts, with implants placed 3 to 6 months post-grafting, and overall a majority of these implants (347/363) were submerged. For the inlay graft procedures almost all implants were immediately inserted at the time of grafting, and the majority of these implants (253/256) were submerged. A total of five and two implant failures were registered during the various study periods for the onlays and inlays, respectively. Marginal bone conditions, around implants in grafted sites, were comparable to what has generally been reported for non-grafted sites.

Conclusions: Bone augmentation for the single-tooth implant is a viable treatment option with predictable graft and implant outcomes.

■ Introduction

Single or multiple teeth are missing mainly due to aplasia, traumatic injuries or as a result of extractions of decayed or periodontally compromised teeth.

The cause of aplasia of teeth is not fully understood, albeit genetic and/or environmental disturbances during tooth development have been suggested. Individual teeth may also fail to develop as a result of irradiation and chemotherapy due to treatment of malignant diseases in early childhood, low birth weight, disorders such as ectodermal dysplasia, Down's syndrome, cleft lip and palate, etc. Prevalence of missing permanent single teeth accounts

for 2.8% to 8.0%, varying according to ethnic background and population (third molar excluded)[1]. Most affected teeth are the lower second bicuspids, followed by upper lateral incisors, upper second bicuspids and lower incisors. In general, females and males show similar incidence figures, although a small but not significant predominance of hypodontia is frequently reported for females[1]. Lack of tooth formation will have an impact on the development of the alveolar bone process, implying risk of compromised bone volumes in vertical, horizontal and transversal dimensions.

Another cause of missing teeth is seen amongst patients subjected to traumatic injuries to the permanent dentition. This is frequently a result of daily mishaps, sports activities and various accidents. Approximately 15% to 20% of the adolescents in Latin American and Caribbean countries have shown some type of trauma to permanent teeth[2]. A review article reported a worldwide prevalence of 25% of traumatic injuries to permanent dentition in school children[3]. In more severe trauma cases, teeth are lost immediately. Over time, repositioned avulsed teeth frequently develop root resorptive processes, accompanied by ankylosis and tooth infraposition. Such teeth are not easily removed and may require bone surgery, which subsequently leave huge bony defects behind.

Dental caries and periodontitis are the main causes of tooth extractions. In the United States, dental caries is the most common chronic childhood disease. During the period 1999 to 2004 it was estimated that the prevalence of treated/untreated caries in permanent teeth was close to 60% in the age group 12 to 19 years old (including all races and ethnicities), in the US[4]. Periodontitis is regarded as the second most common chronic disease after decayed teeth and 5% to 20% of any population suffers from severe periodontitis, while mild to moderate periodontitis affects most adults[5]. This periodontal disease is a more common cause of tooth loss in older age groups. Depending on the remaining amount of alveolar bone to support such teeth and how the extraction procedure was handled, one may face various persistent alveolar bone volumes either immediately post-extraction or after a period of healing.

Rehabilitation of a missing single tooth is frequently achieved with an osseointegrated implant and numerous studies have reported stable conditions of single tooth implants. Based on a meta-analysis, survival of implants supporting single crowns after 5 years of function amounted to 97.2% and at 10 years the corresponding figure was 95.2%[6]. One study reported on 47 single-tooth implants followed for 18 years of function and showed a survival rate of 96.8%[7]. Lack of sufficient jaw bone dimensions to harbour a single implant may call for alternative treatment such as orthodontics to fill the gap by lining up crowded teeth, or conventional fixed tooth-supported prosthetics when adjacent teeth have already been comprehensively restored. However, bone augmentation with buccal/crestal onlays[8] or sinus inlays[9] are valid, and increasingly used techniques in daily practice. A range of methods have been described using autogenous bone or various bone substitutes, applying membranes of various kinds, placing the implant with an immediate, early, or delayed loading protocol, approaching the sinus from the crest or via a lateral window, etc.

The aim of the present review was to evaluate evidence in the literature for differences in outcome in terms of:

- horizontal and vertical bone volume gain and stability of augmented bone over time using autografts, allografts, xenografts or alloplasts in the single-tooth situation;
- single implant survival using immediate or delayed insertion in combination with bone grafts;
- marginal bone resorption around single implants placed in relation to bone grafts.

Materials and methods

Search strategy

The current overview is based on publications identified by the Medline (Pub Med) and Scopus (including Embase) electronic databases and supplemented with a systematic search in the Cochrane Central Register of Controlled Trials (CENTRAL). Papers should have been written in the English language, published over the past 20 years, with the last search performed on 29 April 2015.

The following search terms were used: "single-tooth implant"; "dental/oral implants"; "RCT (randomised controlled trial) "; "bone augmentation"; "bone graft"; "bone transplantation"; "sinus lift"; "jaw bone defects"; "autogenous bone"; "allografts"; "xenografts"; "bone substitute material"; and "distraction osteogenesis". Terms were used in various combinations, utilising Boolean searching by combining keywords with operators AND and OR.

Inclusion criteria

Publications using a prospective or a retrospective study design and even a case series on human subjects were included for analyses. Furthermore, a hand search was performed of selected journals, and reference lists of related meta-analyses and reviews were screened. Selection was based on:

- only studies published in peer-reviewed journals;
- handling immediate extraction sites or healed sites;
- staged or immediate augmentation, i.e. augmentation prior to or at single implant placement;
- studies on bone augmentation, not bone preservation;
- type of used augmentation material is clearly stated;
- time at single implant placement, i.e. immediate, early or delayed insertion is clearly stated;
- studies with a minimum of 10 patients reporting on single-tooth bone augmentation with or without implant placement;
- minimum follow-up time of 3 months for studies reporting on bone augmentation in the single-tooth situation, only evaluating bone parameters;
- minimum follow-up time of 1 year for studies reporting on bone augmentation with implant placement in the single-tooth situation, evaluating both bone and implant parameters.

Study selection and data extraction

The somewhat wide search resulted in 585 titles after exclusion of duplicates. Analyses of article titles and abstracts reduced the number to 93 studies, which were subsequently full-text analysed. A final selection was made based on how the sections "Material and methods" and "Results" of each article met the listed inclusion criteria.

Results

Main characteristics of selected studies

The current material was characterised by great diversity in techniques used, materials, measurements/data collection, follow-up time and thus not suitable for meta-analysis. After the final full-text examinations, a total of 24 studies were included, of which 13[10-22] reported on single implants and mainly horizontal/vertical (onlay) augmentation (Table 1), 10[23-32] focused on single implants and sinus (inlay) augmentation (Table 2) and one study presented the outcome of single implants and distraction osteogenesis[33].

Five[10,12,14,15,20] out of the 13 onlay studies, comprising 145 sites/implants, handled fresh extraction sites and mainly described how bone was gained in post-extraction vertical defects. The remaining eight studies presented various augmentation techniques of 222 healed sites (Table 1).

Seven onlay studies[13,15,17,19,20-22], comprising 235 sites/implants, used autografts as augmentation material. Two of these reports used autografts solely[21,22]; in one report a resorbable membrane was added to the autograft[13]; in one study the outcome of five patient groups (two different membranes, autograft and membrane, autograft solely and no material at all) were compared[20]; two reports compared autografts and xenografts[17,19]; while in one study the investigator added a synthetic bone substitute to the autograft[15]. Another four studies[11,12,16,18], comprising 79 sites/implants, used allografts as augmentation material, of which two reports added cortical allografts on top of cancellous allografts (sandwich technique)[11,18], and one added xenograft to the allograft[12]. Regarding the two remaining studies[10,14], comprising 53 sites/implants, only xenogenic bone was used as augmentation material. Ten out of the 13 studies used either resorbable or non-resorbable membranes of different brands. In 6 out of 7 studies, of which various materials/techniques were compared, the different

Table 1 Characteristics and main outcomes of onlay graft studies: Gr = Group, mo = months, Prosp = prospective, Retrosp = retrospective, Extr = extraction, bucc = buccal, Pal = palatal, mes = mesial, dist = distal, impl = implant, pat = patient, measurem = measurement.

Study	Design	No. of sites	Follow-up	Region	Technique	Graft material	Defect	Mean bone gain/volume	Implant survival	Marginal bone loss	Complications
Jung et al; 2015[10]	Prosp RCT	18 Gr.1	60 mo	Post mand/ max	Extraction, immediate implants and bone augment	Xenograft particles + porcine resorbable membrane	6.5 mm (defect height)	4.3 mm	100% of 17 followed	No data	None reported
	Prosp RCT	19 Gr.2	60 mo	Post mand/ max	Extraction, immediate implants and bone augment	Xenograft particles Synthetic resorbable membrane	7.7 mm (defect height)	4.8 mm	100% of 15 followed	No data	None reported
Fu et al; 2014[11]	Prosp RCT	13 Gr.1	6 mo	15-25	Healed site; immediate implants	Cancellous allograft + cortical allograft	7.77 mm (defect height)	1.92 mm (defect height)	100%	1.62/1.51 mm mesial/distal	3 patients with wound exposure
	Prosp RCT	13 Gr.2	6 mo	15-25	Healed site; immediate implants	Cancellous allograft + cortical allograft resorbable membrane	7.62 mm (defect height)	0.92 mm (defect height)	100%	0.89/1.44 mm mesial/distal	3 patients with wound exposure
Block et al; 2014[12]	Retrosp	14	3-6 mo	Ant maxilla	Extr; bone augmentation; implants after 4-6 months	Allograft + sintered xenograft	Initial bucc/pal dimension5.4 mm	8.6 mm after 3-6 months	100% (11 impl placed)	No data	None reported
Pieri et al; 2013[13]	Prosp	29	6 mo	Ant maxilla	Healed site, bone augment, implants after 6 months	Autograft + resorbable membrane	Horisontal defect ≥3 mm, vertical defect ≤3 mm	Horisontal gain 4.23 mm, vertical gain 1.71 mm	100%	0.61 mm at 5 years	3 pat with exposed grafts, one needed re-grafting
Schneider et al; 2011[14]	Prosp	16	6 mo	12-22	Extr in 13 pat; 6-8 w healing; implants + bone graft; 6 months healing	Xenograft particles + non-resorbable membrane	Bucc. bone defect, no data on defect size	0.72 mm	100% of 15 followed	No data	None reported
Hassan et al; 2009[15]	Prosp	8 Gr.1	9 mo	15-25	Extr, buccal dehiscence, impl, bucc augm	Autograft + non-resorb membrane	12.0 mm defect height	5.0 mm defect height	100%	No data	None reported
	Prosp	8 Gr.2	9 mo	15-25	Extr, buccal dehiscence, implants, buccal augmentation	Autograft + synthetic bone gel/ powder + non-resorb membrane	12.1 mm defect height	5.3 mm defect height	100%	No data	One membrane exposed
Nissan et al; 2009[16]	Retrosp	12	4-6 mo;	Incisors maxilla	Healed sites bone augment impantsl after 4-6 months	Allograft + resorbable membrane	3 mm bucco/pal dimension	5 mm mean bone gain	100%	Bone loss to first implant thread	None reported
Meijndert et al; 2008[17]	Prosp RCT	31 Gr.1	12 mo	15-25	Healed sites, bone augmentation, implants after 3 months	Autograft	Class 4 (Misch and Judy 1987)	No data; allowed impl. ≥ 12 mm	100%	0.1–0.2 mm	None reported
	Prosp RCT	31 Gr.2	12 mo	15-25	Healed sites, bone augmentation, implants after 3 months	Autograft + resorbable membrane	Class 4 (Misch and Judy 1987)	No data; allowed impl. ≥ 12 mm	100%	0.1–0.2 mm	None reported
	Prosp RCT	31 Gr.3	12 mo	15-25	Healed sites, bone augmentation, implants after 6 months	Xenograft + resorbable membrane	Class 4 (Misch and Judy 1987)	No data; allowed impl. ≥ 12 mm	93.5%	0.1–0.2 mm	2 implant failures

Park et al; 2008[18]	Prosp. RCT	9 Gr.1	6 mo	Maxilla and mandible	Healed sites, bone augmentation, implants after 6 months	Cancellous allograft + cortical allograft + Acellular dermal matrix	18.93 mm^2 (defect area)	2.96 mm^2 (defect area)	100%	No data	2 exposures
		9 Gr.2	6 mo	Maxilla and mandible	Healed sites, bone augmentation, implants after 6 months	Cancellous allograft + cortical allograft + bovine resorbable membrane	18.30 mm^2 (defect area)	3.25 mm^2 (defect area)	100%	No data	5 exposures
		9 Gr.3	6 mo	Maxilla and mandible	Healed sites, bone augmentation, implants after 6 months	Cancellous allograft + cortical allograft	13.82 mm^2 (defect area)	4.51 mm^2 (defect area)	100% (8 pat followed)	No data	2 exposures
Meijndert et al; 2005[19]	Prosp RCT	5 Gr.1	3 mo	Anterior maxilla	Healed sites, bone augmentation, implants after 3 months	Autograft	No data	2-4 mm	100%	No data	None reported
	Prosp RCT	5 Gr.2	3 mo	Anterior maxilla	Healed sites, bone augment, implants after 3 months	Autograft + resorbable membrane	No data	2-5 mm	100%	No data	None reported
	Prosp RCT	5 Gr.3	6 mo	Anterior maxilla	Healed sites, bone augment, impl after 6 mo	Xenograft + resorbable membrane	No data	2-3 mm	100%	No data	None reported
Chen et al; 2005[20]	Prosp RCT	12 Gr.1	6 mo	15-25	Extractions, immediate implants	Non-resorbable membrane	8.4 mm (vertical defect height)	74.9% reduction	100%	No data	None reported
	Prosp RCT	11 Gr.2	6 mo	15-25	Extractions, immediate implants	Resorbable membrane	7.5 mm (vertical defect height)	69.1% reduction	100%	No data	2 exposed cover screws
	Prosp RCT	13 Gr.3	6 mo	15-25	Extractions, immediate implants, bone augmentation	Autograft + resorbable membrane	9.1 mm (vertical defect height)	83.1% reduction	100%	No data	Infection, recovered with antibiotics; one exposed cover screw
	Prosp RCT	14 Gr.4	6 mo	15-25	Extraction, immediate implants, bone augmentation	Autograft	9.9 mm (vertical defect height)	75.3% reduction	85.7%	No data	Infections, 2 implant losses; one exposed cover screw
	Prosp RCT	12 Gr.5	6 mo	15-25	Extraction, immediate implants	No material	9.7 mm (vertical defect height)	73.6% reduction	100%	No data	None reported
Jemt et al; 2003[21]	Prosp	10	12 mo	11,21	9 healed sites, one root remnant extracted, bone augmentation, implants after 6 months	Autograft	Baseline set to 0, 4 levels of measurem.	2,64–8.51 mm^2 immediate gain; 1.40–3.93 mm^2 gain at 12 mo	100%	Mean 0.3 mm	>50% graft resorption after 12 mo
Widmark et al; 1997[22]	Retrosp	10	10 mo	11,21; one pat with 2 implants	Healed sites, bone augmentation, implants after 4 months	Autograft	Baseline mean 4.8 mm; 4 levels of measurem.	4.3 mm immediate gain; 1.7 mm gain at 10 mo	90%	No data	60% graft resorption after 10 mo; one implant failed

Table 2 Characteristics and main outcomes of inlay graft studies; * Not Applicable; ^ Bone level registered (not bone resorption); postop = postoperative, pat = patient, Gr = Group, mo = months, submerg = submerged, allogr = allograft, Premol = premolar, augment = augmentation.

Study	Design	No. of sites	Follow-up	Region	Technique	Graft material	Implant placement	Residual bone height	Postop mean bone height/ bone gain	Implant survival	Marginal bone loss	Complications
Gulie et al; 2014[23]	RCT	20	12 mo	Premol/ molar maxilla	Lateral approach	Autograft Xenograft no membrane	Immediate submerged; loading after 3 mo	6-8 mm	No data, allowed 11 mm implants	100% 19 sites evaluated 1 pat died	0.1 mm	None reported
	RCT	21	12 mo	Premol/ molar max	6 mm implants, no grafting procedure	NA*	Submerged; loading after 3 mo	6-8 mm	NA*	100%	0.1 mm	None reported
Jodia et al; 2014[24]	Retrosp	11	30 mo	Premol/ molar	Lateral approach	Synthetic bone graft resorbable membrane	Immediate submerged; loading after 6 mo	5.8 mm	9.6 mm (mean bone height at 30 mo)	100%	0.68–1.22 mm	Membrane perforations in 2 patients
Fermergård et al; 2012[25]	Retrosp	11; subsample of 53 implants	36 mo	Mainly premolar	Crestal approach, osteotome	No augmentation material	Immediate submerged; loading after 3-4 mo	6.3 mm	4.4 mm (mean bone gain of total material; 53 implants)	100%	0.5 mm	None reported
Sisti et al; 201226	Prosp	14	24 mo	Molar?	Crestal approach	Synthetic bone graft No membrane	Immediate submerged; loading after 4 mo	4.1 mm	8.6 mm (mean bone gain at 24 mo)	100%	No data	None reported
Irinakis; 2011[27]	Retrosp	27 Gr.1	12 mo	Premol/ molar	Lateral approach	Particulate allogr bone resorbable membrane	Immediate submerged; loading after 6 mo	5.1 mm	No data, allowed ≥10 mm implants	100%	< 1.5 mm	None reported
		22 Gr.2	12 mo	Premol/ molar	Lateral approach	Paste allogr bone resorbable membrane	Immediate submerged; loading after 6 mo	4.7 mm	No data, allowed ≥10 mm implants	100%	< 1.5 mm	None reported
Kahnberg et al; 2011[28]	Retrosp	20	24 mo	Premol/ molar	Lateral approach	Autograft No membrane	Immediate submerged; loading after 6 mo	5.8 mm	10.6 mm (mean bone height at 24 mo)	100%	0.83 mm ^	None reported
Hu et al; 2009[29]	Retrosp	28	16 mo	Premol/ molar	Crestal approach; osteotome and water balloon	Xenograft Platelet -rich fibrin No membrane	Immediate submerged 23; non-submerged 3; loading after 6 mo	4.9 mm	10.9 mm (mean bone height at 6 mo)	1 implant failure	No data	Membrane perforations in 2 patients; not treated and excluded
Krenn-mair et al; 2007[30]	Retrosp	28 Gr.1	>24 mo	Premol/ molar	Lateral approach; 1-stage	Autograft xenograft resorbable membrane	Immediate submerged; loading after 6 mo	7.8 mm	No data, allowed 15-16 mm implants	100%	2.2 mm	Membrane perforations in 58% of patients
		12 Gr.2	>24 mo	Premol/ molar	Lateral approach; 2-stage	Autograft xenograft resorbable membrane	Immediate submerged; loading after 9 mo	3.5 mm	No data, allowed 15-16 mm implants	100%	2.1 mm	Membrane perforations in 58% of patients
		14 Gr.3	>24 mo	Premol/ molar	Crestal approach; osteotome	Xenograft no membrane	Immediate submerged; loading after 6 mo	9.6 mm	No data, allowed 13 mm implants	100%	2.3 mm	Membrane perforation in 21% of patients
Stricker et al; 2003[31]	Retrosp	41; subsample of 183 implants	12 mo	Premol/ molar	Lateral approach	Autograft no membrane	Immediate submerg 48 staged 135; loading after 4.1 mo	≤5 mm	No data, allowed 10-14 mm implants	99.5% of total study material	0.26 mm	Membrane perforation in 37.8% of total study material
Mazor et al; 1999[32]	Prosp	10	36 mo	Premol/ molar	Lateral approach	Autograft allograft resorbable membrane	Immediate submerged; loading after 9 mo	5.4 mm	No data, allowed 13-15 mm implants	100%	0 mm	Membrane perforation 40%

patient groups were randomly selected. Five studies[12,15,20-22] presented some data on graft resorption over time (Table 1).

Seven[23,24,27-32] out of the 10 sinus graft studies, comprising 191 sites/implants, described a lateral window approach. However, one subgroup in the Krennmair et al[30] study, comprising 14 sites/implants were treated with a crestal approach. The remaining five studies presented various augmentation techniques at 53 sites with a crestal approach (Table 2).

Five sinus graft studies[23,28,30-32], comprising 131 sites/implants, used autografts as augmentation materials. Two of these reports used autografts solely[28,31]; in one report the investigators compared the outcome of autograft/xenograft augmented sinus, receiving 11 mm-long implants, with the non-augmented sinus, receiving 6 mm-long implants[23]. Furthermore, one report used a combination of autograft and xenograft, albeit one subgroup of 14 sites/implants received xenografts only[30], while another report used a combination of autograft and demineralized freeze-dried bone allograft[32]. Another two studies used synthetic bone (25 sites/implants)[24,26], one study used allograft only (49 sites/implants)[27], one study used xenograft only (28 sites/implants)[29] and one study refrained from inlay materials and instead used an osteotome technique (11 sites/implants)[25]. Four out of the 10 studies used membranes, all resorbable, and consisting of different brands. In one[23] out of three studies, of which various materials/techniques were compared, the different patient groups were randomly selected. Three studies[24,26,28] presented some data on graft resorption over time (Table 2).

As an alternative to bone grafting procedures, vertical alveolar ridge distraction attempts to augment deficient bone regions by producing new bone. A callus is formed as a result of an osteotomy and bone parts are separated from each other by applying mechanical forces. After the distraction phase the bone gap is allowed to consolidate during remodelling and mineralisation. No study fulfilled the inclusion criteria completely, but one report with single-tooth loss and distraction treatment in nine sites/implants was subsequently included[33].

Horizontal/vertical augmentation (onlay)

All 13 studies on onlay grafting (Table 1) showed bone gain over time to such an extent, that implants of good lengths could be placed in favourable positions. However, the presentation of bone augmentation outcomes showed such a great disparity that a general conclusion could not be drawn. Follow-up periods of bone grafts ranged between 3 to 60 months, with the majority of studies presenting data at 6 months. The anterior maxilla predominated amongst the anatomical areas treated.

Six studies described horizontal (bucco/palatal) bone gain in mm[12-14,16,19,22], ranging from 0.72 mm[14] to 5.00 mm[19], although not always including baseline data. Another study[21] measured horizontal (bucco/palatal) bone gain in mm^2. Two studies described vertical bone gain in mm[10,13], ranging from 1.71 mm to 4.80 mm, whereas four other studies presented vertical defect height reductions in mm[11,15], in percentage[20] and in mm^2 [18]. Furthermore, one study[17] used the classification of partially edentulous arches (class[4]) as a baseline[34], stating that the subsequent outcome allowed placement of implants ≥ 12 mm.

Three studies reported major bone resorption of autografts (23% to 64%) during the first year[20-22], while one study using allograft with xenograft[12] and another study using autograft with synthetic bone graft[15] only showed minor resorption over the first 6 to 9 months. One study reported a small but statistically significant difference of augmented volume in favour of autograft and synthetic bone graft, compared to autograft only[15]. Otherwise, the various bone materials did not reveal any statistically significant differences when compared. Thus similar results were accomplished for autografts, allografts, xenografts and synthetic bone substitutes. However, three out of five studies testing bone augmentation with or without membranes, showed a significant improvement in horizontal bone gain/bone preservation when membranes were added[11,18,20]. One study reported less labial plate resorption with non-resorbable membranes, compared with resorbable ones[20], which was statistically significant.

A total of 363 implants were placed in 367 bone augmented sites. In one study, augmentation was

performed in 14 sites, but implants were not inserted in three of those because of financial/personal issues[12]. One subgroup in the Park et al study received only eight implants in 9 augmented sites because of an unexpected health issue of one patient[18]. A total of 281 rough surface implants were used in 10 studies, representing at least seven different implant brand names, with a huge variation in macro design and micro-structure. Three studies, comprising 82 sites, used similar turned surface implants[20-22]. In eight studies, including 206 implants, a staged-approach was used, i.e. implants were placed 3 to 6 months after the bone augmentation procedure. Only one study, with 16 implants, reported on immediate loading, albeit claiming a non-functional load[16]. All other 347 implants were first loaded after 4 to 7 months. In the various follow-up periods, 7 implants were withdrawn in three studies[10,14,18]. Ten studies showed an implant survival rate of 100% during the study periods, whereas three studies reported a total loss of five implants out of a total of 165 implants (delayed loading)[17,20,22]. Three of the five failed implants had a turned surface[20,22]. Data on marginal bone maintenance was sparse and only five studies reported values[11,13,16,17,21], being in the range of 0.10 to 1.62 mm for the various follow-up periods.

The main complications, apart from the five implant losses, were exposed membranes, exposed grafts or exposed cover screws, which occurred at 20 sites. One site was in need of a re-grafting procedure[13].

Sinus augmentation (inlay)

All 10 studies on sinus grafting (Table 2) showed bone gain over time, which allowed implants of 10 to 16 mm lengths to be placed. Follow-up periods of bone grafts ranged between 12 to 36 months, with a mean of 22 months. The procedure was more frequently performed in the molar, compared to the premolar region. Residual (preoperative) bone height was presented in all 10 studies and ranged from 3.5 to 9.6 mm. However, only five studies reported the resulting bone height/bone gain after the sinus procedure (bone gain range was 3.8 to 8.6 mm)[24-26,28,29], whereas the remaining five studies stated that the subsequent outcome allowed placement of implants 10 to 17 mm long.

Three studies reported minor bone resorption in the vertical dimension (0.6 to 1.4 mm) of sinus autografts during 2 years of follow-up[24,26,28]. One study compared maxillae with augmented sinuses accommodating 11 mm-long implants and maxillae with non-augmented sinuses accommodating 6 mm-long implants. Both patient groups were equally successful at the 1-year follow-up[23]. Also for the sinus graft studies, the use of autografts, allografts, xenografts or bone substitutes resulted in similarly excellent outcomes. Two studies compared either different allografts[27] or autografts and xenografts[30]. No statistically significant differences were found, which also held true for the various tested membranes. The lateral and crestal sinus approaches showed similar bone gain and implant survival.

A total of 256 implants were placed in 258 sinus augmented sites. In the report by Hu et al[29], augmentation was performed in 28 sites, but implants were not inserted in two of these because of Schneiderian membrane perforations. The interpretation of the current analysis was that no turned surface implants were used. A huge variation in implant design and micro-structure was seen among the medium rough to rough surface implants used. In two studies some grafting procedures were staged[30,31]. Otherwise implants were inserted at the time of grafting and all but three implants[29] were placed submerged. Time before loading (re-entry) ranged from 3 to 9 months. Two studies reported one implant failure each[29,31], but in the Stricker et al study[31], it is not clear if the failed implant belonged to the single-implant group. Thus, eight studies showed an implant survival rate of 100% during the follow-up periods. Data on mean marginal bone maintenance was reported in eight studies, being in the range of 0 to 2.3 mm for the various follow-up periods, whereas in two studies no data was presented[26,29].

The main complication, apart from the two implant losses, was perforation of the Schneiderian membranes, which was reported in 5 studies[24,29-32] and ranged from 7% to 58% of performed sinus surgeries.

Vertical alveolar ridge distraction

A subsample of nine out of 35 patients, were treated with vertical alveolar ridge distraction in the single tooth situation, comprising seven central and two lateral maxillary incisors[33]. The mean residual vertical bone height ranged between 3 to 5 mm and the mesiodistal space ranged between 8 to 12 mm. The used distraction system incorporated a distraction implant, which was not removed and thus remained in the augmented bone for subsequent prosthetic treatment. After the osteotomy, bone was allowed to heal for 7 to 10 days, followed by the distraction phase of 8 to 24 days. The daily distraction rate was 0.25 to 0.50 mm and resulted in an increase of 3 to 6 mm of alveolar ridge height. All implants were allowed to heal for 4 to 6 months prior to prosthetic treatment and then followed for another 9 months. The total study period after distraction was thus 13 to 15 months. One implant failed because stability of the distracted bone segment was lost, giving a single-implant survival rate of 88.9%.

Discussion

Horizontal/vertical augmentation (onlay)

A Cochrane Database of Systematic Reviews established that various techniques could augment bone horizontally and vertically, without being able to state whether any technique was more superior than another. Furthermore, some bone substitutes (xenografts and alloplasts) were said to be preferable alternatives to autogenous bone[8]. This is in accordance with the current review in which all reported techniques and materials proved to function correctly. The Cochrane Database of Systematic Reviews[8] raised questions about whether augmentation procedures at immediate single implants placed in fresh extraction sockets were needed. Several reports have focused on outcomes of implant placement in intact alveoli and with bone fill mainly in the buccal gap between the implant and the bone wall[35-40]. It must be justified to differentiate such procedures from bone augmentation interventions, since the former targets bone preservation mainly. They were consequently not considered in the present review.

The overall majority of analysed reports on onlay procedures presented various measurement data on horizontal or vertical bone gain outside the bone envelope. Irrespective of measurement technique, all studies showed bone volume improvements to such an extent, that placement of implants of good lengths in favourable positions could be accomplished. However, prior to implant placement, extensive bone resorption of autografts was recorded in three reports[20-22]. The fact that autografts and cancellous allografts are prone to resorption have resulted in efforts to overcome this problem, and three studies[11,12,18] used the so-called sandwich grafting technique. In two of them, a more resorption-resistant material (cortical allograft) was added to the cancellous inner allograft[11,18], while the third report added a xenograft to the allograft[12]. Protective membranes were used in 10 out of the 13 investigations with just as many different membrane brands. The overall majority of membranes were resorbable, seemingly serving their purpose, to the investigators' satisfaction, but it was not possible to rank them in any way. However, augmented bone was better preserved when membranes were utilised, compared to the ones without their use[11,18,20].

A staged-approach predominated amongst the onlay studies, i.e. 206 out of 363 implants were placed months after the grafting procedure. All investigators acted carefully and only 16 out of 363 implants were immediately non-functionally loaded, which may have contributed to a successful outcome with only five implants lost during the various study periods. Two of them belonged to the 281 medium-rough/rough surface implants[17] and three to the 82 turned implants[20,22].

The marginal bone condition around implants was obviously not an important focus for the majority of investigators since no data were reported in 8 out of 13 studies. The remaining five studies all reported values within normal ranges[11,13,16,17,21].

Membrane or cover screw exposures were the most common complications and a total of 23 events were recorded in five studies[11,13,15,18,20]. In one study these perforations probably resulted in the loss of two implants[20], otherwise they had little impact on the outcome.

Sinus augmentation (inlay)

The Sinus Consensus Conference, held in 1996 by the Academy of Osseointegration in Massachusetts, USA, resulted in a number of statements regarding sinus augmentation[41]. Based on available literature at that time and data presented at the conference, together with the clinical experience of the participants, it was stated that using immediate or delayed implant placement in autogenous or non-autogenous (allografts, xenografts and alloplasts) bone graft materials, alone or in various combinations, could be clinically efficacious in properly selected patients. Less than 8 mm residual vertical bone height was regarded as indicative for the sinus grafting procedure. Rough surface implants did better than turned surface implants. The combined database of all materials, used alone or in combinations, showed implant survival rates of 90% in the 3 to 5 year perspective[35].

All consensus statements referred to major sinus grafting, but most of them are valid also for the sinus augmentation in the single-tooth situation. Furthermore, according to a more recent review of augmentation procedures of the maxillary sinus[9], the statements are still relevant after 19 years, and they are also in line with the present review. Thus, utilised graft materials (autografts, allografts, xenografts and alloplasts) all resulted in excellent outcomes, but data on bone gain was rather sparse. Two studies clearly reported the volume changes during the first 24 to 30 months[24,28], while the majority chose indirect data by stating that the outcome allowed for placement of implants of 10 to 17 mm lengths.

The overall majority of implants were successfully placed at the time of sinus grafting. Procedures used today are perhaps a bit more aggressive than before, allowing immediate implant placement, also when the residual bone volume is sparse, for example 4 to 5 mm.

One consensus statement claimed that rough surface implants were more successful than turned surface implants in connection with sinus grafting[41]. Turned implants are rarely used today and none of the reviewed sinus augmentation studies on single-tooth implants reported on such implants. There is little evidence that any particular type of implant has superior long-term success[42]. Jungner et al compared 5-year data of 47 turned and 45 oxidised surface implants with delayed placement in autologous sinus grafts, and found no differences between any of the analysed parameters[43]. The overall 90% implant survival rate reported at the consensus conference[41] has surely improved during the time period to date. In the current review, only two out of 256 placed implants in augmented sinuses were reported as failures. Thus, an overall implant survival rate of > 99% was accomplished during the mean study period of 22 months.

Quite contrary to the onlay reports, marginal bone resorption around implants was frequently recorded in the sinus inlay reports. Eight out of 10 studies presented data within normal ranges (0 to 2.2 mm) up to 36 months post-insertion, while two studies[26,29] had no such data.

It is of interest to note that, short implants in non-augmented sinuses versus longer implants in augmented sinuses, were just as successful at the 1-year follow-up[23], which may mean the use of less invasive treatment, less time-consuming treatment, a lower cost and lower patient morbidity[9]. This is in accordance with the Cochrane Database of Systematic Reviews[8], questioning whether it was justified to perform major grafting procedures in resorbed mandibles and that short implants in such jaws appeared to be a better alternative to vertical bone grafting.

Perforation of the Schneiderian membrane was the most common complication reported in the sinus studies, reaching figures between 21% to 60% in three of them[30-32]. These perforations had little impact on the outcome, since all 105 implants of the three studies were 10 to 16 mm in length, with one implant failure[31] only during the study periods of 12 to 36 months.

Vertical alveolar ridge distraction

Distraction osteogenesis of the human alveolar ridge was first described in 1996[44], but its clinical use has been quite limited. The report by Gaggl et al[33] presenting the outcome of 35 patients, of which nine were treated for a missing single-tooth, described the potential of this technique. Vertical bone augmentation is challenging with conventional grafting techniques and is perhaps more easy to obtain with distraction osteogenesis. The immediate incorpora-

tion of a distraction implant as permanent support for the prosthetic device made the technique simpler with only one surgical procedure. The technique is however afflicted with some complications and of the total patient material, Gaggl et al[33] reported two cases with ankylosis of the distracted bone segment, overcorrection of the alveolar ridge and hypoesthesia of the lip.

■ Conclusions

Publications on onlay and inlay bone augmentation procedures at single-tooth implants were reviewed for the last 20 years. All bone materials i.e. autografts, allografts, xenografts and alloplasts, were used with comparable satisfactory results, allowing for placement of 10 to 17 mm-long implants. Stability of bone graft volume over time was sparsely documented. Some onlay autografts tended to resorb early, i.e. prior to implant placement, but minor bone resorption was also seen for other grafts over time. A continuous but small bone resorption of inlay autografts and alloplasts was seen over time for the few sites recorded. A staged-approach predominated for the onlay grafts, with implants placed 3 to 6 months post-grafting, and overall, the majority of these implants (347/363) were placed submerged. For the inlay graft procedures on the other hand, almost all implants were immediately inserted at the time of grafting, and the majority of these implants (253/256) were placed submerged. A total of five implants, out of 363, and two implants, out of 256, failed during the various study periods of the onlay and inlay reports, respectively. Marginal bone conditions around implants in grafted sites were comparable to what has generally been reported for non-grafted sites.

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Guided surgery with tooth-supported templates for single missing teeth: A critical review

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Key words *computer-assisted surgery, computer guided surgery, single-tooth implant*

Aim: To systematically scrutinise the scientific literature to evaluate the accuracy of computer-guided implant placement for single missing teeth, as well as to analyse the eventual clinical advantages and treatment outcomes.

Material and methods: The electronic and manual literature search of clinical studies published from January 2002 up to November 2015 was carried out using specified indexing terms. Outcomes were accuracy; implant and prosthetic failures; biological and mechanical complications; marginal bone loss (MBL); sulcus bleeding index (SBI); plaque score (PS); pink esthetic score [PES]; aesthetic and clinical outcomes.

Results: The search yielded 1027 relevant titles and abstracts, found during the electronic (n = 1020) and manual (n = 7) searches. After data extraction, and screening of titles, abstracts, and full-texts, 32 studies fulfilled inclusion criteria and were included in the critical review: two randomised controlled clinical trials, six prospective observational single cohort studies, one retrospective observational study, three *in vitro* comparative studies, 10 case reports and 10 systematic reviews. A total of 209 patients (18 to 67 years old) were treated with 342 implants using computer-guided implant surgery. The follow-up ranged from 12 to 52 months. The cumulative survival rate ranged from 96.5% to 100%. Eleven implant planning softwares and guided surgery systems were used and evaluated.

Conclusions: Computer-guided surgery for single missing teeth provides comprehensive treatment planning, reliable implant positioning, favourable clinical outcomes and aesthetics. A tooth-supported template for the treatment of single missing teeth results in greater accuracy of implant positioning than with mucosa-supported or bone-supported templates. The limited scientific evidence available suggests that guided surgery leads to implant survival rates as good as conventional freehand protocols. Computer-guided surgery implies additional costs, that should be analysed in terms of cost-effectiveness, considering the reduction of surgery time, postoperative pain and swelling, as well as, the potential increased accuracy. Long-term randomised clinical trials are eagerly needed to investigate the clinical performance of guided surgery in partially edentate patients.

Conflict-of-interest statement: *This review was performed by invitation from the Foundation for Oral Rehabilitation (FOR). This foundation is an independent, international initiative that unites professionals from various disciplines to improve oral health care and support humanitarian leadership and which provides no compensation for authors. The study was self-supported and the authors report no conflict of interest.*

■ Introduction

The actual standard of care for oral rehabilitation by means of implants expects not only the replacement of missing teeth in terms of function, but also the achievement of satisfactory aesthetics[1]. Optimal positioning of the implant through prosthetically driven decision-making is mandatory to achieve these goals[2,3].

Since its development in the mid-nineties, computer-guided implant surgery has quickly gained popularity[4-6]. The introduction of cone beam computed tomography (CBCT), allowing volumetric jaw bone imaging at reasonable costs and low radiation doses[7,8], facilitates the preoperative acquisition of large amounts of information[9] such as the available bone volume and quality, the presence and location of relevant anatomical structures and pathologies, and their relationship with the future rehabilitation.

Computer-aided methods may offer significant advantages in the treatment planning and help clinicians to perform successful implant-based rehabilitation while avoiding elevation of large mucoperiosteal flaps or eliminating them at all, causing less pain and discomfort to patients[10-12]. The surgeons, when operating freehand, commonly elevate mucoperiosteal flaps to better visualise the recipient site. This may become unnecessary when computer-guided implant placement is performed since the surgeon may trust the guidance provided by the surgical template.

Patients can benefit from having implants placed flapless and loaded immediately. However, to achieve this, the implant-based rehabilitation has to be carefully planned in advance[10]. The conventional freehand implant placement is challenged by several factors including patient movement during drilling, a restricted visualisation of the operative field which is limited to the tissues surface, interpretation and transfer of two-dimensional radiographs into the three-dimensional surgical environment, and the integration of aesthetic, biomechanical and functional constraints. Thus the surgeon has to take numerous decisions ranging from surgical aspects to the implant positioning in a limited time period. A thorough preoperative planning will free the surgeon's mind, allowing more time to concentrate on the patient and the tissue handling[13].

The growing interest in minimally invasive implant placement with the option of delivering a pre-fabricated temporary prosthesis immediately to restore function and aesthetics, have led to the development of numerous three-dimensional (3D) planning software programmes[4,14-19]. The 3D visualisation of the implant recipient site characteristics and neighbouring anatomy provides the clinicians with more insight into the surgical, prosthetic and aesthetic requirements of the treatment and may enhance decision-making, increasing the reliability of the overall implant treatment[10]. Computer-guided implant placement implies 3D imaging of both the jaw bone and the planned prosthesis. Such integration of the planned prosthesis within the craniofacial model can be achieved through a double-scan technique with fiducial marker-based matching i.e. gutta-percha[20]. First, the patient is scanned with the prosthesis in the mouth, stabilised in the proper position by an occlusal silicone index. The planned prosthesis is than scanned separately, with different exposure parameters in order to allow its 3D visualisation in the software independently or overlapped to the patient anatomy. As the markers are visible in both sets of scans, they can be fused and the prosthesis properly positioned within the maxillofacial structures[6,14]. The double-scan technique with fiducial marker-based matching (i.e. gutta-percha) can also be a possible source for deviation both in partially edentulous and edentulous patients, if the matching is incorrect[21]. Furthermore, Pettersson et al[22] experienced that the automatic superimposing procedure of gutta-percha markers sometimes proceeded without any notification of errors, while motion artifacts were present. Therefore, the surgeon remains responsible for checking the accuracy of the procedure. A double-scan technique can be applied in partially edentulous patients, but the introduction of a novel digital integrated workflow offers an appealing alternative. A recently introduced 3D implant planning software (NobelClinician, Nobel Biocare, Kloten, Switzerland), automatically combines the Digital imaging and communications in medicine (DICOM) data belonging to the CT/CBCT examination of the patient with the STL data derived from the optical digital high-resolution scan of the preoperative patient master cast and tooth setup through a proprietary algorithm process (SmartFusionTM,

Nobel Biocare, Kloten, Switzerland). Therefore the cast is scanned and integrated with the craniofacial model to create a more accurate 3D model of the teeth[23,24]. It is thus possible to visualise hard and soft tissue anatomy and to obtain a more precise segmentation of the residual dentition.

An additional benefit to streamline the workflow comes from the use of an intraoral optical scanner to retrieve the surface scanning of the residual dental arch and soft tissue architecture[25]. A virtual digital wax–up is usually used to visualise the ideal prosthetic setup. Once the planning is completed and approved by the clinician, the digital information is used to produce the surgical stent or template that will be tooth-supported, with CAM rapid prototyping (milling or 3D printing).

Peri-implant soft tissue aesthetics constitute a relevant aspect of implant success and also one of the main motivating factors for a patient's decision toward implant therapy in the anterior maxilla[26]. Implant treatment in the aesthetic zone still represents a challenging task from both the surgical as well as the prosthodontic perspective[27-29]. It is well established that sufficient bone volume and favourable implant positioning are prerequisites for long-term aesthetic success[26,29,30], even if peri-implant mucosal conditions depend heavily upon the underlying bone topography. Potential advantages of a computer-guided implant placement in the aesthetic site include a reduced mucosal recession and maximum preservation of peri-implant papillae in case the implant is properly positioned.[29-32].

However, after a few enthusiastic preliminary reports[14,33], some prospective studies[16,17,34-37] drew attention to the potential 3D deviations between virtual planning and the actual final position of the implants. Computer-guided implant placement is technique-sensitive and perioperative complications have to be taken into account[38]. Although, in general, tooth-supported templates are more accurate than mucosa-supported ones[15], the application of guided surgery to enhance single-tooth implant positioning and aesthetic outcome have so far not been widely reported in the literature.

One might assume that, in case of complex clinical scenarios, as immediate post-extraction implant placement, aesthetic zone and bone atrophy with closeness of critical anatomic structures, both patients and clinicians could benefit from computer-guided template-assisted surgery. However, introducing new treatment methods for clinical use is always challenging. Moreover, in the rapid development of computer technology, the clinical benefit of computer-guided implant placement has to be consistently evaluated[39]. Otherwise the commercially driven marketing may become the guiding principle.

Aim

The aim of the present review was to systematically scrutinise the current scientific literature regarding the eventual clinical advantages of computer guidance of implant placement for single-tooth replacement using template-assisted surgery. The following question was addressed: is there scientific evidence supporting the hypothesis of a clinical advantage to the use of such computer-guided template-assisted implant placement for the rehabilitation of single missing teeth compared to conventional treatment protocols?

Materials and methods

Protocol

Prior to the systematic literature search, a review protocol was determined with the software Review Manager, version 5.2.

Structure of the review

The systematic review was edited according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[40].

Eligibility criteria

The focused question was formulated according to the PICOS (P = Population/Patients; I = Intervention; C = Comparator/Control; O = Outcomes; S = Study Design) format, as suggested by the Center for Evidence-Based Medicine and served as a basis for the systematic literature search (Asking Focused Questions 2014):

- Patients: partial edentate patients (both jaws or either the maxilla or mandible) with single-tooth implant-retained fixed prosthesis.
- Interventions: insertion of either machined or rough-surfaced endosseus titanium single implants with a tapered or cylindrical form, by means of a computer-guided template-assisted implant surgery, irrespective of implant number, length, diameter, position, or angulation, into either residual or augmented bone, prosthodontic rehabilitation with fixed single dental prostheses, either screw-retained or cement-retained, according to an immediate, early or conventional loading protocol.
- Comparisons: single implant placement using different surgical procedures (computer-guided template-assisted vs conventional freehand approach), in one or between both jaws.
- Outcomes: accuracy, implant and prosthetic failures, biological and mechanical complications, marginal bone loss (MBL), sulcus bleeding index (SBI), plaque score (PS), pink esthetic score (PES), after an observation period of at least 1 year. However, no specific follow-up period was required to evaluate accuracy, surgical or prosthetic complications at implant insertion or patient-centered outcomes of surgery and immediate postoperative period.
- Study design: systematic reviews, randomised controlled trials (RCTs), prospective clinical studies, whose enrolled population needed to have at least five patients in each group. Retrospective clinical studies, clinical reports, or technical notes, were included, when providing relevant scientific information on the subject. Excluded from this review were studies not reporting on the above listed outcome variables, or publications with a follow-up < 12 months. The initial search included data from *in vivo*, *ex vivo* and *in vitro* studies written in English, and published from 2002 up to November 2015 in referred journals.
- Definitions: An implant planning using a 3D software and an implant placement by means of a computer-aided design-computer-aided manufacturing (CAD-CAM) surgical template was defined as 'computer-guided surgery'. An implant placement either freehand or assisted by a laboratory fabricated template was defined as 'conventional free hand surgery'. 'Accuracy' was defined as the difference in location or angulation between the computer-guided implant positioning and the final implant position in the patient mouth and evaluated as deviations at entry point, at the tip of the implant, in height, and at the implant axis. The loading protocols were defined as 'immediate loading', within 1 week after implant insertion, 'early loading', between 1 week and and 2 months, and 'conventional loading' after a healing period of more than 2 months[41]. An implant was considered an 'implant failure' if it presented mobility, assessed by tapping or rocking the implant head with the metallic handles of two instruments, and/or any signs of radiolucency, progressive marginal bone loss or infection, and any mechanical complications (e.g. implant fracture) rendering the implant unusable, although still mechanically stable in the bone. A prosthesis was considered a 'prosthesis failure' if it needed to be replaced by an alternative prosthesis.

Information sources

The following electronic databases were scrutinised: PubMed database of the US National Library of Medicine (http://www.ncbi.nlm.nih.gov/pubmed/), SCOPUS scientific abstract and citation database (www.scopus.com) and the Cochrane Library (http://www.cochranelibrary.com/). According to the AMSTAR (http://amstar.ca/index.php) checklist, the grey literature was screened at the New York Academy of Medicine Grey Literature Report (http://catalog.nyam.org) in order to find possible unpublished works. A supplementary manual search in private databases (End Note libraries) and in the database of the following journals was conducted: Clinical Implant Dentistry and Related Research; Clinical Oral Implants Research; European Journal of Oral Implantology, International Journal of Oral and Maxillofacial Implants, Journal of Prosthetic Dentistry, Journal of Oral Implantology, International Journal of Computerized Dentistry, The International Journal of Periodontics and Restorative Dentistry. Additionally, new research excluding 'Dental/Oral Implants' and 'Single-Tooth' from the previously used MeSH terms was performed, followed by a manual search, in order to find single-tooth dental

implants placed using computer-assisted template-based surgery in larger cohorts of patients. Moreover, the authors used personal contacts in an attempt to identify unpublished or ongoing eligible studies. The authors of the eligible manuscripts were contacted, in case further information or data were needed. The results were limited to studies published between January 2002 and December 2015 in referred journals and written in English and Italian. The last date of the search was November 8, 2015.

Search strategy

The electronic search complied with the PICOS question addressing Patients, Intervention, Comparison, Outcome and Study design. An electronic literature search was carried out with the intention of collecting relevant information about accuracy; implant and prosthetic failures; biological and mechanical complications; MBL; clinical and aesthetic outcomes of single implants placed using computer-assisted template-based surgery. The electronic databases were searched using the following MeSH (Medical Subject Headings) terms: („Surgery, Computed/r-Assisted" [Mesh] OR "Therapy, Computed/r-Assisted" [Mesh] OR „Computer-Aided Design"[Mesh]) AND („Dental/Oral Implants"[Mesh] OR „Dental Implants, Single-Tooth"[Mesh] OR „Dental Prosthesis, Implant-Supported"[Mesh]).

Free text terms ("Implant treatment" OR "Computed guided" OR "Single-tooth gap" OR "Guided surgery") were added to all searches.

Study selection

Study selection and data extraction were performed by two assessors (MT and SM) who independently read the articles and recommended inclusion or exclusion according to the predetermined criteria. To assess consistency among the reviewers, the inter-reviewer reliability using Cohen's Kappa statistic (κ) was analysed. Any disagreements were resolved by a discussion with the aim of reaching a consensus. The resulting initial hits of the above-mentioned search were screened, and a first preselection by title was undertaken. Titles were sequentially excluded if they indicated non-relevant content (e.g. no oral or dental implants, no single missing teeth, no single implant- supported fixed dental prostheses). In case of any uncertainty, an additional abstract reading was performed. Abstracts of the selected titles were inspected for relevance resulting in a choice of possibly eligible full texts. If studies were published by the same author or institution several times, these manuscripts were thoroughly read and compared to avoid the inclusion of duplicate data. After full-text selection and data extraction, it was decided whether the publication was adequate for the intended systematic review. When at least one author considered that a publication met the initial inclusion criteria, the paper was ordered and read using the full text version.

Risk of bias within and across studies

The potential risk of bias within the included studies was assessed using the methodology checklists provided by the Scottish Intercollegiate Guidelines Network (SIGN), which comprise the critical appraisal of the selection of subjects, the assessment used, potential confounders, the statistical analysis and the overall methodological quality of the study:

- High quality: (++) Majority of criteria met. Little or no risk of bias. Results unlikely to be changed by further research.
- Acceptable quality: (+) Most criteria met. Some flaws in the study with an associated risk of bias, conclusions may change in the light of further studies.
- Low quality: (-) Either most criteria not met, or significant flaws relating to key aspects of the study design. Conclusions are likely to change in the light of further studies.

The review included data extraction of only articles that reached a consensus between the reviewers as 'High and Acceptable quality'

Data extraction, interpretation and evaluation of evidence from retrieved literature

Extracted data were added to predefined forms, which included the following parameters: author, year, total number of patients/prostheses investigated, observation period, total number of implants,

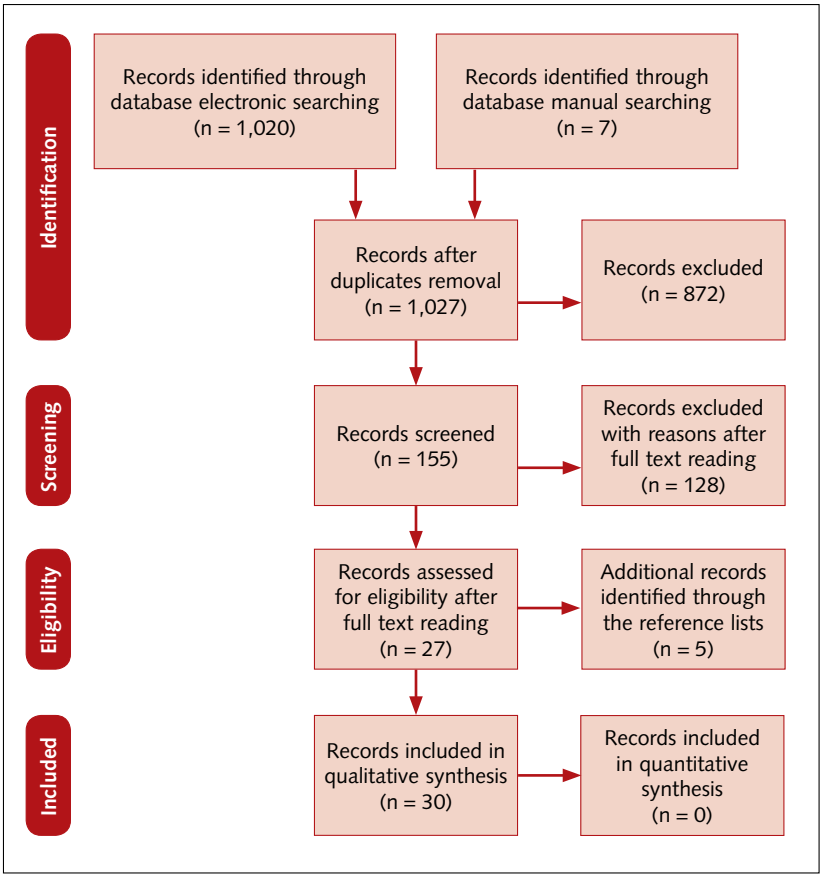

Fig 1 Flow chart of search process and retrieval of publications.

number and time of dropouts on implant level, number of implants per patient, type of implant prosthesis, type of anchorage system, implant survival and implant losses before and after loading. In addition, implant system, implant surface, loading protocol and bone augmentation procedures were noted. All variables were predetermined and no additional variables were added after the reviewing had started.

Results

Literature search

Figure 1 depicts a flow chart of the selection process for publications relevant to our review. The first step of the search, using a series of combined search terms, yielded 1027 potentially relevant titles and abstracts, found during the electronic (n = 1020) and manual (n = 7) searches. During the first step of study selection, 872 publications were excluded based on their title and abstract (inter-reviewer agreement; k = 0.72). Therefore 155 publications were read in the full text version and thoroughly evaluated. One hundred and twenty-eight out of 155 publications had to be excluded at this stage because they were 'low quality' due to either most criteria not being met, or because significant flaws relating to key aspects of study design were found (inter-reviewer agreement; k = 0.99). A manual search of reference lists and systematic reviews provided five additional publications for inclusion which fulfilled the inclusion criteria and quality assessment required for this critical review. A total of 32 manuscripts reporting on guided surgery for single missing teeth were identified and included in the review: two randomised controlled clinical trials[10,43], six prospective single cohort studies[17,44-48], one retrospective study[32], three *in vitro* comparative study[48-50], 10 cases reports [51-61] and 10 reviews of the literature[13,38,39,62-68].

Accuracy of computer-guided template-assisted surgery for missing single teeth

The most common concern in implant surgery regarding computer-guided surgery is the accuracy associated with transference of the virtual data for the planned implant position to the actual surgical procedure to place the implant and its final position intraorally. Accuracy is defined as the deviation between the position of the 'planned' and the 'inserted' implant[13]. The accuracy is most often verified via a second, postoperative CBCT, through dedicated software that allow the matching of preoperative and postoperative implant positioning. Alternatively, preoperative and postoperative master casts can be compared ('model matching')[34]. The accuracy is commonly investigated at four levels: deviation at the entry point, deviation at the apex, deviation of the long axis (angulation) and deviation in depth. More recently, additional attention has been given to deviations in mesiodistal and buccolingual direction[13, 21].

Understanding the accuracy of a computer-guided implant surgery system is of paramount importance for the clinician during virtual implant position planning and accounting for the 'safety zone' that is factored in all implant planning software programs. The 'safety zone' feature establishes a dimension measured in mm to provide a margin of

safety from vital anatomic structures or neighbouring components such as the implant body[9].

Several reviews of scientific literature have been performed to evaluate the accuracy of stereolithographic surgical templates[13,38,39,61-68]. Schneider and colleagues[65] calculated a mean deviation of 1.1 mm (95% CI: 0.8 to 1.2 mm) at the implant shoulder and 1.6 mm (95% CI: 1.3 to 2.0 mm) at the apex; 0.5 mm in height and 5° to 6° in axis. D'haese and colleagues[68] reported coronal deviations ranging between 0.20 and 1.45 mm (mean 1.04 mm), apical deviations ranging between 0.95 and 2.99 mm (mean 1.64 mm) and mean angular deviation ranging between 0.17° and 7.90° (mean 3.54). Van Assche and colleagues (meta-analysis)[61] reported a mean error of 1.0 mm (95% CI: 0.7 to 1.3 mm) at the entry, 1.4 mm (95% CI: 1.1 to 1.7 mm) at the apex, and a mean angular deviation of 4.2° (95% CI: 3.6° to 5.0°) when analysing *in vivo* studies. They took into consideration up to nine different computer-assisted systems, *in vivo*, *ex vivo* and *in vitro* studies, stereolithographic and laboratory fabricated templates, different surgical templates classified according to the type of support provided for the surgical template based on specific anatomic structures (bone, mucosa or teeth), and different preoperative and operative workflows (fully guided, semi-guided, freehand dilation of the borehole and freehand implant placement). These studies address the accuracy of computer-guided implant placement in different ways, making interstudy comparison difficult. A standardisation of research parameters will lead to a better comparison of research outcome data.

Although various clinical studies have specifically measured the accuracy of tooth-supported CAD/CAM templates for missing single teeth, most of these investigations due to the intrinsic nature of their study design, were unable to determine whether the computer-guided implant surgery was more accurate than the freehand conventional implant placement. The data is summarised in Table 1. Two *in vivo* prospective studies and 1 *in vivo* retrospective study investigated the accuracy of 55 implants placed with computer-guided template-assisted surgery[31,43,44]. One *in vivo* prospective study reported on the accuracy of 18 implants planned with computer-assisted method and placed

Table 1 In vivo accuracy of computer-guided/computer assisted surgery for missing single teeth: deviations from the planned position (mean ± SD [range]).

Study	**Implant Number**	**Implant procedure**	**Entry Point mm (range mm)**		**Apex Point mm (range mm)**		**Angle ° (range °)**	
Behneke et al 2012*	19	Computer-guided planning laboratory-fabricated template.	0.21 ± 0.16 (0.01-0.92)		0.32 ± 0.34 (0.03-0.59)		1.35±1.11 (0.07-3.33)	
Ersoy et al 2008**	9	Computer-guided planning stereolithographic-template.	0.74 ± 0.40		1.66 ± 0.28		3.71 ± 0.93	
Furhauser et al 2014***	27	Computer-guided planning stereolithographic-template.	0.84 ± 0.44 (0–1.6)		1.16 ± 0.69 (0–2.6)		2.7 ± 2.6 (0–12.7)	
Study	**Implant Number**	**Implant procedure**	**MI Distance: mesial tooth to the implant fixture**		**DI Distance: distal tooth to the implant fixture**		**LI Distance: lingual plan to the implant fixture**	**IT angle: clinical crown to the implant fixture**
Bencharit et al 2015#	18	Computer-guided planning hand-free implant placement	-0.02 (-0.40, 0.37)		-0.02 (-0.42, 0.39)		-0.11 (-0.73, 0.50)	1.23 (-1.59, 4.05)
Study	**Implant Number**	**Implant procedure**	**Entry Point mm (range mm)**		**Apex Point mm (range mm)**			
Farley et al 2012§	10	Computer-guided planning stereolithographic-template	–1.20 ± 0.70 mm vertical	0.638 ± 0.370 mm horizontal	–1.24 ± 0.68 mm vertical	1.11 ± 0.71 mm horizontal		
	10	Computer-guided planning laboratory-fabricated template	–1.51 ± 1.02 mm vertical	1.15 ± 0.57 mm horizontal	–1.59 ± 1.09 mm vertical	1.84 ± 0.97 mm horizontal		

* Software implant 3D (med3D GmbH, Heidelberg, Germany system) and the Schick Hexapod positioning device (X1med3D positioner; SchickDental GmbH, Schemmerhofen, Germany).
** Stent Cad (Media Lab Software, La Spezia, Italy).
*** NobelClinician (Nobel Biocare, AG, Zurich, Switzerland).
# SimPlant Pro 15 (Dentsply, Waltham, Massachusetts, USA).
§ iDent software (iDent Imaging, Ft. Lauderdale, Florida, USA)

Table 2 Comparison of the potential sources of deviations in the double scan protocol and in the integrated digital workflow for tooth supported CAD/CAM surgical template.

	Impression taking	Master cast pouring	Rx template Scan prostheses laboratory fabrication	Fit Rx template patient mouth	Optical scanning master cast tooth set-up	Intraoral optical scanning	CBCT intrinsic errors CBCT/patient movements	Correct segmentation matching process	Adequate implant planning	CAD/CAM template production	CAD/CAM template fitting	Tolerance surgical sleeve/ drill guide/drill	Limited mouth opening reduced inter-arch clearance tight surgical space Kennedy Class I-II
Double Scan	√	√	√	√	-	-	√	√	√	√	√	√	√
Conventional digital workflow	√	-	-	-	√	-	√	√	√	√	√	√	√
Fully Digital workflow	-	-	-	-	-	√	√	√	√	√	√	√	√

with a conventional freehand approach[47]. Only one randomised split-mouth prospective trial has compared the accuracy of computer-guided surgery CAD/CAM templates with conventional laboratory fabricated templates for the treatment of a single-tooth gap[41]. The split-mouth design used by Farley et al[42], allowed for a comparison of the accuracy of the two templates within the same patients, minimising bias and variability, and is the only source of evidence that was able to determine whether the computer-guided implant surgery was more accurate than the freehand conventional implant placement. All the implants were planned with the same 3D implant planning software and then allocated toward one of the two groups. Twenty single implants were placed in 10 patients. At entry point, implants placed with the CAD/CAM guides deviated more from the planned positions in a vertical direction (-1.20 ± 0.70 mm) than in the horizontal direction (0.638 ± 0.37 mm), while conventional guides had greater vertical and horizontal distance deviations (-1.51 ± 1.02 mm and 1.15 ± 0.57 mm, respectively) than CAD/CAM guides. At the tip of the implant, vertical (-1.24 ± 0.68 mm) and horizontal (1.11 ± 0.71 mm) differences for CAD/ CAM guides were similar, while for conventional guides the vertical error was -1.59 ± 1.09 and the horizontal error was 1.84 ± 0.97 mm. Single implants placed with CAD/CAM surgical guides were generally closer to the planned positions in all eight categories examined, however statistically significant differences ($P = 0.0409$) were shown only at the entry point per horizontal deviation, providing greater accuracy than implants placed with conventional guides. In addition, CAD/CAM guides were more consistent in their deviation from the planned locations than conventional guides.

Several factors leading to inaccuracy have been identified: presence of debris in the drilled hole preventing the implant from reaching its final position, resilience of mucosal tissues, setting of the radiological Gray values during segmentation, improper seating of the template and deformation of the guide during surgery[20,37,69,70].

Deviations may reflect the sum of all errors occurring, which includes imaging, the transformation of data into a guide and the improper positioning of the latter during surgery. All errors can eventually have a cumulative effect (Table 2).

The present paper reviewed the computer-guided surgery accuracy according to four factors that presumably may influence the overall outcome: type of arch (maxilla/ mandible), kind of template (single-tooth gap/interrupted dental arch/shortened dental arch/reduced residual dentition), type of guided surgery (fully guided placement/freehand placement/freehand dilation of the borehole) and the surgical technique (flapless/open flap)[43].

Type of arch (maxilla/ mandible)

In a prospective study[44], 52 partially edentulous subjects received 132 implants. Nineteen implants were placed to restore a single-tooth gap in 19 partially edentate patients. Preoperative planning was merged with postoperative CBCT data to identify linear and angular deviations between virtually planned and placed implants. No essential differences could be found regarding the influence of the type of arch. After the matching procedure, a borderline significant difference was found between maxillae and mandibles for the linear deviation at the tip of the implants, which was larger in the maxillae (0.50 vs 0.40 mm, $P = 0.033$), while no significant differences were found for the linear regarding the linear deviation at the neck or the angular deviation. These low deviations are clinically not meaningful. These findings are in partial agreement with previously published studies not limited to missing single teeth[16,71,72], reporting that the maxilla is more susceptible to transfer inaccuracies than the compact mandibular bone. The lower accuracy in the maxillary cases may be determined by the type of template support. In completely edentulous patients the mucosal resilience could result in micromovements and lack of accuracy, where as in the single missing tooth situation, the surgical template will always be tooth-borne, providing more stability.

Type of template (single-tooth gap/ interrupted dental arch/shortened dental arch/reduced residual dentition)

Low deviations can be observed, if single-tooth gaps with mesial and distal tooth-supported templates are treated. A mean error of 0.21 ± 0.16 mm (range 0.01 to 0.92) at the entry point, 0.32 ± 0.34 mm (range 0.03 to 0.59) at the tip of the implant, and 1.35° ± 1.11° (range 0.07° to 3.33°) of the radial deviation at the tip were reported for single-tooth gap surgery[42]. Thus there was significantly less deviation at the tip for the single-tooth loss group than for the partially edentulous group. A wider variation of values was reported for sites with a reduced residual dentition, as only a few teeth could ensure the support of the guide. Therefore a larger deviation for templates with unilateral anchorage could be expected due to tilting and bending of the template itself[42]. The use of a rigid material for fabricating the surgical template or the relining of the templates in order to obtain sufficient stiffness to prevent such tilting should be advocated. This observation corroborates findings previously reported by Ersoy et al[45], reporting a mean error of 0.74 ± 0.40 mm at the implant neck, 1.66 ± 0.28 mm at the tip, and an angular deviation of 3.71° ± 0.93° for nine implants placed with single tooth gap supported templates; and 1.23 ± 0.67 at the implant neck, 1.59 ± 0.74 at the apex, and an angular deviation of 4.78 ± 1.86 for 20 implants placed with free-ending tooth-supported templates in Kennedy Class I or II partial edentate patients. A statistically significant higher accuracy was measured for single tooth gap supported templates compared to partially and edentulous patients. These results agreed with D'haese et al[63], a systematic review indicating that tooth-supported guides showed significantly smaller deviations compared with mucosal- and bone-supported guides: 0.87 ± 0.40 mm (coronal deviation), 0.95 ± 0.60 mm (apical deviation) and 2.94° (angular deviation) These results are also in accordance with the third EAO Consensus Conference 2012 concluding that tooth- and mucosa-supported templates can give more accurate results than bone-supported templates[62,73].

Type of guided surgery (fully guided placement, semi-guided placement/ pilot drilling with freehand dilation of the borehole and freehand implant placement)

The titanium sleeves fixed in the surgical template may be used for different steps of the site preparation up to the implant placement. The use of the template can be limited to guide the pilot drilling or for the entire osteotomy up to the implant placement. Nevertheless, particularly in situations with limited mouth opening or restricted interarch clearance, surgical guides may interfere with the effective use of the drills in the posterior quadrants and therefore the templates may be used only for the initial steps of implant bed preparation, affecting the overall accuracy of the procedure. Moreover, intrinsic inaccuracies of hardware must be addressed to

minimise inaccuracies resulting from the fit of instrumentation through the surgical template and the fit of the template to the dentition[74-79].

Behneke et al[44] reported in partially edentulous patients that the freehand dilation of the borehole, results in significantly less accuracy than that achieved with fully template-guided drilling and implant placement. A mean error of 0.21 ± 0.20 mm (range 0.03 to 0.60) at the entry point, 0.28 ± 0.24 mm (range 0.03 to 0.77) at the implant tip, and 1.49° ± 1.39° (range 0.07° to 4.53°) of apical radial deviation were reported for fully guided implant placement, which means that maximum deviations measured were 0.6 mm at the entrance, 0.77 mm at the tip, and thus distinctly lower than the safety zone of 1.5 mm, usually recommended by most of the planning softwares[10].

The aforementioned mean deviations are also lower than those experienced by Fürhauser et al[32] using stereolithographic templates for the rehabilitation of single-tooth implants in the anterior maxilla by superimposition of CBCT scans, with a mean follow-up of 2.3 years. The mean deviation between planned and actual implant position was 0.84 ± 0.44 mm at the implant shoulder (range: 0 to 1.6 mm) and 1.16 ± 0.69 mm at the implant tip (range: 0–2.6 mm). Mean angular deviation was 2.7° ± 2.6° (range: 0°–12.7°) and was significantly correlated to the deviation at the tip but not at the implant shoulder.

To clarify whether computer-guided surgery offers a better accuracy it is important to compare it to the accuracy of the freehand implant placement. Two *in vitro* studies examined this issue. They reported a maximum error at the entry point ranging from 0.80 to 1.00 mm[49] and a mean error at the entry point of 1.35 mm[50] for the conventional freehand surgery. Both studies demonstrated a statistically significant higher accuracy for the computer-guided systems compared to the freehand implant placement. This is in agreement with the clinical findings of Farley et al[42], who in a split-mouth comparison of implant placement for missing single teeth, which compared planned and actual implant positions using three-dimensional analyses, showing that implants placed with CAD/CAM guides were closer to the planned positions in all eight categories examined, but this reached significance only in a horizontal direction at the neck of the implants. Therefore, the aforementioned deviations reported for the conventional freehand surgery seem higher than the similar deviations reported using computer-guided surgery for the rehabilitation of single missing teeth[32,44,45].

Regarding the surgical technique (flapless/open flap)

In a prospective clinical study, Behneke et al[44], compared the computer-guided surgery accuracy when the soft tissue was punched (flapless implant placement) with the conventional technique when a full-thickness flap was raised. A borderline significance ($P = 0.027$) was found between both conditions for the implant neck radial deviations (slightly higher values for the flapless approach). For the linear deviation at the implant apex, and for the angular deviation, no significant differences were found. Flap elevation did not negatively influence the positioning of the tooth-supported surgical templates. These findings were in agreement with the results reported by the clinical study of Ersoy et al[45], who could not find any difference in accuracy for the open flap procedure vs the flapless procedure for completely or partially edentulous patients. In a retrospective study, Fürhauser et al[32] reported on the 3D accuracy of 27 single-tooth implants placed for delayed replacement of upper incisors, using stereolithographic templates. Regardless of the mean deviations reported, highly aesthetic and predictable results were achieved by flapless implant placement using guided surgery in the anterior maxilla. The aesthetic outcome was evaluated using the PES[80]. The authors found that the 3D inaccuracy is low in guided implant surgery (median PES: 13, $P = 0.039$), but, on the other hand, small deviations, toward the labial/buccal aspect ≥ 0.8 mm, resulted in significantly worse implant aesthetics in the anterior maxilla (median PES: 9.5) compared with more accurate implant positions. These results confirm the hypothesis that the three-dimensional implant position has an important influence on the aesthetic outcome, for example an implant position angled too far to the facial will result in an increased crown length compared to the contralateral tooth as well as mid-facial (bone or gingival) recession over time[81].

Avoidance of flap elevation seems to benefit peri-implant mucosal conditions, particularly in terms of maximum preservation of peri-implant papillae and reduced mucosal recession when there is sufficient mesial-distal dimension, in agreement with previous evidence[82]. However, soft tissue punching and removal, generally associated with a flapless approach, may not be indicated in patients with a narrow zone of keratinized mucosa and limited soft tissue volume or mesial-distal space. In such instances, surgical modifications, such as punch reposition or limited flap technique[83] may be favoured.

Clinical outcomes of computer-guided template-assisted surgery for single missing teeth

Computer-guided surgery has been developed to allow for more comprehensive preoperative planning and a implant placement, with adequate consideration of the future prosthetic suprastructure, in terms of efficiency and aesthetics. Only few clinical studies investigating the clinical outcome of the computer-guided surgery for missing single teeth have been published to date. Two randomised controlled clinical trials[10,42], six prospective single cohort studies[17,43-47], one retrospective study[32] and 10 case reports[51-60] treating single-tooth gaps were identified and included in the review. A total amount of 342 single implants were placed in 209 patients (18 to 67 years old). The follow-up ranged from 12 to 52 months. The cumulative survival rate ranged from 96.5% to 100.0%.

The NobelClinician software and the pristine version NobelGuide (Nobel Biocare, Kloten, Switzerland) software was the most investigated[10,17,32,84]. Other 3D implant software programs evaluated include: SimPlant (Dentsply, Massachusetts, USA)[47,59,60], Implant 3D (med3D, Heidelberg, Germany)[44], iDent software (iDent Imaging, Florida, USA)[42], Stent Cad (Media Lab Software, La Spezia, Italy)[45], Codiagnostix (Dental Wings Inc, Montreal, Canada)[51], Facilitate (Astra Tech, Dentsply Implants, Mölndal, Sweden)[53], Dental Slice Program version 2.7.2 (BioParts Prototipagem Biomedica, Brasilia, Brazil)[54], Micerium Implant Planning software (Micerium, Avegno, Italy)[55], Ray Set implant software (Biaggini Medical Devices, La Spezia, Italy)[57] and ImplantMaster (I-Dent, Hod Hasharon, Israel)[58].

However, most of these studies examined the clinical performance in completely edentulous patients, with little or no evaluations performed in the partially edentulous patients. Only two clinical randomised controlled trials[10,42] have been published reporting the clinical outcomes of computer-guided template-assisted implant placement, compared to freehand surgery, for the treatment of a single-tooth gap. Pozzi et al[10] used the 3D implant planning software (NobelClinician, Nobel Biocare, Kloten, Switzerland) to plan 51 patient treatments (partially edentate: n = 22; fully edentate : n = 29). They were randomly allocated toward either the flapless or mini-flap approach. All were immediately loaded. A total of 202 implants were placed, where 37 implants were used to rehabilitate a missing single tooth either by means of computer-guided surgery (19 implants in nine patients) or freehand surgery (18 implants in 10 patients). No dropouts occurred and all patients were followed up to 1 year after loading. No implant or prosthesis failures have been observed at 1 year follow-up yielding implant and prosthetic survival rates of 100%. Extrapolating the data related to the treatment of the single-tooth gaps 1 year after loading, implants of the computer-guided group lost 0.71 ± 0.44 mm of marginal bone versus 0.95 ± 0.25 mm for the freehand surgery group ($P = 0$). All patients followed a tight recall appointment schedule and at 1 year, no bleeding on probing and only small amounts of plaque were recorded. Papilla improvement over time was observed (PI: 93.7%). This multicenter randomised controlled trial was conducted to understand which procedure is preferred after having planned the treatment with a dedicated implant software on the 3D CBCT scan. Both techniques were able to achieve the planned goals. The only significant difference was more postoperative discomfort (self-reported pain and swelling) for patients having implants placed freehand, most likely due to more frequent use of flap elevation in the latter group.

The split-mouth study used by Farley et al[42] compared the accuracy of computer-guided surgery assisted by a CAD/CAM template to conventional freehand surgery, which was assisted by a laboratory hand-crafted template, in the treatment of the single-tooth gap. Ten patients were selected for this study with symmetric edentulous areas in the mandible

and with similar bone heights. This accommodated the use of the same implant size on each side. The iDent software was used to plan the implant positioning of both groups and to design the CAD/CAM surgical template. The authors did not report any difference regarding the clinical outcomes between the groups for the 20 implants placed. Neither implant nor prosthesis failures were experienced.

Vasak et al[17], conducted a 12-month prospective clinical study on the use of computer-guided surgery (NobelClinician) with respect to implant success and survival rates, which resulted in peri-implant soft tissue conditions and potential surgical and prosthetic complications. Thirty patients with partially dentate and edentulous maxillae or mandibles were included. All patients were treated using computer-guided surgery. Overall, 163 implants were placed (mandible/maxilla = 107/56 implants). All 30 patients and 161 implants completed the 1-year follow-up resulting in a cumulative survival rate of 98.8%. For eight patients it concerned the restoration of single missing teeth using one-stage implant surgery achieving a primary stability ≥ 35 Ncm, and immediately restored with single crowns, which achieved occlusal contact. Both implant and prosthetic survival rates were 100%. Clinical soft tissue parameters improved in a majority of the implants.

Nikzad et al[46], evaluating the outcome of computer-guided flapless surgery for the treatment of partially edentulous patients in a prospective 12-month clinical study also reported an overall implant survival rate of 96.5% (57 implants placed in the mandible of 16 patients). The mean marginal bone loss after 1 year of follow-up was 0.6 ± 0.2 mm mesially and 0.5 ± 0.1 mm distally, meaning the authors concluded that CAD/CAM technology and flapless implant surgery is reliable in partially edentulous patients. Ersoy et al[45] reported on 21 consecutive patients (seven with missing single teeth and seven partially edentulous) treated with computed-generated stereolithographic surgical guides. The cumulative implant survival rate was 100%.

Pozzi and Moy[84] designed a prospective, cohort study to validate the proof of concept of a minimally invasive surgical technique for sinus elevation using computer-guided surgery and CAD/CAM fabricated templates (NobelClinician), in combination with expander-condensing osteotomes. In 66 consecutive patients, 136 computer-guided single implants were placed by transcrestal-guided sinus floor elevation technique. The drilling protocol was customised, based on the bone density of each implant site to achieve an insertion torque ranging between 45 and 55 Ncm, thus allowing immediate provisionalisation. Mean follow-up was 43.96 (range: 36 to 52) months. Cumulative implant survival rate was 98.53%. No biological or mechanical complications were encountered and no prosthetic failures occurred during the entire follow-up period. Mean marginal bone loss during the first year of function was 0.33 ± 0.36 mm, while at the 3-year follow-up, the mean MBL was 0.51 ± 0.29 mm. The mean residual bone height of the alveolar crest prior to surgery was 6.7 ± 1.6 mm (range 5.1 to 9.2 mm), while, the mean bone height gained was 6.4 ± 1.6 mm (range 3.2 to 8.1 mm). All patients reported low levels of postoperative pain.

In some single-tooth gaps, the proper seating of the CAD/CAM template can be hampered due to the limited amount of space available thus limiting the use of a fully guided sleeve. As an alternative, Edelmann et al[47], recently reported that the 3D implant planning performed on dedicated software coupled a semi guided sleeve and a conventional freehand 1-to-2-drill osteotomy preparation protocol may allow appropriate implant placement, overcoming the problem related to the fitting of the fully guided template in tight surgical spaces. They enrolled 18 patients requiring extraction of a tooth followed by a single immediate implant placement. Small volume preoperative CBCT scans were used. The planning of implant positioning and implant size was performed using SimPlant Pro 15 software. Eighteen tapered screw implants were immediately placed in the aesthetic zone into fresh extraction sockets and immediately loaded. The implant and prosthesis cumulative survival rate reached 100%. Postoperative CBCTs were used for the analysis of actual implant positionings. The analysis showed no statistical difference between the planned position and final implant placement position in any measurement.

Using the software program Implant 3D, Behneke et al[44] reported on the clinical outcomes of 52 partially edentulous patients. Guidance was provided by laboratory-fabricated tooth-borne templates. Out of a total of 132 implants 19 were placed to rehabili-

tate single missing teeth. The cumulative implant survival rate was 100%. The implants were placed fully guided, with freehand implant placement after having drilled through the template sleeve, and freehand final drilling and implant placement. Significant differences were seen at all aspects of measurement (implant shoulder level, apical level and angulation), yielding generally higher deviations for the freehand final drilling and implant placement group.

For the aesthetic outcomes of computer-guided surgery, compared to freehand surgery for managing a single tooth gap, limited data are available. In a retrospective study, Fürhauser et al[85] reported the 3D accuracy of 27 single-tooth implants, placed for delayed replacement of upper incisors, using computer-assisted implant treatment planning software (NobelClinician) and stereolithographic templates. No implant or prosthetic failures were reported. They assessed the aesthetic outcome using the PES[80]. The authors found that the 3D inaccuracy is low in computer-guided implant surgery. Nevertheless, deviations toward the buccal side ≥ 0.8 mm resulted in significantly worse implant aesthetics (median PES: 9.5, IQR: 8 to 11) compared with more accurate implant positions (mean PES: 13, IQR: 12 to 13). These results confirm the hypothesis that the three-dimensional implant position has an important influence on the aesthetic outcome. Within the deviations reported, the inaccuracy toward the buccal side was the most frequent at 70%, and may result in an increased crown length compared to the contralateral tooth and in midfacial gingival recession over time.

Moreover, computer-guided surgery showed significantly better results regarding mesial papilla presence (89% vs 57%, $P < 0.001$), distal papilla presence (81% vs 61%, $p = 0.010$), as well as natural soft tissue contour (67% vs 43%, $p = 0.004$) with a mean follow-up of 2.3 years[32], compared with other studies[85-87], in which the PES score was used to evaluate the outcome of single-tooth implant aesthetics in the anterior maxilla following delayed placement with flap elevation. These findings may be attributed to less damage to interdental gingiva and favourable mucosal contouring by soft tissue punching using the flapless surgical approach. High aesthetic and predictable results may be achieved by flapless computer-guided implant placement, demonstrating that preplanned implant positions in the 3D software are precisely tranlated into surgical reality and, therefore, enhanced the achievement of a favourable emergence profile and soft tissue architecture in the aesthetic zone[54,56,59,85], as well as in the posterior quadrants[58].

Kamposiora et al[53] published a clinical report of two patients who belong to a larger ongoing clinical trial of 20 patients with missing single tooth in the aesthetic zone. The Facilitate 3D implant planning software was used to fabricate stereolithographic models, surgical templates and a zirconium dioxide definitive abutment with a provisional crown. The implants were placed with a flapless approach and the abutments immediately delivered and provisionalised. A final restoration was fabricated from all-ceramic material after several months. The stereolithographic model was used to simulate the surgical procedure and allow a real zirconia implant abutment to be fabricated and placed in position using the surgical template. The authors were contacted in order to implement their data, by considering the entire sample of 20 patients. No implant and prosthetic failures were experienced at 1-year follow-up. The only complication reported were small occlusal adjustements to compensate for the inaccuracy of the guidance system in the z axis. Mandelaris et al[60], more recently, confirmed how the digital integrated workflow allow novel streamline tooth replacement strategies as the fabrication of a CAD/CAM patient-specific abutment before surgical treatment. They performed a flapless minimal invasive implant placement with simultaneous delivery of a CAD/CAM customised abutment and a provisional crown with no occlusal contact, in a single visit. The result was a preserved emergence profile in the presence of high aesthetic results[57].

Clinical relevance and recent developments

The surgeons should not put blind trust on the transfer precision from the 3D virtual planning. Although, in general, tooth-supported templates are accurate, the application of guided surgery to enhance single-tooth implant positioning and aesthetic outcome have so far not been widely investigated. Clinicians should not only consider the mean inaccuracy but the largest reported, in order to treat with adequate safety.

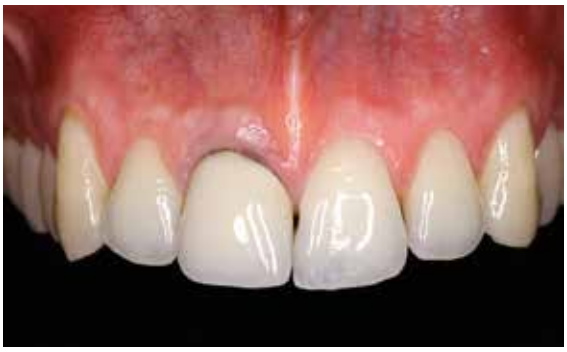

Fig 2 Pre-operative frontal view of anterior maxilla with failed PFM crown and fistula; thin gingival biotype.

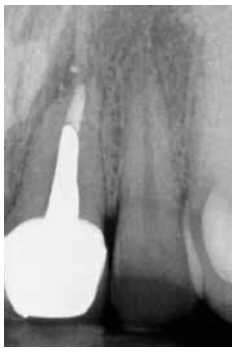

Fig 3 Preoperative radiograph showed the metal post the periapical infection. The inter-proximal bone peaks are maintained.

Fig 4 Preoperative master cast with the temporary crown to be delivered the day of the tooth extraction and implant placement. The patient model was scanned with a digital high resolution optical scanner.

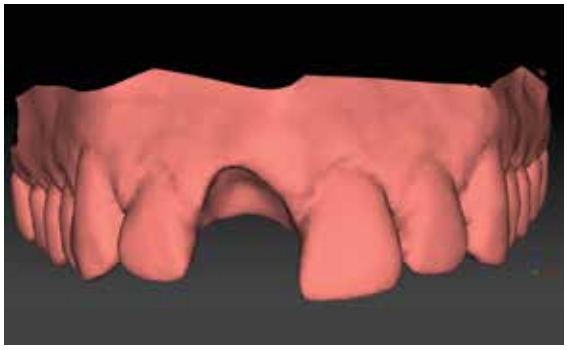

Fig 5 Three-dimensional visualisation of the patient upper arch surface anatomy without the central incisor to show the ideal soft tissue architecture and prosthetic emergence.

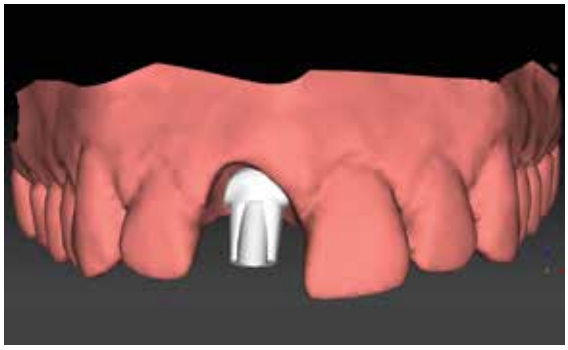

Fig 6a Three-dimensional visualisation of the patient upper arch surface anatomy with the CAD-designed anatomic abutment in accordance with the ideal gingival margin, papilla height and prosthetic emergence.

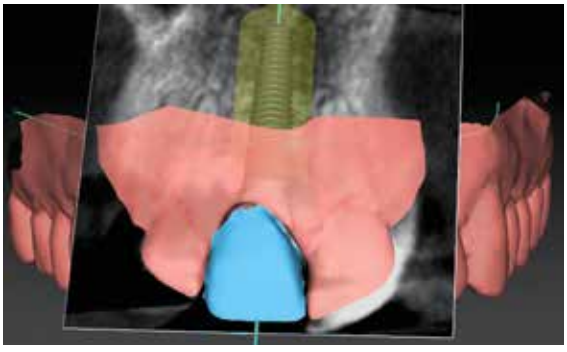

Fig 6b Three-dimensional visualisation of the patient surface anatomy, tooth design , implant positioning and the related CBCT cross-section in accordance with the ideal gingival margin, papilla height and prosthetic emergence.

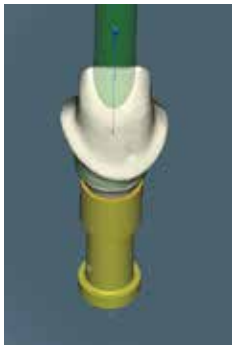

Fig 7 Preoperative CAD design of the Zirconia definitive abutment.

Fig 8 CSAD-CAM Zirconia abutment try-in onto the pre-operative mater cast.

Flapless surgery reduces patient discomfort[10,12,88,89]. Flapless computer-guided surgery may allow implant treatment in medically compromised patients who would be excluded due to the stress related to the length of the surgical intervention and the higher risk of intraoperative and postoperative complications[90]. Flapless surgery in patients with newly grafted bone may also reduce the bone resorption associated with interruption of the periosteal blood supply[91]. Planning based on CBCT data often over-

Fig 9 Immediate provisionalization the day of tooth extraction and implant placement.

Fig 10 Fully guided surgery and implant placement through the sleeve.

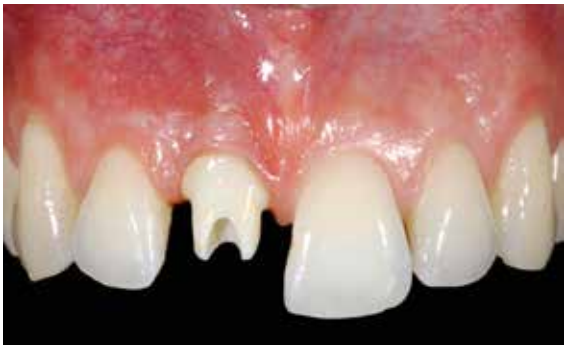

Fig 11 Five months after the healing of the soft tissue around the anatomically shaped Zirconia abutment delivered the day of the surgery.

Fig 12 One -year clinical outcome of the definitive crown cemented onto the zirconia abutment delivered the day of the tooth extraction and implant placement.

looks the soft tissue anatomy[62]. New technologies combining CT/CBCT DICOM data with information on the soft tissues and crown morphology, obtained through digital high-resolution optical scanners, should be encouraged (Figs 2 to 14). Ritter et al[92], assessed the accuracy of this newly developed digital workflow on 16 patients through 1792 measurements. All data pairs were matched successfully and mean deviations between CBCT and 3D surface data were between 0.03 (± 0.33) and 0.14 (± 0.18) mm. According to the results of this study, they concluded that registration of 3D surface data and CBCT data works reliably and is sufficiently accurate for implant planning. The recently introduced 3D software program (NobelClinician), automatically combines the DICOM data from CT/CBCT examination of the patient with the STL data from the surface high-resolution optical scanning of the patient preoperative master cast and tooth setup, through a proprietary algorithm process (SmartFusionTM, Nobel Biocare). Technically, the accuracy of this automatic matching workflow is 1 voxel size below (internal data, Nobel Biocare), manual segmentation workflow based on pairing, at least three points on the surface of the patient CT/CBCT anatomy with the equivalent ones of the patient anatomy achieved by the digital high-resolution optical scanning. Thus, the current workflow is reversed so that CBCT/CT scans can be performed as a first step prior to any laboratory fabrication of a radiographic template or wax-up, which can later be scanned and merged with the CBCT/CT data. The availability of tooth morphology digital libraries within the planning software will streamline the digital planning further.

Fully digitally planned guided surgery and prosthetics can thus be performed in two visits without the need for conventional intraoral impressions, laboratory procedures and advanced manual skills[51].

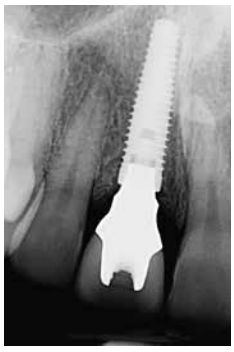

Fig 13 One-year periodical radiographs assessing the bone levels with the bone overgrowth onto the implant platform.

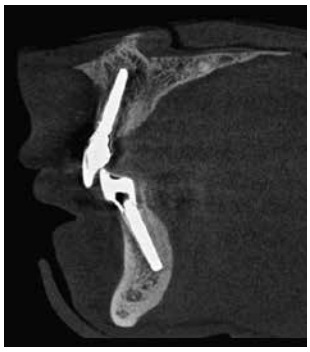

Fig 14 One-year CBCT evaluation of the fully guided implant placement.

Learning curve-experience

Several clinical trials pointed out the importance of the learning curve[10,16,17], while other studies did not[48,72,79,93]. Recently published *in vitro* research on computer-guided surgery for missing single teeth in the posterior mandible[48] did not find significant differences in the angular and linear deviations between experienced and inexperienced operators. Almost all implants (95%) were placed more coronally than the planned position. The amount of vertical deviation in the coronal direction of the implants placed by the inexperienced operators was about twice that placed by the experienced ones. Nevertheless, these results suggest that the vertical position control of the computer-guided system provides adequate safety features, as most of the errors were in the coronal direction; therefore, the risk of encroaching on vital structures (such as the inferior alveolar nerve and the maxillary sinus) when dealing with missing single molars is minimal.

Computer-guided implant surgery remains technically demanding and is not free from complications, such as fracture of the template, incorrect implant positioning or misfitting of the prostheses[37,94]. A recently published review[38] reported template fracture (3.6%), change in surgical plan (2%) and lack of primary stability (1.3%) as the most frequent complications.

Conclusions

The evidence supporting the hypothesis that there is a clinical advantage using computer-guided surgery compared to conventional freehand implant placement for the treatment of single-tooth gap is still limited. Nevertheless 19 clinical studies, investigating the clinical outcomes of the computer-guided surgery for missing single teeth, were identified and included in this review, accounting for an overall amount of 342 single implants placed in 209 patients (18 to 67 years old), with a follow-up between 12 and 52 months and a cumulative survival rate ranging from 96.5% to 100%. The survival rates of computer-guided surgery were comparable with those of conventional freehand implant placement after an observation time of 12 to 60 months[65], and therefore this systematic review revealed no obvious differences between the two clinical workflows.

The specific computer-guided surgery-related complications, such as fracture of the template, incorrect implant positioning, change in surgical plan, lack of primary stability or misfitting of the prostheses were not experienced by the clinical studies included in the review. Clinicians should take into consideration the software specific differences and their mean inaccuracy, in order to perform the implant placement procedures with adequate safety.

Given the recently developed fully digital workflow with 3D soft tissue virtual visualisation, the computer-guided surgery minimal-invasive flapless implant placement is becoming a more predictable procedure in terms of improved planning, accuracy and survivability. Avoidance of flap elevation seems to benefit peri-implant mucosal outcome, particularly in terms of maximum preservation of peri-implant papillae and reduced mucosal recession. When the width of keratinized mucosa is limited, specific surgical approaches may be favoured.

Clinicians should inform patients that computer-guided surgery implies additional costs. However, these costs should be analysed in terms of cost-effectiveness and assessed towards the reduction of surgery time and postoperative discomfort as well as, the potentially increased accuracy. Randomised clinical trials comparing computer-guided surgery with conventional 'freehand' implant placement for the treatment of missing single teeth are very much required.

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A systematic review of survival of single implants as presented in longitudinal studies with a follow-up of at least 10 years

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Background: Placement of single implants is one of the most common applications for implant treatment. Millions of patients have been treated worldwide with osseointegrated implants and many of these patients are treated at a young age with a long expected remaining lifetime. Therefore long-term evidence for such treatment is important.

Aim: To report patient treatment, implant and implant-supported single crown survival over at least a 10-year period of follow-up. Material and methods: After reviewing long-term publications, included by Jung et al (2012), a complementary PubMed search was performed using the same search strategy for the period September 2011 to November 2014. Data on implant and single implant crown treatment survival were compiled from included studies.

Results: Four new publications were identified from the 731 new titles. They were added to an earlier list of five manuscripts by Jung et al (2012) , which were already included. Accordingly, nine publications formed the database of available long-term evaluations. The database consisted of 421 patients altogether, provided with 527 implants and 522 single crowns. From the 367 patients that were followed-up for at least 10 years (87%), altogether 502 implants were still in function at the completion of the studies (95.3%), supporting 432 original and 33 remade single implant crowns. Based on patient level and implant level data, implant survival reached 93.8% and 95.0%, respectively. The corresponding survival rate for original crown restorations was 89.5%.

Conclusions: Single implant treatment is a predicable treatment over a 10-year period of time, with no indication of obvious changes in implant failure rate between 5 and 10 years. However, replacement of new single crowns must be considered during the follow-up as part of regular maintenance. Compared to the number of treated patients worldwide, the available numbers with a follow-up of 10 years was low.

■ Introduction

Today, implant-supported single crowns can be regarded as a favourable treatment option for single tooth gaps. From a health economic viewpoint implant-supported single crowns have been suggested to be preferable to tooth-supported 3-unit prostheses[1]. Furthermore, implant-supported single crowns are tooth-tissue preserving in comparison to tooth-supported prostheses and their 10-year survival seems to be 10% higher[2,3]. In addition, with the development of treatment procedures such as bone and soft tissue augmentation and development of crown and abutment materials, an increased aesthetic outcome can be achieved[4,5]. Single tooth gaps may often result from trauma at a young age,

associated with sport activities or traffic accidents. Another common cause in young patients can be aplasia of one or more teeth. As a consequence, many patients are young and start their implant treatment in late adolescence. Thus, due to the youth of the patients, the implant-supported single crowns should hopefully remain in place for decades and with as few complications as possible during this time span.

In a systematic review, Jung et al reported the survival of implants supporting single crowns and of implant-supported single crowns[6]. After five years, the calculated survival of implants was 97.2% (95% CI: 96.3 to 97.9%), and 96.3% (95% CI: 94.2 to 97.6%) for implant-supported single crowns. Cumulative incidence of technical, biological and aesthetic complications was also calculated[6]. Yet, even though long-term, up to 10-year results were also estimated, the review was basically limited to longitudinal studies with a mean follow-up time of 5 years[6]. Considering the youth of many patients at the time of treatment, as mentioned above, there is a need for reviews of studies with a longer follow-up time than 5 years.

The aim of the present review was therefore to assess the 10-year survival of single implants and implant-supported single crowns, and to present the incidence of biological and technical complications.

Material and methods

Search strategies

In the present review, two search strategies were used. First, the total reference list of included studies from a recent previous systematic review on single implants was screened[6]. In the second search, a PubMed search was performed for studies published from September 2011 to November 2014, and limited to the English language, based on search terms, as used by Jung et al[10]. The search terms were (((((complication* AND Humans [Mesh])) OR (((survival) OR survival rate) AND Humans [Mesh])) AND Humans [Mesh])) AND dental implants [MeSH Terms]. The two searches were complemented by manual searches of the reference lists of all full-text studies selected from the electronic search and associated reference lists.

Inclusion criteria

- Original studies on humans with a minimum amount of 15 patients with single crowns.
- Assumed minimum follow-up of at least 10 years for the majority of patients i.e. this means that a mean follow-up time of 9.5 years could be accepted.
- Less than 50% of dropouts.
- Data reported on patient level, where single implant patients could be identified as a group if mixed groups of partially edentulous patients were followed-up.
- Randomised controlled trials, controlled clinical trials, prospective case series, cohort studies and retrospective studies.

Exclusion criteria

- Studies not meeting all inclusion criteria.
- Studies not reporting on numbers of all patients included and lost to follow-up.
- Studies not reporting on implant survival.
- Studies based on questionnaires, interviews and charts.

Selection of studies

The three authors screened the titles from the studies found in the two broad searches independently, considering the inclusion criteria. After discussion, disagreements were resolved. In the next step, abstracts of all studies agreed upon, were obtained and screened according to the inclusion criteria by the three authors, independently of each other. Once selected, the full texts of the studies were acquired. These publications were again independently scrutinised and a final discussion took place to reach a consensus. All selected studies were then examined and analysed (Fig 1).

Extraction of data and analysis

Data from all included studies were extracted by using data extraction forms. Information on the survival of the single crowns and of biological and technical complications was retrieved. 'Survival' was defined as the implant/restoration remaining *in situ*

at follow-up examination visits. The three authors checked the extracted data, and eventual disagreements were discussed until a consensus was reached. The numbers of events were extracted and the corresponding total exposure time of the single crowns was calculated.

Statistical analysis

In the present report, descriptive data are presented as numbers and frequencies. Mean values have been calculated as weighted values based on the individual group mean value and number of participating patients. Data are being presented on 'patient', 'implant' and 'crown restoration' levels. Survival rates were calculated as:

Survival rate (%) = (1-(failures/(included-(dropouts/2)))*100

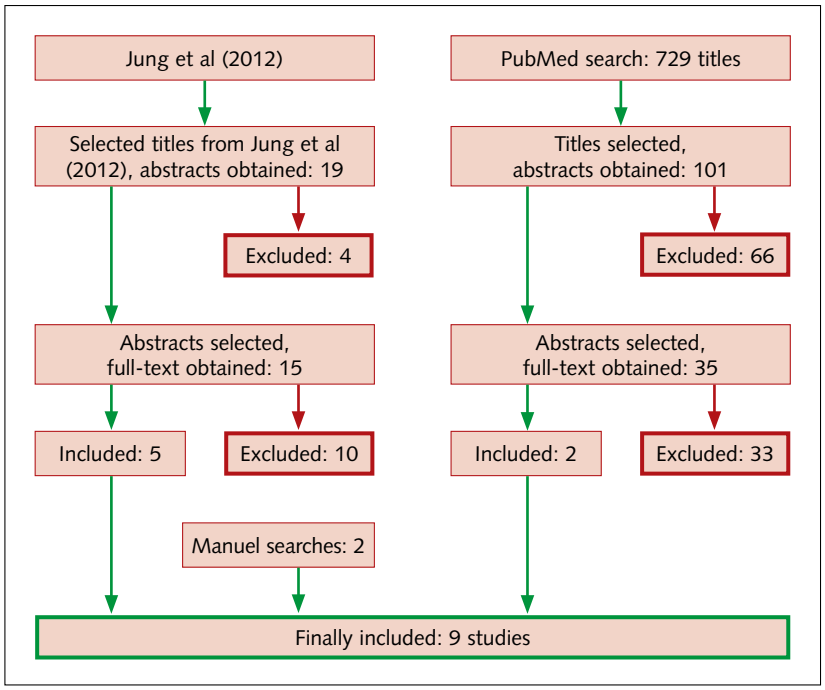

Fig 1 Search strategies and results for the previous review by Jung et al (2012), the complementary PubMed search from September 2011 to November 2014 and the manual search.

Results

From the reference list from the previous review by Jung et al[6], 19 abstracts were selected. Full-text articles from 15 of these were scrutinised, including 8 out of 10 studies referred to as long-term studies by Jung, and finally, five studies were selected for the present review. These five included studies corresponded to 'long-term/10-year' studies included by Jung et al[6] (Fig 1).

The new PubMed search resulted in 729 study titles. Abstracts were scrutinised from the 101 study titles selected. Full-text articles were obtained from 35 of these abstracts. Finally, two of these studies were included in the present review and consequently, 33 were excluded. The manual searches resulted in two additional studies. The main reasons for exclusion of the 43 reviewed full-text articles were:

- Mixed data or not reported at single crown restoration level (n =18).
- Less than 10 years of follow-up or unclear follow-up time (n = 8).
- Less than 15 patients included (n = 6).
- Dropout exceeding 50% (n = 5).
- Review studies (n = 4).
- Not reporting on the number of all patients included and lost to follow-up (n = 2).

Accordingly, nine studies were included in the study, four prospective and five retrospective ones (Table 1). Treatment had been performed in specialist clinics in five studies and in a university setting in four studies. None had been performed in a general dentistry clinic.

Altogether 421 patients were treated with single implants at a calculated average age of 36.3 years (Table 1). In total, 60 patients were lost to follow-up (14.3%), while the remaining patients (n = 361) were followed up for a calculated average of 11.7 years (range 7.5 to 19 years). Patients were provided with 527 single implants from at least four different implant manufactures and had both turned and moderately rough surfaces (Table 1; one publication – 'not reported system'). Implants were placed using both one- and two-stage surgery protocols in both the maxilla and mandible and in both anterior and posterior parts of the jaw. Most of the included studies covered Brånemark System implants (Nobel Biocare AB, Göteborg, Sweden) with a turned implant surface (Tables 1 and 2).

The patients were provided with 522 single implant crown restorations, with the majority reported as porcelain fused to metal restorations (n = 283),

Table 1 Study design and patient characteristics; N = number of patients, N/A = not available/reported.

Study		Patients			Follow-up				Implant system	Clinical Setting
Author (Year of publication)	Design	N	Mean age	Age range	Dropout (%)	Dropout (No. of patients)	Mean time (years)	Range (years)		
Thilander et al (2001)	Prospective	15	15.3	13-17	0	0	10	N/A	Brånemark	Specialist clinic
Jemt (2008)	Retrospective	38	25.4	NA	29	11	15	N/A	Brånemark	Specialist clinic
Jemt (2009)	Retrospective	35	31.3	18-75	31	11	10	N/A	Brånemark	Specialist clinic
Gotfredsen (2009)	Prospective	20	33.0	18-59	5	1	10	N/A	Astra Tech	University
Bonde et al (2010)	Retrospective	51	43.0	19-79	12	6	10	7.5-12.0	Brånemark	University
Matarasso et al (2012)	Retrospective	80	47.3	NA	7.5	6	10	N/A	Brånemark Straumann	University
Covani et al (2012)	Prospective	98	N/A	23-75	7.1	7	10	N/A	Premium	Specialist clinic
Bergenblock et al (2012)	Prospective	57	31.9	15-57	16	9	18.4	17.0-19.0	Brånemark	Specialist clinic
Misje et al (2013)	Retrospective	27	N/A	17-41	33	9	N/A	12.0-15.0	N/A	University
Total		**421**	**36.3**	**14-79**	**14.3**	**60**	**11.7**	**7.5-19**		

Table 2 Implants and single crown restorations; N/A = not available/reported.

Study	Patients	Implants	Single crowns					
Author (age)	Number included	Number included	Number included	Sites / jaws	Cemented	Screw retained	Metal / ceramics	All ceramics
Thilander et al (2001)	15	29	29	Maxilla / Mandible	15	0	15	0
Jemt (2008)	38	47	47	Anteririor Maxilla	47	0	47	0
Jemt (2009)	35	41	41	Incisors / premolars	23	18	41	0
Gotfredsen (2009)	20	20	20	Anteriror Maxilla	20	0	20	0
Bonde et al (2010)	51	55	52	Maxilla / Mandible	52	0	N/A	N/A
Matarasso et al (2012)	80	80	80	Maxilla / Mandible	N/A	N/A	N/A	N/A
Covani et al (2012)	98	159	157	Incisors / premolars	0	157	157	0
Bergenblock et al (2012)	57	65	65	Maxilla / Mandible	65	0	3	62
Misje et al (2013)	27	31	31	Anterior Maxilla	N/A	N/A	N/A	N/A
Total	**421**	**527**	**522**		**222**	**175**	**283**	**62**

and some as all-ceramic crowns (Table 2; n = 62). Two hundred and twenty-two of the crowns were reported as 'cemented' and 175 as 'screw retained' (Table 2). However, data were not available to distinguish between crowns that were cemented to the abutment and screw retained thereafter, and those that were cemented directly onto the abutment, without access screw holes in the oral cavity.

Altogether 25 implants were removed during follow-up, in presumably 25 different patients (Table 3). Five of these implants were reported to be lost before crown placement. No detailed information over time was available to allow for calculation of a 'patient survival' / 'implant survival' life table. No study reported implant survival rate at 'patient level'. Four studies reported no implant failures at all during follow-up. The remaining studies reported an implant failure rate between 3.2% and 8.2%, corresponding to an implant survival rate between 91.8% and 96.8%, respectively (Table 4). An overall estimation of implant survival in the database on 'patient level' was calculated at 93.8%. Correspond-

Table 3 Complications and failures at implants and single crown restorations; N/A = not available/reported.

Study	Patients	Implants			Original single crowns				
Author	**Included**	**Placed**	**Failures**	**Mean bone loss**	**Placed**	**Followed up***	**Porcelain fractures**	**Loose**	**Remade**
Thilander et al (2001)	15	29	0	N/A	29	29	N/A	N/A	0
Jemt (2008)	38	47	0	0.7	47	25	1	1	11
Jemt (2009)	35	41	0	0.3	41	29	N/A	5	1
Gotfredsen (2009)	20	20	0	N/A	20	18	2	2	2
Bonde et al (2010)	51	55	3	N/A	52	46	3	3	3
Matarasso et al (2012)	80	80	6	2.1	80	74	N/A	N/A	N/A
Covani et al (2012)	98	159	13	N/A	157	144	2	9	2
Bergenblock et al (2012)	57	65	2	0.8	65	48	2	2	8
Misje et al (2013)	27	31	1	1.5	31	16	4	1	6
Total	**421**	**527**	**25**	**1.3**	**522**	**429***	**14**	**23**	**33**

* No accurate data available for individual studies; numbers estimated to be in total between 429 and 434 original crowns (mean 432 original crowns).

Table 4 Reported and estimated patient / implant and single implant crown failure rates over >10 years of follow-up.

Study	Patients*		Reported failure rate (%)		Estimated >10 year survival (%)		
Author	**Included**	**End**	**Implants**	**Crowns**	**Patients*#**	**Implants***	**Crowns***
Thilander et al (2001)	15	15	0.0	0.0	100.0	100.0	100.0
Jemt (2008)	38	27	0.0	23	100.0	100.0	76.6
Jemt (2009)	35	24	0.0	N/A	100.0	100.0	97.6
Gotfredsen (2009)	20	19	0.0	10.0	100.0	100.0	90.0
Bonde et al (2010)	51	45	6.0	6.0	94.1	94.5	94.2
Matarasso et al (2012)	80	80	7.5	N/A	92.5	92.5	N/A
Covani et al (2012)	98	91	8.2	N/A	86.7	91.8	91.8
Bergenblock et al (2012)	57	48	3.2	16.2	96.5	96.9	84.6
Misje et al (2013)	27	18	4.5	4.5	96.3	96.8	77.4
Total/mean (Range)	**421**	**367**	**(0.0-8.2)**	**(0.0–23.0)**	**93.8 (86.7–100.0)**	**95.0 (91.8–100.0)**	**89.5 (76.6–100.0)**

* calculations based on inclusion data
# estimated; assumed one implant failure per patient

ing estimation of survival rate on 'implant level' was 95.0%. Implant level survival rates showed a variation between the studies, reported from 91.8% to 100.0% (Table 4). Mean marginal bone loss during the entire follow-up was reported in five studies, ranging from 0.3 mm to 2.1 mm (Table 3). An overall mean bone loss was calculated to reach 1.3 mm during 10 years of follow-up.

It was estimated that 37 of the crowns had been lost to follow-up due to various reasons (dropout). Another 20 crowns were lost due to implant failure and 33 were remade (Table 3). Accordingly, it was estimated that 432 of 522 original single crown restorations were followed up for the entire 10-year period (Table 3). Overall original single crown survival rate was estimated to be 89.5% (Table 4). Reasons for remaking the single crowns were reported as aesthetical or technical, i.e. fractures of veneer material and implant crown infraposition. Available data in the publications were not considered suitable to allow for a detailed presentation of these observations.

■ Discussion

Single implant treatment is today one of the most common implant treatment options worldwide. From the millions of patients provided with oral implants, a significant proportion received single implant restorations. It can be assumed that many of them belong to the young age group, thus with a long remaining lifetime. It is therefore important to collect data on clinical long-term outcome of single implant restorations. Altogether nine studies, four prospective and five retrospective, fulfilling the present inclusion criteria could be selected (Figure 1). The present review is based on studies included in the literature review by Jung et al[6], complemented with a similar PubMed search, but up to the end of 2014. The present included studies report altogether on 421 patients, where 367 patients were followed for 10 years or more (Table 4). However, these patients cover only a small fraction of all single implant patients that have been treated worldwide, and accordingly, long-term evidence for single implant treatment must be considered to be low. Furthermore, the treatments described in the studies included in the present review were all performed in specialist clinics or university hospitals, and not in general practice.

In the present review, a calculated mean of only 14.3% of the patients were lost to follow-up which must be considered as a low dropout ratio for 10 years of follow-up. One reason for this high level of compliance might be that the performed implant treatments described in a number of the included studies were following new treatment protocols as pioneer groups (Thilander et al 2001, Gotfredsen 2012 and Bergenblock et al 2012). As a consequence, the included patients can be considered to be highly motivated both for the treatment, but also for the follow-up and the results may not necessarily reflect clinical results in daily practice.

Interpretation of the clinical outcome of oral implants is often difficult since different investigators neither use similar study designs nor success and survival criteria. Furthermore, patient selection and dropouts are often improperly described and there are frequently variations in follow-up time of the patients, even in a single study. Yet, however desirable, it does not seem realistic to perform a large scale high quality randomised, double-blinded, prospective clinical trial for long-term evaluation of implant prosthodontics. In many situations treatment protocols may have changed so much over time that studied protocols are not in use any more at termination of the study. This raises both cost and ethical considerations[7,8]. As an alternative strategy, systematic reviews can be regarded as tools for the clinicians to make appropriate clinical decisions in individual patients, which are as evidence-based as possible[9,10]. The present results, based on mostly implants with a turned surface could be taken as an example of this challenge where introduction of new implant surfaces may have an obvious impact on implant failures[11].

One should be aware that 5- and 10-year survival rates and complication frequencies presented in systematic reviews are commonly calculated through advanced algorithms and statistical methods. They are therefore theoretical assumptions and not observations per se. Since the selected studies forming the base of the present review, report on relatively few patients and show variations in inclusion, type of treated patients, implant systems, performed treatments and follow-ups, it was decided to only calculate an 'overall survival rate'. Therefore the authors refrained from more sophisticated calculations which would imply more accurate data than actually observed.

Inclusion of studies in review publications is based on inclusion criteria and the compliance and interpretation of these criteria during the process. Sometimes the criteria for inclusion may become too strict which results in the inclusion of no or very few studies. Most of the present studies were also included by Jung et al[6]. However, some of the 'long-term/10-year studies' included by them were excluded from the present review. The main reason for this was that the follow-up time was too short as defined in the pre-set inclusion in the present study. Yet, two studies were excluded for other reasons; Brägger et al[12], because there were problems when extracting patient level data, and Jung et al[13], because there were problems in finding detailed information on inclusion criteria and the number of individual patients with single crowns.

The most frequent reason for exclusion in the present review was mixing up data for single crown

restorations with those of other restorations in the partially edentulous jaw, reported in the same study. Sometimes an inconsistency in, for example the number of included patients and implants in earlier publications for the same study group led to the exclusion. The present long-term results are comparable to those reported by Jung et al[6] indicating that about 94 % of the patients (95% of implants) will not experience a failure during follow-up. This observation is re-assuring, indicating that compared to data for 5 years of follow-up[6], no obvious increase in failure rate seems to occur during the last 5 years. However, the present long-term observation is basically based on implant systems with implant surfaces – mostly turned - that are not in use today (Table 1). Future long-term studies based on implant surfaces used today may reveal other survival rates.

Compared to the relatively low levels of implant failures over the years, failure rate of the original crown restoration seems to be higher (11.0 %). This review reveals that a number of crown restorations were remade due to the learning curve associated with a new technique, or due to more time dependent factors, such as fractures, changed shade of adjacent teeth, mucosal recession and implant infraposition after facial growth.(5, 14) Thus, it must be considered that remaking some single crowns is part of the maintenance protocol during the lifetime of the patient.

Conclusions

- Nine publications covering 10 years or more of clinical follow-up of single implant treatment were included in the present study. These studies comprised altogether 421 patients at inclusion and 367 patients at termination of the studies (87%).
- Altogether 25 patients presented an implant failure (25 implants) during follow-up, resulting in an estimated overall patient implant treatment survival rate of 93.8% at termination. Corresponding implant survival on 'implant level' was 95.0%.
- Fifty-three single implant crown restorations were reported to be lost, either as a result of implant failures (20 crowns) or were remade due to various reasons (33 crowns). Original single implant crown survival rate was calculated to be 89.5%.
- Data on mechanical complications were not consistently reported amongst the studies to allow an overview.
- Data on other biological problems were not consistently reported amongst the studies to allow an overview.

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Single implants in dorsal areas – A systematic review

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Key words *delayed loading, delayed placement, immediate loading, immediate placement, posterior quadrant, single implant*

Aim: This study evaluated the efficacy of replacing single missing teeth in the posterior quadrants of the maxilla and/or mandible with an implant-supported dental prosthesis.

Material and methods: Three scientific literature databases – Medline (Pubmed), Ovid Medline and Cochrane Central Register of Controlled Trials (CENTRAL) – were used to perform a search of publications over a period from 1985 to 2014. One hundred and forty one (141) articles were reviewed; 36 articles met the inclusion criteria and were included in the final review.

Results: The survival rates, success rates and mean bone loss for immediate implant placement were 96.9%, 100% and 0.85 mm, respectively. The survival rates, success rates and mean bone loss for delayed implant placement were 96.8%, 94.1% and 0.55 mm respectively. The survival rate, success rate and the mean bone loss in studies comparing immediate versus delayed implant placement showed 96.8% and 96.3%, 85.8% and 93.3%, and 0.57 ± 0.57 mm and 0.55 ± 0.37 mm, respectively.

Conclusion: The prognosis for single molar implants provides a viable treatment option for replacing a single missing tooth in the posterior quadrants of the maxilla and mandible. There does not appear to be a significant difference in the survival rates of immediately placed implants compared with delayed implant placement. However, the success rates were slightly higher with delayed loading protocols than immediate loading protocols.

Conflict-of-interest statement: *Authors report no conflicts of interest.*

Introduction

Implant-retained dental prostheses have provided new treatment options for restoring dental arches with missing teeth or completely edentulous mouths. It is well known that endosseous implants show remarkable ability for osseointegration and are effective in supporting numerous dental prosthetic designs[1,2]. However, the efficacy of placing an implant in the posterior regions of the jaws has not been well addressed. Urban and his colleagues have looked into risk factors for implant failure in the molar and pre-molar regions such as smoking, buccal dehiscence and infection[3]. While studies have examined implant placement techniques and associated complications, there is heterogeneity with publications reporting on the survival and success rates of implant placement in the posterior region.

Furthermore, the various staging and loading protocols to manage the implant after placement remain controversial. Brånemark's traditional protocols for implants used a staged approach. After

extraction of tooth/teeth, a healing period of 3 to 6 months was permitted, followed by implant placement, and another healing period of 3 to 6 months, followed by second stage surgery to expose the implant, and finally loading of the implant with a prosthetic restoration. This traditional protocol has longer treatment times and more surgical steps requiring multiple recovery times. As research on dental implants has progressed over the decades, specifically by modification of the implant surface roughness and macro-design, clinical researchers have started to look toward immediate implant placement following tooth extraction. Advantages of immediate implant placement following extraction are reduced number of procedures, shortened treatment times, and therefore fewer recovery periods with less discomfort for the patients. Another possible benefit is found in studies showing that immediate implant placement in fresh extraction sockets may limit the bone remodelling which typically takes place with the alveolar ridge after tooth extraction[4].

Several studies have shown that there is no difference in survival rates between immediate implant placement and delayed implant placement[5]. The immediate placement of implants have shown survival rates between 95% to 100% and success rates of 89% to 98%, irrespective of the loading protocols. The loading protocols in the studies varied from the traditional, delayed approach to early loading and immediate loading. However there seems to be more failures with both immediate and early loading than with delayed loading[6].

The aim of this review is to study the efficacy of implant placement in the posterior region with different placement (immediate and delayed) and loading protocols (immediate, early and delayed).

Materials and methods

PICO (P - patient problem or population, I - intervention, C - comparison, O - outcome[s])

- Patients requiring extraction of molar teeth.
- Intervention: immediate implant placement/ delayed implant placement.
- Comparison: no comparison required/delayed implant placement.
- Outcome: implant success and survival.

Search strategy

A search strategy was conducted using Pubmed, Ovid Medline and Cochrane Central databases using a combination of Medical Subject Heading (MeSH) terms and [ALL Fields] were used for searching the literature for studies relevant to the topic. A manual search was also conducted from the reference list of the selected articles. The search was limited to only articles that met the inclusion criteria. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol has been used as a guide when reviewing the selection of the articles. Total number of articles found are 138 with initial search terminology: Immediate [All Fields] AND Implants [All Fields] AND Delayed [All Fields] AND Implants [All Fields] AND („Molar" [MeSH Terms] OR „Molar" [All Fields]) AND („Tooth" [MeSH Terms] OR „Tooth" [All Fields] OR „Teeth" [All Fields]).

From 141 articles (138 electronic, 3 manual), 52 articles were available for review with the search limited to clinical trials, comparative studies, controlled clinical trials, randomised clinical trials, meta analyses, reviews and systematic reviews. The following combination of words were used to limit the study: (Immediately [All Fields] AND Implants [All Fields] AND Delayed [All Fields] AND Implants [All Fields] AND („Molar" [MeSH Terms] OR „Molars" [All Fields]) AND („Tooth" [MeSH Terms] OR „Tooth" [All Fields] OR „Teeth" [All Fields]) AND ((Clinical Trial [ptyp] OR Review [ptyp] OR Systematic [sb] OR Randomized Controlled Trial [ptyp] OR Meta-Analysis [ptyp] OR Controlled Clinical Trial [ptyp] OR Comparative Study [ptyp]) AND „Humans" [MeSH Terms])

After reviewing all the manuscripts, 36 articles were included for this review.

Inclusion criteria

- Prospective case series.
- Randomised clinical trials.
- Retrospective studies.

- May have an implant placed immediately after extraction, irrespective of the loading protocols.
- May or may not have delayed placement group.
- Must have included at least one of the following outcomes: a) survival rate and b) success rate.
- Articles that were published in English.

Exclusion criteria

- Case reports (reporting on < 5 patients).
- Studies that included medically compromised patients.
- Non-compliant patients.
- Non-stable implants at the time of primary placement.

Data extraction

The data were extracted from all eligible studies and were recorded on a prefabricated data extraction table. All studies reviewed for the collection of data met the inclusion criteria. Information retrieved from the studies pertained to the study design, inclusion and exclusion criteria, intervention performed and the outcome. The effectiveness of interventions was assessed in terms of its effect on the outcomes: 1) the implant survival rate and 2) the implant success rate.

Success of the implant is based on the following assessment criteria:

- mean marginal bone loss;
- bleeding on probing around the implants;
- probing depths around the implant.

The data were obtained by calculating the mean of all the means from various studies.

Results

The study selection and number of articles (36) were included in the primary assessment with the final review based on different outcomes:

- Ten immediate implant placement studies reporting survival rate as an outcome.
- Three immediate implant placement studies reporting success rate as an outcome.
- Three immediate implant placement studies measuring bone loss as an outcome.

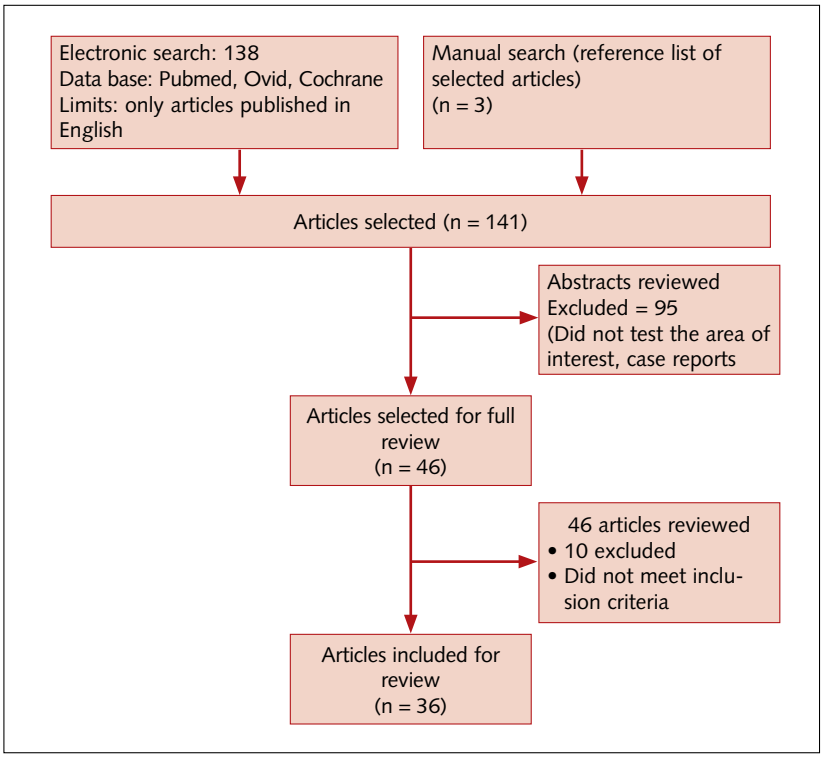

Fig 1 Search strategy.

- Three immediate vs delayed implant placement studies reporting survival rate as an outcome.
- Four immediate vs delayed implant placement studies reporting success rate as an outcome.
- Four immediate vs delayed implant placement studies measuring bone loss as an outcome.
- Fifteen delayed implant placement studies reporting survival rate as an outcome.
- Five delayed implant placement studies reporting success rate as an outcome.
- Ten delayed implant placement studies measuring bone loss as a primary outcome.

Out of 36 articles, 11 were case series studies involving immediate implant placement, five were retrospective or prospective case studies comparing immediate versus delayed implant placement, and 20 examined delayed implant placement with varying loading protocols. The total number of patients reported in immediate implant placement case series studies was 974. The total number of patients reported in case series studies comparing immediate versus delayed implant placement was 267 with a mean study size of 53. The total number of patients reported in delayed implant placement

studies was 2905 with a mean study size of 145. In total, 1077 implants were included in the immediate implant placement case series studies with a mean of 98 implants per study. One hundred and thirty-seven immediate implants and 201 delayed implants were included in the case series studies reporting immediate and delayed implant placement protocols. Three thousand six hundred and forty-six implants were included in the delayed implant placement studies with a mean of 182 implants per study. Of the 3646 implants in the delayed placement studies, 618 underwent immediate loading while 3028 underwent delayed loading. The follow-up times for the immediate implant placement case series studies ranged from 4 to 96 months, whereas the delayed implant placement studies ranged from 5 to 144 months. The retrospective case series studies and randomised control trials comparing immediate vs delayed implant placement had average follow-up periods of 12 months.

Details of intervention

The aim of the review is to study the efficacy of implant placement in the posterior region. As a result, all of the studies included evaluated placement of implants in the molar region. The case series articles reporting on immediate implant placement also varied in their research design as 10 out of the 11 were prospective and one was retrospective. It must also be noted that one of the case series articles reported data from immediate loading, whereas the other 10 studies reported delayed loading of implants after placement. Additionally, the method by which success was determined varied between the articles. Success rate of implants was assessed in the majority of articles reviewed, by using radiographic analysis to measure changes in marginal bone level with the exception of one study that used implant stability quotient (ISQ) measurements[7], another study which used measurements from the Periotest[8], and another study, which used both radiographs and Periotest[9] measurements. The majority of studies used the Albrektsson et al[2] success criteria. According to the success criteria for currently used implant systems, the inserted implants must be immobile at clinical examination and the radiographs must show absence of peri-implant radiolucency. After 1 year of functional loading of the implant, annual vertical bone loss must be less than 0.2 mm and there must be absence of irreversible and/or persistent signs or symptoms of pain, infection, neuropathies, paresthesia or violation of the mandibular canal. At the end of 5 and 10 year periods of observation, an 85% and 80% success rate, respectively must be reached. However, three studies[10-12] based implant success on the Buser clinical and radiological criteria for success: absence of clinically detectable implant mobility, pain or any subjective sensation, recurrent peri-implant infection and continuous radiolucency around the implant after 3, 6 and 12 months of loading[13]. All 16 articles that reported marginal bone loss used radiographic evaluation. The studies all used similar preoperative and postoperative protocols with standard antibiotic regimens.

Primary outcomes

For this review, the two primary outcomes of implant survival and success were evaluated. Out of the 11 case series articles evaluating immediate implant placement, 10 articles measured survival rate as a primary outcome, with a mean survival rate of 96.87% (82.64% to 100%; Table 1). Only three case series articles regarding immediate implant placement measured success rate as a primary outcome with a mean success rate of 100% (100%; Table 2). As one of the criterias for success, the three articles reporting success rate also reported on average bone loss. The Prosper et al[14] study indicated average bone loss results of 1.31 ± 0.44 mm and 1.01 ± 0.59 mm for immediate and delayed loading, respectively, while the overall mean bone loss between the three studies was 0.85 mm (Table 3).

Out of the five immediate versus delayed implant placement studies, three measured survival rates as a primary outcome, with a mean survival rate of 96.8% for immediately placed implants and 96.3% for implants with a delayed placement (Table 4). Four of the studies measured success rate as a primary outcome, with a mean success of 85.8% for immediately placed implants and 93.3% for implants undergoing delayed placement (Table 5). All of the studies involving immediate and delayed placement of implants, with the exception of the Polizzi study, reported the average amount of bone loss, with a

Table 1 Immediate implant placement studies reporting survival rate as an outcome.

Study	No. of implants	DL or IL	Survival	Follow-up (months)
Prosper et al[14]	120	IL-60, DL-60	96.67%	72
Urban et al[15]	92	DL	82.64%	12
Cafiero et al[16]	82	DL	100%	12
Artzi et al[17]	12	DL	100%	6
Fugazzotto[18]	341	DL	99.00%	72
Fugazzotto[19]	83	DL	100%	12-18
Hamouda et al[9]	20	DL	95.00%	18
Jiansheng et al[8]	162	DL	99.40%	12-56
Block et al[7]	35	DL	100%	4
Schwartz-Arad et al[20]	56	DL	89.3%	15
	Total = 1003		**Mean survival = 96.87%**	**Range: 4-72**

DL: Delayed Loading, IL: Immediate Loading

Table 2 Immediate implant placement studies reporting success rate as an outcome.

Study	No. of implants	DL or IL	Success	Follow up (months)
Hayacibara et al[21] (retrospective)	74	DL	100%	12-96
Artzi et al[17]	12	DL	100%	6
Fugazzotto[19]	83	DL	100%	72
	Total = 169		**Mean success = 100%**	**Range: 6-96**

DL: Delayed Loading, IL: Immediate Loading

Table 3 Immediate implant placement studies measuring bone loss as an outcome.

Study	No. of implants	DL or IL	Bone loss (mm)
Prosper et al[14]	120	IL-60, DL-60	1.31 ± 0.44 (IL), 1.01 ± 0.59 (DL)
Urban[15]	92	DL	0.48
Hamouda et al[9]	20	DL	0.6 ± 0.4
	Total = 232		**Mean bone loss = 0.85**

DL: Delayed Loading, IL: Immediate Loading

Table 4 Immediate vs delayed implant placement studies reporting survival rate as an outcome.

Study	No. of implants	Immediate placement	Delayed placement	DL or IL	Survival (IP)	Survival (DP)
Vandeweghe[22]**	93	69	24	IL and DL	95.70%	95.80%
Peñarrocha[31]	123	35	88	DL	97.10%	95.50%
Annibali et al[32]	41	20	21	DL	100%	100%
	Total = 257	**Total = 124**	**Total = 133**		**Mean survival = 96.8%**	**Mean survival = 96.3%**

** Bone loss ≤ 1.5mm during the first year was considered a success and if > 1.5mm then considered part of survival group.

DL: Delayed Loading, DP: Delayed Placement, IL: Immediate Loading, IP: Immediate Placement.

Table 5 Immediate vs delayed implant placement studies reporting success rate as an outcome.

Study	No. of implants	Immediate placement	Delayed placement	DL or IL	Success (IP)	Success (DP)
Atieh et al[23] (prospective)	24	12	12	IL	66.70%	83.30%
Vandeweghe[22]**	93	69	24	IL and DL	86.20%	93.50%
Annibali et al[5]	41	20	21	DL	95.00%	100%
Polizzi et al[24]	57	1	56	DL	100%	92.90%
	Total = 215	**Total = 113**	**Total = 102**		**Mean = 85.8%**	**Mean = 93.3%**

** Bone loss ≤ 1.5mm during first year was considered a success and if > 1.5mm then considered part of survival group.

DL: Delayed Loading, DP: Delayed Placement, IL: Immediate Loading, IP: Immediate Placement.

Table 6 Immediate vs delayed implant placement studies measuring bone loss as an outcome.

Study	No. of implants	Immediate placement	Delayed placement	Bone loss (IP) (mm)	Bone loss (DP) (mm)
Vandeweghe[22]	93	69	24	0.41 ± 1.19	0.61 ± 0.63
Peñarrocha[10]	123	35	88	0.56 ± 0.22	0.67 ± 0.17
Atieh et al[23]	24	12	12	0.41 ± 0.57	0.04 ± 0.46
Annibali et al[5]	41	20	21	0.90 ± 0.30	0.88 ± 0.20
	Total = 240	**Total = 116**	**Total = 124**	**Mean bone loss = 0.57 ± 0.57**	**Mean bone loss = 0.55 ± 0.37**

DP: Delayed Placement, IP: Immediate Placement.

Table 7 Delayed vs immediate loading studies with delayed implant placement comparing and reporting survival rate as an outcome.

Study	No. of implants (IL/DL)	IL survival	DL survival	Follow-up (months)
Wolfinger[25]***	250 (30/220)	96.7%	98.2%	36-144
Degidi[26]	100 (10%)	100%		36
Schincaglia[27]	30 (15/15)	93.3%	100%	12
Zollner[28]	197 (197/0)	98.0%		5
Guncu[29]	24 (12/12)	91.7%	100%	12
Romanos[30]	72 (36/36)	94.9%	91.7%	24
Meloni[31]	40 (20/20)	100%	100%	12
Abboud et al[32]	20 (2%)	95.0%		12
Artzi et al[17]	12 (0/12)		100%	6
Rocci et al[33]	121 (121/0)	90.5%		108
Jung et al[34]	305 (0/305)		98.0%	72
Kim[35]	96 (0/96)		91.1%	36
Koo[36]	521 (0/521)		95.1%	60
Misch[37]	1377 (0/1377)		98.9%	120
Simon[38]	126 (0/126)		96.0%	6-120
	Total = 616 (521/95)	**Mean IL survival = 96.1%**	**Mean DL survival = 97.5%**	**Mean follow-up time = 39.6**

***Single molar crowns supported by two implants therefore were not included in total or mean calculations

DL: Delayed Loading, IL: Immediate Loading

Table 8 Delayed vs immediate loading studies with delayed implant placement comparing and reporting success rate as an outcome.

Study	No. of implants (IL/DL)	IL success	DL success	Follow-up (months)
Levine et al[39]	21 (21/0)	100%		60
Cornelini et al[11]	40 (4%)	97.5%		12
Barone et al[12]	12 (6/6)	100%	100%	6
Becker[40]	212 (0/212)		91.5%	47
Becker[40]	70 (0/70)		82.9%	47
	Total = 355 (67/288)	**Mean IL Success = 98.5%**	**Mean DL Success = 89.6%**	**Mean follow-up time = 34.4 months**

DL: Delayed Loading, IL: Immediate Loading

Table 9 Delayed implant placement studies measuring bone loss as a primary outcome.

Study	No. of implants (IL/DL)	IL bone loss (mm)	DL bone loss (mm)
Levine[39]	21 (21/0)	0.58	
Degidi[26]	100 (10%)	0.947	
Schincaglia[27]	30 (15/15)	0.77 ± 0.38	1.20 ± 0.55
Zollner[28]	197 (197/0)	0.81 ± 0.89	
Guncu[29]	24 (12/12)	0.45 ± 0.39	0.68 ± 0.30
Meloni[31]	40 (20/20)	0.83 ± 0.16	0.86 ± 0.16
Abboud et al[32]	20 (2%)	0 ± 0.59 maxilla; 0.03 ± 0.36 mandible	
Becker[40]	212(0/212)		0.09
Becker[40]	70 (0/70)		0.31
Kim[35]	96 (0/96)	0.13	
	Total = 810 (385/425)	**IL Mean bone loss = 0.55 mm**	**DL Mean bone loss = 0.55 mm**

DL: Delayed Loading, IL: Immediate Loading

Table 10 Studies on fixed partial dentures measuring survival and success rate as a primary outcome.

Study	No. of FPDs	Survival	Success rate	Follow-up time (years)
Haff [41] (retrospective)	33	94.0%	73.0%	3.0-13.1
Van Heumen[42]	96	77.5%	71.2%	4.5-8.9
Cenci[43] (longitudinal)	22	81.8%		8
Lops [44]	24	88.9%	81.8%	6
	Total = 175	**Mean survival = 85.6%**	**Mean success = 75.3%**	**Range: 3.0-13.1 years**

FPDs: fixed partial dentures

mean bone loss 0.57 ± 0.57 mm for immediately placed implants and 0.55 ± 0.37 mm for delayed implant placement (Table 6).

Out of the 20 delayed implant placement studies, 15 measured survival rate as a primary outcome, with a mean survival rate of 96.1% for immediately loaded implants and 97.5% for implants undergoing delayed loading (Table 7). Only five studies measured success rate as a primary outcome, with a mean success of 98.5% for immediately loaded implants and 89.6% for implants undergoing delayed loading (Table 8). Ten studies also reported the average amount of bone loss, with a mean bone loss of 0.55 mm for immediately loaded implants and 0.55 mm for implants undergoing delayed loading (Table 9).

The present review also included four retrospective and prospective studies for reporting the survival and success rates of single tooth fixed partial dentures in the posterior region as a comparison for alternate treatment of posterior sites. These studies reported a mean survival rate of 85.6% and mean success rate of 75.3% (Table 10).

■ Discussion

Implant placement in the posterior quadrants has been reported but not studied extensively in the literature. This review was conducted to identify the success and survival rates on implant placement in the posterior quadrant using various loading protocols. We have included both case series and comparative studies in our review. A decision was made to perform a narrative review rather than a meta-analysis, since performing a meta-analysis calculation on this topic was impossible due to the heterogeneity of the studies. The survival and success rates of many of the studies included in the review are similar to the overall survival and success rate reported for conventional delayed implant placement. Urban et al, when

reporting on implant placement in conjunction with bone regenerative procedures to manage residual peri-implant defects, indicated the lowest implant survival rate (83%), while several other studies have shown implant survival rates of 100%.

The 11 immediate implant placement case series studies involving 1077 implants reported overall success rates of 100%. Most studies (10) looked at delayed rather than immediate loading protocol, except one, which included both immediate and delayed loading. The reason for this may be the lower success rates with immediate loading shown in the literature. Hence, more randomised control trials are needed on immediate implant placement and immediate loading protocols for implants in the posterior quadrants of the mouth.

We have also included studies that compared immediate implant placement versus delayed implant placement. The overall survival rate in the immediate placement groups was 96.8% and in the delayed groups it was 96.3%, which is similar to studies by Slagter et al[45] and Lang et al[46], reporting on immediate implant placement in the anterior zone. While the overall success rate in the immediate placement group is 85.8%, it reaches 93.3% in the delayed group, which is similar to findings from Tawse-Smith et al[47], who report on implants in the symphyseal area of completely edentulous mandibles. The drawback of these studies is the dissimilarity in sample size between the groups. The results from these studies should thus be interpreted with caution, as these studies did not include randomisation of the test subjects.

From the 20 studies looking at delayed implant placement, a total number of 2905 patients received implants in the posterior quadrant with either immediate or delayed loading of prostheses. The survival and success rates for immediate loading were slightly lower than that of delayed loading. With the published data over the last 5 to 8 years, the success rates of implants with delayed loading are actually lower[27,29]. However, the difference in survival and success rate between immediate loading and delayed loading was insignificant, which is consistent with the literature[48]. Consequently, we can conclude that the survival and success rates of delayed placement of implants in the posterior quadrant irrespective of loading protocol is comparable to that of implants placed in the anterior regions.

Attention should be drawn to the fact that the survival and success rates of posterior fixed partial dentures (FPDs) were significantly lower than that of implants placed in the posterior region, irrespective of time of placement and loading protocols for dental implants. The use of a single implant to support a single restoration seems to be a superior treatment option to FPDs in the posterior region.

Most of the studies looked at survival rates rather than success rates. This may be because the criteria used to determine success of the implant has not been well defined in the literature. Most of the studies in this review used Albrektsson et al[2] criteria for success. However, the methodology and reference points used to measure marginal bone level changes varied amongst the studies.

This review also showed that there could be marginal bone gain with immediately placed implants. The overall bone gain did not differ significantly between immediate and delayed placement of implants, with mean values of 0.57 ± 0.57 and 0.55 ± 0.37, respectively, which is similar to the reviews published by Lee et al[49] and Pellicer-Chover et al[50]. Of the immediately placed implants, those that underwent delayed loading showed more favourable bone gain than the immediately loaded ones, which seems reasonable since delayed loading allows for longer healing times for both hard and soft tissues in between stage I and II surgeries. Although the data shows fairly conclusive evidence for bone level changes, in response to implant placement, this review is still limited by the number of studies and heterogeneity amongst the included studies. Marginal bone loss and biomechanical immobility were used as a criteria for success but studies used different measurement methods such as intraoral radiographs, Periotest values and ISQ values, which might affect the definition applied to implant success.

■ Conclusion

While survival rates of immediate or delayed implant placements seem similar, the success rates were slightly superior for the latter. Time of loading seems more relevant with immediate loading, leading to less favourable success rates for single implants in the posterior quadrants.

According to four studies included in the present review, the mean survival and success rates of FPDs in the posterior region were 85.6% and 75.3%, respectively. In comparison, the mean survival and success rates of single implants placed in the molar region, irrespective of placement and loading protocols, were 96.7% and 93.4%, respectively. Both the survival and success rates of implants were superior to that of fixed partial dentures in the posterior region. Consequently, we can conclude that placement of implants in the posterior quadrants can lead to better treatment outcomes than using fixed partial dentures.

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Foundation for Oral Rehabilitation (FOR) consensus text on "The Rehabilitation of Missing Single Teeth"

Methodology used for establishing the consensus text

The Foundation for Oral Rehabilitation (FOR) gathered 11 experts for 2 days at the University of Mainz Medical Center to discuss the rehabilitation of missing single teeth. They had distributed their review papers to each other ahead of the meeting, which were written during the preceding months. The main conclusions of each review were briefly presented and discussed during the meeting.

The key findings of all review papers were integrated in the consensus text, which was iteratively composed by all participants. After the meeting another opportunity was provided to react to the final draft of the consensus and to amend it. Finally all experts agreed and no minority viewpoints were expressed.

Prevalence and treatment options

Prevalence of missing single teeth, which was defined as a gap of one tooth bordered by one or more natural teeth on either side, is high and thus a relevant oral health issue.

The experts listed a whole range of treatment options such as orthodontic space closure, removable partial dentures, resin-bonded fixed dental prostheses, tooth-supported fixed dental prostheses and implant-retained crowns. No treatment with professional monitoring was another alternative.

To propose a patient-centered treatment option, one must take into account general patient characteristics such as age, general health, medication, social interaction, psychology, professional background and economic constraints.

Oral health parameters are of course key decision factors, such as for example the health status of the neighbouring teeth and mucosa, and whether the edentulous space is visible during social interactions or interferes with phonetics or other oral functions.

Only after listening to the patient's wishes and expectations, eventually involving the relatives, and after thoroughly explaining the different options, i.e. their costs, benefits and side-effects, is the patient in a position to consent to a certain treatment.

Preoperative radiological evaluation of missing single teeth[1]

Pretreatment diagnostics assessing a missing single tooth area usually involves radiological imaging. Justification for imaging should be defined at the individual patient level. Thus one cannot impose general rules for the type of imaging that is indicated. Consideration should be given to the risks and benefits of radiation and its cost-effectiveness.

Particular attention to justification needs to be given where the radiation dose is known to be significant, such as with cross-sectional imaging with some Cone beam computed tomography (CBCT) equipment and multislice computerised tomography. This especially applies in younger age groups.

An important consideration in favour of cross-sectional imaging is when it is likely to have an impact upon diagnosis, treatment planning and patient outcome, but the body of research is small, of mixed quality and sometimes contradictory.

For the prosthetic rehabilitation of missing single teeth, intraoral radiographs suffice in the great majority of patients. For the dorsal areas, panoramic

radiographs may provide sufficient information but not as good as intraoral radiographs. However, when an implant-based treatment is considered to be cross-sectional imaging, CBCT is widely used but the evidence for efficacy is limited. In some studies, the use of cross-sectional imaging appeared to increase the confidence of the surgeon in terms of bone volume evaluation and the selection of the proper implant size. CBCT should not be the first imaging option when assessing a new patient, because an intraoral radiograph may reveal conditions which would eliminate use of an implant as a treatment option.

■ Missing upper lateral incisors[2]

Congenitally missing upper lateral incisors can be a relevant clinical problem. It is the second most common agenesis, after that of the third molar. Although the evidence is weak because of the absence of Randomised Controlled Trials (RCT), comparative studies indicate that orthodontic space closure leads to a better periodontal condition than when a fixed prosthesis on teeth is used. One comparative study reveals patient satisfaction to be superior after orthodontic treatment, when compared to prosthetic rehabilitations on teeth, while another study found no difference.

Early diagnosis of the congenitally missing lateral incisor is important, since it allows for the planned extraction of the primary lateral incisor and the guided eruption of the canine into a position adjacent to the secondary central incisor. Subsequently, this may be followed by space closure or by opening of the space for prosthodontic rehabilitation. If aesthetic problems may occur after orthodontic closure because of size, shape and colour differences between the canines and the central incisors, restorative interventions may be required. In such patients, the use of an implant may be advisable. In growing patients with a high smile line the orthodontic option should be considered first to obtain long-term aesthetic results. Not all patients are suitable for orthodontic space closure, for example individuals with sagittal skeletal discrepancies.

Even when prosthetic rehabilitation of missing lateral incisors is used, it is often preceded by orthodontic treatment to establish an appropriate space.

Single implant placement is considered as the most conservative prosthodontic approach in cases of sound adjacent teeth. The long-term survival rates reported renders it an attractive therapeutic option. Distalising a mesially erupted canine can lead to a sufficient bone volume to allow implant insertion in the lateral incisor area. When planning the timing of implant placement, one must consider the growth phase of the patient.

■ Guided surgery for single implant insertion[3]

Although high accuracy and high cumulative survival rates – better than for mucosa-supported templates in edentulism - have been reported for single tooth replacement by implants using fully guided surgery, the evidence supporting the advantages of using a template-based approach remains weak.

The use of 3D software can improve diagnostics, increase the surgeon's confidence and eventually reduce perioperative complications. Fully guided surgery facilitates a minimally invasive (flapless) approach which seems to improve the soft tissue appearance. The higher cost should be considered but the shorter treatment time and reduced side effects should also be taken into account.

The literature suggests that proper training remains a prerequisite even for single implant insertion using surgical templates.

■ Impact of immediate placement and/or loading (functional or not) of single implants on hard and soft tissues in the anterior region[4]

Recent literature, limited to the anterior maxilla, indicates that immediate implant placement after a single tooth extraction is a favourable option. Prospective studies on the immediate placement of implants (flapless for > 400 out of 626 implants) with immediate provisional prosthetic rehabilitation out of occlusal contact, report a 98.25% survival rate.

The remaining space between the placed implant surface and the alveolar wall reached up to

4 mm and satisfactory results were obtained while no grafting was performed in one third of the patients.

Those studies which report on marginal bone level show similar changes for the staged as for the immediate approach. Mean marginal bone loss was less than 1 mm for a mean of 31 months of follow-up.

Primary stability was generally high as measured by a minimum insertion torque value of 32 Ncm and/or an ISQ value of 60, in order to meet the inclusion criteria of those individual studies. Gingival papillae migrate incisally when a crown with a proper contour is placed. This can take up to 1 year.

Minimal invasivity in most of the studies was reflected by flapless implant insertion. None of the papers used soft tissue grafting or bone grafting, except in some papers for filling the gap between the implant surface and the alveolar wall.

These findings are divergent from a previous review which did not favour immediate implant placement and rehabilitation because of subsequent midfacial mucosal recession. This difference may be due to the fact that in the present review minimal surgical invasiveness was used by most authors. The patient inclusion criteria were stringent and may also have positively influenced the results.

■ Replacement of missing single teeth in posterior areas[5]

In the posterior areas of the mouth, reports on missing single teeth were limited to molars[5], as data were not available for premolars. The definitions of immediate and of delayed loading were very variable, therefore no meta-analysis could be performed. In two comparative papers reporting on nearly a thousand implants, the survival and success rates were higher for delayed loading of single implants in the molar areas (98.3% vs 95.4%).

For the alternative treatment option of fixed partial dentures on teeth, the literature reports a mean survival rate of 85.6% with follow-up times of 3 to 13 years.

The tendency to use large diameter implants may explain the observation of increased marginal bone loss around implants in the molar region but less so for immediately placed implants: average of 0.91 mm for delayed vs 0.73 mm for immediate loading. Survival rates did not reveal significant differences between immediate implant placements in extraction sockets when compared with delayed placement. When success rates were considered, delayed implant placement seems more favourable.

■ Bone augmentation for single tooth implants[6]

When bone augmentation procedures prior to implant placement are needed, several studies report on onlay and inlay grafts and only one reports on distraction osteogenesis. Autografts, allografts, xenografts and alloplasts all seem to function with very high implant survival rates. The subsequent graft resorption is sparsely evaluated in the literature, although autogenous grafts seem more prone to volume reduction than the other materials. The use of postoperative CBCT to evaluate the change of graft volumes over time is not justified in routine clinical practice.

The majority of studies of onlay grafts used a staged approach and a delayed loading protocol. A variety of membranes were used in conjunction with bone augmentation and seemed to preserve the graft better.

Sinus inlay grafts with immediate implant placement and delayed loading seems to be the treatment protocol of choice in the posterior maxilla.

Shorter implants without grafting when compared with longer implants in former grafted regions may have similar outcomes.

■ Bonded vs all-ceramic and metal-ceramic fixed prostheses[7]

Single tooth replacement can also be achieved by tooth-supported all-ceramic vs metal-ceramic or resin-bonded fixed dental prostheses. Resin-bonded fixations perform better in the anterior segments when abutment teeth are being prepared and when a single-retainer cantilever design is chosen. The most frequent complication is debonding. For all-ceramic prostheses based on zirconia frameworks, chipping fractures of the ceramic veneer are frequent. Based

on systematic reviews, the 5-year survival rates for these three treatment options (all-ceramic, metal-ceramic and resin-bonded prostheses) are 94.3%, 94.4% and 92.3%, respectively. For the latter, a 2-unit cantilever design was used in the anterior region. However, since the year 2008, two 5-year prospective clinical studies have been published showing 100% survival for 3-unit zirconia fixed dental prostheses. It indicates the technology for zirconia all-ceramic restorations reached a mature level.

Monolithic zirconia restorations which were introduced with the aim of eliminating veneer chipping fractures remain a matter of concern because of the low temperature degradation phenomena. There are also fiber reinforced composite resins and inlay retained dental prostheses but these have no predictable long-term outcome.

■ Long-term outcome of single implant-based restorations[8]

Long term (≥ 10 years) survival rates have been reported for single implants but more or less exclusively for titanium implants with a turned surface.

The literature reveals a 93.8% cumulative patient-implant treatment survival and 95.0% at 'implant level' but, because of the retreatment need, only an 89.5% cumulative survival for the supported single crown.

The 10-year survival rate of implant-based crowns was always better when compared to fixed 3-unit prostheses on teeth (90%).

Recent unpublished data on 620 patients from one center reveal that for implants with a moderately rough surface, the 10-year survival rates are even better than for the turned surface implants: reaching 98.5 % vs 95.8%, respectively for the maxilla and 97.2% vs 95.1%, respectively for the mandible.

■ Timing of single implant placement and long-term observation of marginal bone levels[9]

Available literature is inconclusive regarding the impact on the timing of implant placement on the outcome after single tooth extraction. Indeed, the meaning of the terms immediate, early, delayed and late varies greatly in scientific literature.

Interproximal bone level changes in relation to implants placed in non-healed sockets (immediate or early) vs in healed sockets (late) was not significantly different in short-term (at 1 year) and long-term studies (at 10 years).

In 14 out of 22 controlled studies, survival rates appeared lower in the test group (immediate/early) compared to the control group (delayed/late), while only one study showed the opposite (seven studies showed identical survival rates in the two groups).

In long-term peri-implant bone remodelling, mostly bone loss but sometimes bone gain was observed. However one should keep in mind that the implants that underwent follow up over the years were those which survived. Therefore neglecting to give consideration to the lost implants can bias the conclusions when it comes to whether the timing of implant placement has a long-term impact on marginal bone level.

The buccal bone level was assessed by CBCT in only a few trials. Due to low resolution and various types of artefacts related to this radiographic method, CBCT should not be used as a standard in monitoring the marginal bone around implants.

■ Patient information on treatment alternatives[10]

Data on patient knowledge and transfer of information on treatment options for replacing missing single teeth mostly originate from Asia (20 out of 29 papers). The patient sample size varied from 109 to 10,000, with a total of 23,702 responding participants. The treatment choices were 62% for fixed partial dentures, 54% for removable partial dentures and 50% for implant-supported prostheses. The socioeconomic and cultural heterogeneity amongst those studies should be stressed. When patients were questioned about the origin of their information, 45% indicated their clinician vs 28% for the media. It is noteworthy that most reports indicate slightly more than half the patients feel their knowledge is insufficient and more than two-thirds feel a need for more information. The cost factor was

the most important impeding factor for choosing the implant option in Austrian Gallup studies. The surgeon and or clinician were identified as being the people responsible for the greatest proportion of the total cost of treatment.

Cost-effectiveness of treatment options[11]

The cost-benefit aspects of the different therapeutic approaches for single tooth replacement are very difficult to analyse systematically, considering the large variation in personnel and overhead costs or social healthcare systems in different countries. However, since most scientific reports on this subject compare the cost of different procedures in a well-defined area, some useful information can still be gathered.

Most papers concluded that implant-based treatments are generally more cost-effective than fixed dental prostheses supported by teeth. However endodontic treatment and retreatment, to maintain a compromised tooth, are more cost-effective than a fixed partial denture or implant-supported prosthesis. Autotransplantation of teeth is of course more cost-effective than a tooth or implant-supported replacement.

Patient interviews revealed on the one hand a higher degree of satisfaction with implant-based rehabilitations but on the other hand more complaints about the cost and frequency of postoperative maintenance appointments. The patients' opinion is that implants should become more affordable.

The common use of a tooth-supported fixed prosthesis by clinicians may be related to the familiarity with the procedure and constraints in certain health care and insurance systems. The lower survival rate of fixed partial dentures leads to a higher cost in long-term perspectives because of the retreatments.

No treatment for a missing single tooth can be considered as an alternative when there is an established dental arch stability, a healthy periodontium and when oral functions like phonetics or social appearance are not compromised. Proper professional follow-up is still advocated.

Recommendations of the group of experts

While all review papers presented for this consensus conference detected an impressive number of publications related to each subject, very few papers passed the quality-based inclusion criteria used by the experts to build evidence-based guidelines.

Too few RCTs were available. More evidence-informed guidelines for clinical trial protocols are needed.

In the absence of scientific evidence at the highest level, the expert group felt to the best of their knowledge and experience that:

- The selected treatment should be evidence-based, whenever relevant data are available, and taken in the best interests of the patient rather than depend on the clinician's preferences or abilities.
- Patient referral to qualified specialists should be considered in some circumstances.
- The use of single implants offers a higher survival rate than tooth-supported fixed dental prostheses.
- The profession should become more aware of the cost-effectiveness of different methods for replacing missing teeth.
- Validated checklists, such as the Drummond Checklist, and collaboration with a health economist are recommended for studies involving cost-effectiveness.
- Since, besides hardware, time is a universal measure for cost- effectiveness, future research should identify the time involved by all participants in the treatment team, the patient and relatives when assessing the cost of replacing missing single teeth.
- Scientific organisations, independent from industry and professional interests, with patients and/or public involvement, should provide the public with balanced and evidence-based information to improve the population awareness of different treatment modalities.
- Standardised definitions of immediate, early and of delayed implant placement and loading should be used. It is proposed that immediate placement means within the same day of tooth extraction, while early means within 1 week and up to 8 weeks after extraction. The term immediate

Fig 1 From left to right Drs Gabor Tepper, Stavros Kiliaridis, Paul Weigl, Matthias Karl, Charles Goodacre, Ann Wenzel, Bertil Friberg, Torsten Jemt, Friedrich Neukam, Keith Horner, Daniel van Steenberghe and Christian Walter. Missing for the group picture: Drs Wilfried Wagner, Alexander Pozzi and Peter Moy.

loading should be reserved for oral implants that are subject to a full occlusal load within 3 days, whereas early loading means after 1 to 2 weeks. Occlusal loading after more than 2 weeks, even if the implant has been exposed intraorally and thus subject to eventual loading by the food bolus, should be coined delayed loading.

- Preoperative diagnostic imaging should not systematically opt for cross-sectional viewing unless it will be used in preoperative planning for guided implant surgery. One region which regularly requires cross-sectional imaging is the posterior mandible where the inferior alveolar nerve is a liability.
- In the absence of universally defined guidelines it is proposed that after a baseline radiograph at the fitting of the prosthesis, a control radiograph, with a strict paralleling technique, should be taken after 1 year to monitor the result and bone remodelling. If marginal bone loss appears ≤ 1 mm, then a new radiograph after 5 years seems adequate. A radiograph can be taken at any time point if there is a clinically evident problem.
- There is a need for setting up oral hygiene protocols after immediate implant placement and throughout the surgical healing phase.

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