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the Spanish Society of Implantology (SEI),
the British Academy of Implant & Restorative Dentistry (BAIRD),
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**A FOR consensus conference on
Prosthetic Protocols in Implant-Based
Oral Rehabilitations**

University of Pennsylvania, Philadelphia, USA
November 30th to December 1st, 2016

EJOI

Editorial

This supplemental issue of *EJOI* is dedicated to the Foundation for Oral Rehabilitation (FOR) consensus conference, 'Prosthetic Protocols in Implant-Based Oral Rehabilitations', which was held on the 30th November to 1st December 2016 at the University of Pennsylvania, Philadelphia, USA. 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 this supplement for their efforts.

Marco Esposito, Reinhilde Jacobs and Michele Nieri

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Guest Editorial

The methods by which single crowns and prostheses are designed and fabricated for implant-based treatments have changed over the years. Recently, new innovative materials and techniques have been introduced, along with related scientific evidence. Therefore, this consensus conference was focused on the prosthodontic aspects of such implant-based rehabilitations.

At a time when an over-abundance of information is always readily available through internet-based outlets, discerning sound scientific evidence from questionable and biased data has become increasingly challenging. Systematic literature reviews with meta analyses, where appropriate, are at the pinnacle of the "quality-of-scientific-evidence" pyramid and have, therefore, become invaluable tools in the assessment of clinical data and the decision-making process in the practice of dentistry.

The Foundation for Oral Rehabilitation (FOR) is partnering with academicians and leading universities around the world to provide such assessments on a variety of highly relevant topics and consolidate the outcomes in consensus statements.

A group of 10 international experts was selected, based on their expertise and publications related to specific aspects of prosthodontic treatment. Each participant was tasked with completing a systematic and comprehensive review of the literature and synthesizing it into the form of a literature review. Each

paper was submitted and reviewed by the panel of experts prior to the actual conference meeting. Then, at the meeting, each participant presented a synopsis of their conclusions, followed by time for discussion and critique by all the attendees. After the face-to-face meeting, final papers were submitted and the consensus text was developed for inclusion in this special supplement of the journal.

The conference took place at the University of Pennsylvania, School of Dental Medicine, in Philadelphia, Pennsylvania, for two days. It was a privilege for both of us to serve as co-chairs of this FOR Consensus Conference and have the opportunity to interact with this distinguished group of international experts. We also want to express our appreciation to Dr Daniel van Steenberghe for his invaluable service by providing a written record of the key findings of the conference and helping to develop the consensus text. In addition, we wish to thank Dr Friedrich Neukam, chairman of the FOR Board of Trustees, who provided oversight and input during the conference.

We are pleased to submit the outcomes of this conference as another ongoing service of the Foundation for Oral Rehabilitation to benefit the profession and enhance knowledge regarding the prosthodontic treatments available to the public we all serve.

Charles Goodacre and Markus Blatz



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Foundation for Oral Rehabilitation (FOR) Consensus Text on “Prosthetic Protocols in Implant-Based Oral Rehabilitations”

■ Methodology used for establishing the consensus text

The Foundation for Oral Rehabilitation (FOR) assembled a group of nine international experts to examine specific aspects of prosthodontic treatment. Each participant completed a systematic and comprehensive literature review and their resulting papers were submitted and reviewed by each participant prior to the conference. During the meeting, each participant presented their conclusions with time for discussion and critique by all the attendees. After all the experts had submitted the final papers, the most pertinent findings were synthesized into this consensus text.

■ Background to the conference

Edentulism, both complete and partial, have benefited from osseointegrated endosseous implants that retain or support a prosthesis. After the pioneering epoch of the 1970s, high long-term survival and success rates have been universally reported. Implant-based oral rehabilitations have thus often become the number one treatment choice for partial and complete edentulism.

Over the past two decades, new developments were geared towards increased success/survival rates of implants and prostheses, less-invasive approaches, versatility of treatment options, as well as improved patient satisfaction and quality of life.

Since the scientific literature has well documented high implant success/survival rates, the present consensus conference focused on the prosthodontic aspects of implant-based oral rehabilitation.

■ Prosthodontic outcomes for fixed vs removable complete arch implant prosthesis¹

Based on the results of clinical studies that evaluated both fixed and removable complete arch prostheses in the same study, it was determined that both types of prostheses are associated with high implant survival rates. However, both were affected by post-placement maintenance that could be called “normal wear and tear” and also by prosthetic “complications” that were judged to be unexpected events requiring additional treatment. Implant overdentures were associated with more maintenance needs/complications than fixed prostheses. In addition, the amount of post-placement residual ridge resorption was greater with implant overdentures. The level of patient satisfaction was high with both types of prostheses, but implant overdentures were determined to be more cost-effective.

■ Clinical outcomes of full arch implant-supported zirconia prostheses²

Fixed complete dentures (formerly called “full arch fixed implant-supported prostheses”) have seen impressive material innovations, one being zirconia, which has the highest fracture toughness of all of the ceramic materials used in oral health care. There are several types and designs of zirconia prostheses. A few examples include: zirconia that is monolithic, zirconia that is veneered (conventional, minimal or gingival) or a zirconia framework with individually cemented crowns. Additionally, the zirconia prosthesis may be a one-piece design, or segmented with

multiple fixed prostheses. The present review was focused on one-piece zirconia fixed complete dentures with and without veneered porcelain.

Twelve studies meeting the selection criteria were identified (three prospective and nine retrospective) involving a total of 223 patients with 285 fixed complete dentures and up to 8 years follow-up. The number of implants supporting the one-piece zirconia fixed complete dentures ranged from 3 to 15 implants with an average of 4 implants. Of the 285 prostheses, four frameworks fractured, two in one treatment centre and one each in two other centres. Limited vertical prosthetic space could be a risk factor since it was associated with reported fractures.

Minor prosthetic complications that did not require prosthesis replacement were reported for 46 out of 285 prostheses. Veneered porcelain fracture occurred in 42 prostheses. These minor complications were significantly lower than what is reported in the literature for metal-acrylic resin fixed complete dentures.

Chipping of veneered porcelain did not require a remake of any prostheses. Chairside polishing and adjustment or occasional laboratory fabricated porcelain veneer sufficed in the majority of patients. Chipping of veneered gingival porcelain was not reported in any of the studies.

Based on available data, monolithic zirconia with gingival colouring ("gingival staining"), or zirconia with veneered porcelain limited to the gingival area, offers promising results for fixed complete dentures. Since the complications occurred with various types of zirconia, the properties and manufacturing process of zirconia are relevant factors. None of the studies reported adverse effects on implants, opposing natural dentition, hard and soft tissues, temporomandibular joints or patient dissatisfaction due to the use of zirconia fixed complete dentures on single or double jaw rehabilitations.

■ Impact of prosthetic material on mid- and long-term outcome of implants supporting single crowns and fixed dental prostheses³

The impact of the type of prosthetic material on implant survival was reviewed with implant-supported

fixed complete dentures and restorations on zirconia implants (two studies) excluded from the review.

For the meta-analysis of implant survival rates of single crowns, the results of two study cohorts of veneered base metal alloys, 11 of veneered precious alloys, 13 of veneered zirconia, five of veneered alumina, four of lithium-disilicate (monolithic or partially veneered) and one that used a resin matrix ceramic, were included.

The choice of prosthetic material seems to have no influence on implant or prosthetic survival rates in fixed restorations. Subgroup analyses for the prosthetic complication rates also revealed no statistically significant differences for screw loosening, abutment fractures, or chipping between any of the groups. The incidence rate for decementation in one study was significantly higher for the resin matrix ceramic group relative to all other groups ($P < 0.0001$).

The meta-analysis of all-ceramic vs metal-based fixed partial dentures included one cohort study of all-ceramic prostheses, two of metal-based prostheses with facial resin veneering, and eight of metal-based prostheses veneered with ceramics.

For the survival rate of both implants and prostheses, no differences were observed among the different materials. The incidence rates of screw loosening and abutment fractures were similar. On the other hand, the incidence rate for chipping was significantly higher in the metal-composite resin group when compared with the metal-ceramic and the all-ceramic groups.

■ Influence of implant abutment fabrication method on clinical outcomes⁴

Materials used to fabricate abutments and their manufacturing processes are important to clinical success. This paper investigated the literature relative to the effect of CAD/CAM manufactured abutments on the treatment outcome and on the peri-implant tissues.

The review investigated 24 studies on CAD/CAM manufactured abutments, of which 11 were comparative, to assess factors like survival and success rates, white and pink aesthetic scores and bone loss.

CAD/CAM abutments have good survival and success rates and provide comparable, if not better,

clinical outcomes than conventional abutments. One study reported a better aesthetic outcome at 1 year and another reported less soft tissue recession at 2 years compared with conventional abutments. However, available studies comparing CAD/CAM and conventional abutments are few and the majority are limited to the short-term.

■ Prosthesis survival and complication with immediate loading of zygomatic implants⁵

Zygomatic implants offer an alternative treatment option for patients with severely resorbed maxillae. The overall survival rate after 12 to 72 months is 96 to 100% for the zygomatic implants. This percentage range applies to zygomatic implants where two implants were placed bilaterally and also when there was a single zygomatic implant bilaterally with splinting to conventional anterior endosseous implants. The studies indicated a favourable anterior-posterior spread was achievable by both designs.

There were 17 studies that reported on conventional anterior implants splinted to zygomatic implants, with a survival rate of the conventional implants ranging from 95 to 100%. However, five of these studies reported anterior implant failures along with zygomatic implant failure. The survival of prostheses relates to the number and position of the zygomatic implants. When the prosthetic design used one zygomatic implant bilaterally with anterior endosseous implants, the loss of one zygomatic implant resulted in the loss of part of the prostheses, necessitating remake or modification.

Prosthetic complications were identified in numerous papers and included loosening and fracture of prosthetic screws, with fracture of abutment screws reported in two studies. There were also reports of metal framework fracture and ceramic fracture from the underlying metal substructure. One paper reported excessive wear of the restorative tooth material.

Inflammatory reactions in the maxillary sinus were reported in 12 papers, with incidences ranging from less than 1.0 % to over 20%. Multiple authors report a reduction in sinusitis, with the extra-sinus (external) approach. One paper demonstrated that 15 to 20%

of patients had inflammatory reactions, as noted on radiographic examination, but the patients were asymptomatic. One article suggested use of the buccal fat pad to potentially reduce intraoral mucositis. However, most studies did not apply this approach.

■ Clinical outcome of monolithic ceramic implant supported single and multi-unit prostheses⁶

A systematic review on the clinical outcome of monolithic ceramic implant supported single and multi-unit prostheses identified three studies included in the review.

Two articles reported on monolithic lithium disilicate implant-supported single crowns (SC) and revealed a survival rate of 97.8 and 100% after 28 to 31 months. One study investigated implant-supported monolithic zirconia SCs and fixed partial dentures (FPD) and showed a survival rate of 100% after 5 years. The use of zirconia induces minimal wear to opposing structures, especially after adaptation and polishing of the occlusal surfaces. The risk of fracture and chipping was significantly reduced in monolithic restorations. No study on the clinical performance of monolithic resin matrix ceramic restorations could be identified.

Clinical studies on the long-term outcome of implant-supported monolithic all-ceramic single- and multi-unit restorations are lacking.

■ Digital vs conventional implant impressions⁷

The literature review on digital vs conventional implant impressions identified one *in vivo* and 15 *in vitro* studies. The majority of the studies (n = 12) evaluated accuracy of digital implant impressions (DII) by superimposing images to reference models and reported mean errors ranging from 6 to 337 µm.

Results from three recent *in vitro* studies directly comparing the accuracy of DII and conventional impression techniques reported similar results for single and multiple implants.

Factors such as the type of scanner, angulation and number of implants, distance in between

implants, geometry of scan bodies and scanning techniques that potentially affect the accuracy, were not sufficiently investigated.

High deviations of up to 328 µm were reported by studies investigating accuracy of milled models produced from DII. Further studies are needed to evaluate accuracy of 3D printing techniques to fabricate master models for implant-supported single crowns and fixed partial dentures. Also, data is lacking on IOS accuracy for digital interocclusal records.

Since intraoral scanning is more challenging than *in-vitro* scanning of a model, more *in vivo* studies are needed to define clinical indications for different types of IOS. However, the *in vivo* evaluation of accuracy is limited by the possibilities to obtain true reference values under clinical conditions.

■ Misfit of implant prostheses and its impact on clinical outcomes⁸

Ten articles met the inclusion criteria: five on humans and five on animals, relating to the misfit of implant prostheses.

It was concluded that the available literature does not provide sufficient evidence on the effect of misfit at the prosthesis-implant interface on clinical outcomes of screw-retained implant prostheses. Marginal gaps and static strains due to screw tightening were not found to have negative effects on initial osseointegration or peri-implant bone stability over time. Based on two clinical studies, the risk for technical screw-related complications was slightly higher.

While the degree of tolerable misfit remains a matter of debate, the present data do not imply that clinicians should neglect good fit.

■ Clinical performance of CAD/CAM monolithic ceramic implant-supported restorations bonded to titanium inserts⁹

Current trends and the more frequent application of chairside digital dentistry suggest the clinical application CAD/CAM monolithic implant-supported ceramic restorations. Many of these systems, especially the ones applied chairside, require that these

all-ceramic crowns be bonded to titanium (Ti) inserts with composite resins after adequate pre-treatment of the bonding interfaces. This systematic review of the literature revealed there is currently no clinical evidence on CAD/CAM monolithic implant-supported ceramic restorations that are bonded to Ti-inserts. However, several laboratory studies on select aspects of Ti-inserts and similar prosthetic designs are available.

These studies indicate that Ti-inserts improve the overall fracture strength of ceramic abutments and crowns, protect the implant connection from wear, and offer a better marginal fit when compared to all-ceramic abutments. However, to recommend this prosthetic design for routine use in clinical practice, independent clinical trials that document its long-term performance are necessary.

■ Recommendations of the group of experts

The following statements reflect the opinions of the individuals participating in the consensus conference, to the best of their knowledge and experience:

- The systematic reviews assessed the clinical evidence on a variety of relevant aspects of modern implant prosthetics. It should be cautioned, however, that absence of scientific evidence in the fast-evolving field of implant-based rehabilitation does not necessarily imply that a treatment modality is ineffective.
- The choice of a fixed or removable complete arch prosthesis varies according to patient preference.
- Definitions of professional maintenance, complication and/or failure are missing. Professional prosthetic maintenance implies compensating for the predictable wear of prosthetic components. A prosthetic complication is an unanticipated event that affects the prosthesis and requires intervention or not, but without replacement of the prosthesis. Failure requires removal and remake of prosthesis or change of treatment. Future research should distinguish between these two possible consequences to avoid inflated complication and failure rates.
- The number of prosthetic maintenance issues associated with adjusting and replacing the

retentive device of overdentures indicates the need for longer-lasting retentive devices. One of the members of the group even suggested it would be beneficial to have a retentive device that could be changed by patients, while recognising this process does not and should not replace regular professional care, but could be helpful for those patients who do not have easy access to regular professional care.

- The current scientific evidence does not favour a specific material for single crowns and multi-unit fixed partial dentures.
- The material selection is rather based on the clinician's preference and the aesthetic and functional needs of the patient.
- Although the clinical evidence is currently weak, monolithic all-ceramic implant-supported single crowns and multiunit fixed partial dentures are reliable based on short-term observation.
- Laboratory studies demonstrate that bonded titanium inserts provide several mechanical advantages for all-ceramic abutments and crowns, such as protecting the implant-abutment connection. There is, however, no clinical data currently available to support their routine use.
- Clinical experience favours intraoral digital scanning but evidence is lacking. Clinical factors affecting the accuracy of modern intraoral scanners, as well as accuracy of resulting models and restorations, should be further investigated.
- Current data supports the use of zygomatic implants to support a fixed dental prosthesis. The implants should preferably emerge on the crest of the ridge, as opposed to the palate, to facilitate a more anatomical prosthesis.
- CAD/CAM abutments should be used when possible. Not only do they provide restorations that possess excellent overall survival and success rates, they can be fabricated with proper contours for optimized aesthetic outcomes. They also allow for excellent fit and control of finish line position to facilitate cement removal.
- One-piece zirconia fixed complete dentures have promising outcomes in edentulous patients. The zirconia can be veneered at the gingiva or be monolithic, with only gingival colouring ("gingival staining") to reduce prosthetic complications associated with veneered porcelain fracture.
- Clinical evidence on the effect of misfit of screw-retained implant prostheses is missing for biological factors and weak for technical complications. These findings do not imply that misfit of prosthetic implant components is without consequences. Therefore, the expert panel encourages clinicians to continue aiming for the best fit possible.

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Fixed vs removable complete arch implant prostheses: A literature review of prosthodontic outcomes



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Key words *bone changes, cost-effectiveness, masticatory performance, patient satisfaction, prosthesis complications, prosthesis survival, quality of life*

Aim: To compare implant fixed complete dentures with implant overdentures relative to prosthodontic outcomes.

Material and methods: An electronic Medline (PubMed) with MeSH terms, and Cochrane library search was performed, focusing on studies that included implant fixed complete dentures and implant overdentures in the same study, with the results based on studies that included both types of prostheses.

Results: The following six categories of comparative studies were identified in the literature: 1) Implant and prosthesis survival; 2) Prosthesis maintenance/complications; 3) Bone changes; 4) Patient satisfaction and quality of life; 5) Cost-effectiveness; and 6) Masticatory performance. It was determined that both the fixed and removable treatments were associated with high implant survival rates. However, both types of prostheses were impacted by the need for post-placement mechanical maintenance or prosthetic complications. More maintenance/complications occurred with implant overdentures than with fixed complete dentures. Residual ridge resorption was greater with implant overdentures. Patient satisfaction was high with each prosthesis, with three studies revealing higher satisfaction with fixed complete dentures and five studies finding no difference. All but one study on cost-effectiveness indicated implant overdentures were more cost-effective. Based on two studies, it appears the masticatory performance of implant fixed complete dentures and implant overdentures is comparable.

Conclusions: Multiple factors must be considered when determining whether an implant-fixed complete denture or implant overdentures are best suited for patients with completely edentulous jaws.

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

■ Introduction

Prior to the introduction of osseointegrated implants, complete dentures served as the primary means of replacing the entire dentition. However, multiple studies determined they lacked retention and patients experienced movement of their mandibular dentures¹⁻³. Patients were dissatisfied

with their dentures⁴ and their attitude affected the perception of comfort, speech, and the ability to chew⁵. Difficulties while eating certain foods were documented^{2,3,6-8} and some patients experienced discomfort or pain when chewing or biting^{8,9}. While altered taste sensation was reported to be a short-term effect in one study of complete dentures⁷, another study⁸ reported that complete denture

patients exhibited the lowest scores for taste and texture perception. Additionally, complete denture patients have been known to reduce their social contact due to embarrassment as a result of wearing dentures⁶.

Another important factor is the residual ridge resorption that occurs from wearing complete dentures, this being particularly reflected as mandibular superior surface resorption¹⁰. There is a decrease in the maximum bite force compared with dentate patients¹¹⁻¹³ and the masticatory performance (ability to comminute food) is one-quarter to one-seventh that of individuals with natural dentitions^{11,14-16}. Complete denture patients have a lower intake of nutrient-rich foods such as vegetables^{17,18}, dietary fibre^{18,19-21}, carrots^{18,21}, fruits^{17,18}, and salads²¹ with biochemical analyses of blood samples showing that complete denture patients have lower levels of the nutrients found in vegetables and fruits^{21,22}.

These limitations of complete dentures were first counteracted through the use of complete arch fixed prostheses attached to multiple mandibular implants. The Glossary of Prosthodontic Terms²³ uses the term "fixed complete denture", but other names have been used in the literature for this type of prosthesis, such as hybrid denture, hybrid prosthesis and fixed-detachable prosthesis. In this review, the term "implant fixed complete denture" is used to describe a complete arch prosthesis that is attached to implants and cannot be removed by the patient, and "implant overdenture" is used to describe a complete arch implant prosthesis that the patient can remove.

Following the successful use of multiple implants in conjunction with fixed complete dentures, the implant treatment protocol was expanded to include implant overdentures. Many positive outcomes emerged from the use of these two complete arch implant prostheses compared with complete dentures, including bone preservation²⁴, greater comfort²⁵ and improved masticatory performance²⁶, as well as enhanced patient satisfaction and quality of life²⁷. However, complications can arise with both types of prostheses and it is important to understand what can occur so complications can be avoided, or at least minimised. In addition, it is important to understand how these two types of complete arch prostheses compare with each other as an aid in treatment planning for completely edentulous patients.

Therefore, the purpose of this literature review was to compare implant-fixed complete dentures (IFCD) with implant overdentures (IOD), based on the comparisons that have been studied in the dental literature.

■ Materials and methods

Electronic searches of MEDLINE (PubMed) along with MeSH terms and the Cochrane Central Register of Controlled Trials search were conducted up to and including September 2016. The following keywords were used in the search: implant overdenture, implant fixed complete denture, implant supported prosthesis, implant retained prosthesis, fixed-detachable prosthesis, fixed-detachable implant prosthesis, fixed-detachable implant denture, hybrid prosthesis, hybrid denture, all-on-four prosthesis, fixed vs removable implant prostheses, fixed prosthesis vs implant overdenture, implants overdentures and fixed complete dentures, implant overdentures and fixed implant dentures, implant overdenture and all-on-four dentures, implant overdentures and hybrid implant prostheses, implant overdentures and fixed-detachable prostheses, implant overdentures and fixed-detachable implant prostheses, implant overdentures and hybrid implant prostheses, implant overdentures vs fixed prostheses, implant retained/supported prostheses, survival of implant prostheses, dental implant survival, implant failure, implant complications, maintenance of dental implants, and complications with complete arch prostheses.

As part of the discussions during the consensus conference, a distinction was made between what could be called "normal wear and tear" prosthesis maintenance and prosthesis "complications", judged to be unexpected events requiring additional treatment.

After reviewing the citations using the different search terms, a decision was made to focus the detailed review on only those studies that compared implant-fixed complete dentures with implant overdentures in the same publication, many of which also included conventional complete dentures. As a result of all the citation reviews, the following categories of comparative studies were identified where both IFCDs and IODs were evaluated in the same study:

1. Implant and prosthesis survival;
2. Prosthesis maintenance/complications;
3. Bone changes;
4. Patient satisfaction and quality of life;
5. Cost-effectiveness;
6. Masticatory performance.

In addition to the focused reviews, a limited number of systematic reviews and individual clinical studies were included that provided data related to either implant overdentures or implant-fixed complete dentures, but not both. A synopsis of these studies is presented in the introduction to each of the above categories as background information before reviewing the studies that specifically compared both IFCDs and IODs in the same study.

■ Implant and prosthesis survival: Background information related to implant and prosthesis survival rates

Mandibular implant fixed complete denture systematic review

A 2016 systematic review by Moraschini et al²⁸ included 19 studies. The cumulative implant survival rate associated with prostheses supported by four implants (all-on-4) was 96.3% after a mean follow-up time of 40 months and the rate for prostheses supported by three implants was 95.5% at 32 months. Prosthesis survival rates ranged from 93.7% to 100%, with an overall CSR of 98.6%.

Maxillary implant overdenture systematic reviews

A 2010 systematic review of maxillary implant overdentures was published by Slot et al²⁹ based on 31 studies after a mean follow-up of at least 1 year. The authors identified an implant survival rate of 98.2% per year with six implants and bars. With four implants and bars the implant survival rate was 96.3%, and with four individual implants and ball abutments the implant survival rate was 95.2%. Prosthesis survival was calculated to be 97.4% per year with six or more implants and 96.5% with four or fewer implants and bar anchorage. The authors were unable to calculate prosthesis survival with four

or fewer implants and ball anchorage because only one of the included studies presented the overdenture survival rate for this design. The authors concluded that six implants connected by a bar was the most successful treatment regarding both implant and prosthesis survival.

A similar 2014 systematic review by Raghoobar et al³⁰ included 24 studies after a mean observation time of at least 1 year. The meta-analysis identified an implant survival rate of 98.1% and an overdenture survival rate of 99.5% per year when six or more implants were splinted with bars. When four or fewer implants were splinted with bars, the implant survival rate was 97.0% and the overdenture survival was 96.9% per year. When four or fewer implants were not splinted, the implant survival rate was 88.9% and the prosthesis survival was 98.8% per year. The authors concluded there were high implant and prosthesis survival rates with four or more splinted implants, but there was an increased risk of implant loss when four or fewer non-splinted implants were used.

Systematic review and meta-analysis of post-loading implant loss

A 2016 systematic review by Kern et al³¹ included 54 studies, with an estimated 5-year implant survival rate of 97.9% in the maxilla and 98.9% in the mandible. Implant-fixed complete dentures had significantly lower implant loss rates than implant overdentures.

Systematic reviews of implant survival with all-on-4 fixed complete dentures

A systematic review by Patzelt et al³² included 4,804 implants. Of the 74 failed implants, 37 were axially placed and 37 were tilted. Seventy-four percent of the failed implants occurred within the first 12 months of surgical placement, 12% between 12 and 24 months, 3% within the 24 to 36-month time period, while 11% failed after 36 months. In their systematic review, Menini et al³³ evaluated 778 tilted and 845 upright implants following 1 year of function. The cumulative implant survival rate was 97.97%. No significant difference was found between the failure rates of tilted implants (2.19%) and upright implants (1.89%).

■ Implant survival/success rates when both IFCDs and IODs were included in the same study

Maxillary and mandibular implant survival rates

Mangano et al³⁴ reported the results of a prospective study where completely edentulous patients were restored with 60 fixed complete dentures retained by eight implants and 93 overdentures supported by four implants and bars. The overall implant survival rate was 98.23%, with a maxillary survival rate of 97.25% and a mandibular survival rate was 99.05%.

Studies reporting only mandibular implant survival/success data

The following data compared fixed complete dentures and implant overdentures for the mandibular arch only:

1. Five-year cumulative implant survival rate of 100% with fixed complete dentures retained by six implants and 97.4% with implant overdentures attached to four implants connected by bars³⁵.
2. There was a 100% successful implant integration after 5 years for fixed complete dentures attached to four to six implants and 95% for implant overdentures supported by two implants and a bar³⁶.
3. An implant success rate of 90.1% for fixed complete dentures retained by four to six implants and 92.6% for implant overdentures supported by two to three implants and a bar³⁷.

Studies reporting both maxillary and mandibular implant survival/success data

1. The 1-year implant survival rate was 100% for fixed complete dentures retained by three implants, the same as for overdentures with two ball abutments. The prosthesis survival rate was also 100% for both the fixed complete dentures and overdentures³⁸.
2. The 10-year cumulative implant success rate for eight-implant fixed complete dentures in the maxilla was 92.1%, and 96.2% for eight-implant prostheses in the mandible. For maxillary implant

overdentures, the 10-year rate was 92.2% for six-implant milled bars and 86.9% for four-implant Dolder bars. For mandibular implant overdentures, there was a 93.9% success rate for four-implant Dolder bars and 93.7% for two-implant ball abutments³⁹.

■ Prosthesis survival/success rates when both IFCDs and IODs were included in the same study

1. The 1-year prosthesis survival rate was 100% for fixed complete dentures retained by three implants and the rate was also 100% for overdentures retained by two-ball abutments³⁸.
2. A prospective randomized clinical trial calculated the 36-month survival of maxillary bar-supported implant overdentures and mandibular fixed complete dentures, both placed on five to six implants. The cumulative prosthesis survival for fixed complete dentures was 96.1%. With the overdentures, the prosthesis survival rate was 95.2% for bar-supported overdentures, 90.5% for bar-retained and mucosal-supported designs, and 87.0% for cap-retained overdentures⁴⁰.
3. The 10-year cumulative prosthesis survival rate for eight-implant fixed complete dentures was 96.4% in the maxilla and 100% in the mandible. The maxillary overdenture prosthesis survival rate was 94.7% for six implant milled bars and 87.5% for four-implant Dolder bars. The mandibular overdenture prosthesis survival rate was 97.7% for four-implant Dolder bars and 98.8% for two-implant ball abutments³⁹.

■ Prosthesis maintenance/complications

Implant fixed complete denture systematic review

In 2011, Bozini et al⁴¹ included 19 studies in a systematic review and meta-analysis of prosthodontic complication rates associated with IFCDs after a follow-up time of at least 5 years. Estimated cumulative rates were calculated for observations periods of 5, 10, and 15 years. Almost 70% of the prostheses presented with some form of resin tooth fracture after 15 years, with almost half exhibiting material

wear (resin tooth wear). The 15-year cumulative complication rate for abutment screw loosening was 13.4%, while for abutment screw fracture it was 6.3%. The prosthetic screw-loosening rate was calculated to be 15.0% after 15 years and the prosthetic screw fracture rate was 11.7%. The rate for framework fracture was 8.8%. Aesthetic deficiencies were reported to be 9% at 15 years.

A 2012 systematic review by Papaspyridakos et al⁴² included seven studies that examined the incidence and types of complications associated with implant-fixed complete dentures. They evaluated a total of 281 prostheses after a mean follow-up time of 9.5 years and recorded 653 complication events. After 5 and 10 years, the likelihood of having a complication was 70.7% and 91.4%, respectively. The most common prosthesis-related mechanical complication was chipping/fracturing/wear of the resin teeth, with a frequency of 33.3% at 5 years and 66.6% at 10 years. The most frequent implant-related mechanical complication was abutment/occlusal screw loosening, with a 10-year rate of 20.8%. The authors concluded that complications would continue to occur over time and while these may not lead to failure, the amount of maintenance needs to be considered.

Implant overdenture systematic reviews

A 2010 systematic review by Çehreli et al⁴³ included 49 articles and found similar frequencies of complications and maintenance requirements for overdentures placed in both jaws, in the maxilla alone, or mandible alone. Bars-clips were the most commonly used retentive mechanism in the included studies, with several studies that included ball abutments and a few with magnets. Matrix-patrix maintenance constituted the most common requirement after 5 years, with negligible differences between the different retentive mechanisms. The authors concluded that prosthetic maintenance requirements were comparable for both maxillary and mandibular overdentures regardless of the attachment system. The frequency of fractures, relines and remakes of overdentures were similar during the review time period.

A 2010 systematic review completed by Andreiottelli et al⁴⁴ included 18 studies relating to overdenture maintenance/complications. The most common

prosthetic maintenance issues were associated with the attachment system, regardless of the attachment system used, and included loss of retention requiring repair and/or replacement of the attachment components. The authors indicated there was a higher incidence of mechanical problems associated with maxillary overdentures compared with mandibular overdentures, especially with maxillary overdentures that did not have palatal coverage. Regarding a comparison of different retentive mechanisms, the authors indicated “an objective assessment of the preferred retention system” was not possible due to different prosthetic procedures and small sample sizes.

■ **Prosthesis complications when both IFCDs and IODs were included in the same study**

Systematic review

Berglundh et al⁴⁵ performed a systematic review of multiple types of implant restorations, including 15 overdentures and 14 fixed complete dentures. Maintenance/complications associated with suprastructures were about 4 to 10 times higher with overdentures than with fixed restorations. The number of incidences per patient over a 5-year period was 1.56 for overdentures, compared with 0.19 incidences/patient for fixed complete dentures.

Individual studies

Several articles identified the types of prosthesis maintenance/complications that occurred with fixed complete dentures and overdentures. Table 1 presents implant overdenture data from six of the nine studies summarized below. These six studies either provided data related to specific prosthesis maintenance/complications, or calculations could be made by the authors of this paper. For the Tinsley et al⁴⁶ study, the table reports the percentage of complications that occurred on just one occasion. However, Tinsley et al⁴⁶ also reported complications that occurred twice, and three or more times. Table 2 provides the same information for implant-fixed complete denture maintenance/complications.

Table 1 Implant overdenture complications.

Study Authors	Walton et al ⁴⁸ .	Watson et al ⁴⁹ .	Walton et al ⁵⁰ .	Tinsley et al ⁴⁶ .	De Kok et al ³⁸ .	Katsoulis et al ⁵⁰ .	
Follow-up Time	30 Months	5 Years	22 Months	4-6 Years	1 Year	2 years	
Type (#) of Overdentures in study	Hader (50), Ball (8), Dolder (7), Misc. (6)	Dolder (20)	Bar/Clip (17), Individual(3)	Non-Splinted*(27) One-time complications	Ball (10)	Dolder(16)	Milled Titanium (12)
Clip Loosening/Loss	31.4%	25.0%	55.0%				
Clip Fracture	8.8%					12.5%	
Loss of Retention		55.0%				75.0%	58.3%
Overdenture Reline	27.0%		10.0%	22.0%	10.0%	12.5%	16.7%
Overdenture Remake/Rebase		35.0%		33.0%			
Overdenture Repair			4.0%	4.0%			
Overdenture Fracture							
Denture Modification		50.0%					
Contour Adjustment	50.7%		50.0%				
Occlusal Adjustment	14.7%		11.0%			37.5%	16.7%
Other Adjustments	9.3%		35.0%				
Sore Spot						6.3%	33.3%
Discoloration of Acrylic Resin							25.0%
Fractured Denture Tooth	7.3%				4.6%	68.8%	
Fractured Acrylic Resin	5.8%	25.0%				6.3%	8.3%
Fractured Framework/bar	5.1%					25.0%	
Other Repairs	14.6%		7.0%				
Screw Loosening		35.0%	32.0%		1.5%		
Gold Screw Loosening		30.0%					
Screw Fracture							
Retentive Abutment Loosening	25.3%				10.0%		
Opposing Prosthesis Reline and/or (Remake)				15%(33%)	20.0%		
Opposing Prosthesis maintenance		30.0%		4.0%			
Peri-implant inflammation/Hyperplasia		55.0%				68.8%	8.3%
New Abutment with higher tissue height needed		10.0%					

*Study did not specify exact type of attachment system

Hemmings et al³⁷ completed a 5-year prospective clinical study involving 50 edentulous mandibles, with 25 overdentures (23 bar-clip and two magnet prostheses) and 25 fixed complete dentures (cast metal with acrylic resin and denture teeth). The overdentures required more adjustments than the fixed prostheses during the first year, but over

the 5-year follow-up time, fixed complete dentures required more maintenance. The average number of recalls per year for the fixed prostheses was 2.27, whereas the overdentures recall rate was 1.57. Five patients in each group noticed that their opposing denture was loose following placement of the mandibular prosthesis and therefore required a

Table 2 Implant fixed complete denture complications.

Study Authors	Walton et al ⁴⁸ .	Watson et al ³⁶ .	Walton et al ⁴⁹ .	Tinsley et al ⁴⁶ .	De Kok et al ³⁸ .	Katsoulis et al ⁵⁰ .
Follow-up Time	30 Months	5 Years	22 Months	4-6 Years	1 Year	2 years
Type (#) of Fixed Prostheses in study	FCD(79), IFPD(29), and SC(12) combined data	FCD(20)	FCD(49), IFPD(38), and SC(88) combined data	FCD(21) One-time complications	FCD(10)	FCD(13)
Denture Tooth Fracture	18.0%	10.0%			30.0%	61.5%
Acrylic Resin Fracture	14.4%	10.0%	47.0%			38.5%
Gold Screw Fracture	27.0%					
Abutment screw or Coping fracture	10.0%					
Porcelain Fracture	7.2%					
Framework Fracture	6.3%			4.7%		
Abutment Fracture		10.0%		9.5%		
Other Fracture	17.1%					
Abutment Loosening					10.0%	
Screw Loosening	18.4%	10.0%	27.0%		10.0%	
Gold Screw Loosening		5.0%				
Reseal Screw Access Opening			31.0%	24.0%		
Reline						23.1%
Remake FCD						7.7%
Remake FCD due to tooth wear				9.5%		
Remake FCD due to Hyperplasia				9.5%		
Adjust Contour	43.9%		14.0%			
Denture Tooth Wear						7.7%
Discoloration of Acrylic Resin						7.7%
Other Repair			22.0%			
Occlusal Adjustment	22.4%		14.0%			38.5%
Other Adjustment	15.3%		27.0%			
Clean Implant Prosthesis			18.0%			
Sore Spot						7.7%
Hyperplasia of Soft Tissue		35.0%				
Opposing Prosthesis Maintenance		25.0%				
Opposing Denture Reline				31.0%	20.0%	
Opposing Denture Remake				25.0%		

Fixed Complete Denture (FCD), Implant Fixed Partial Denture (IFPD), Single Crown (SC)

reline. Complications for fixed prostheses included abutment or gold-screw fracture and loosening, acrylic-resin component failure, and peri-implant inflammation or hyperplasia. Complications with overdentures included abutment screw loosening, clip fracture, clip loosening, magnet-keeper loosening/fracture, overdenture reline, reline/remake of

opposing prosthesis, and peri-implant inflammation/hyperplasia. The most common maintenance requirement with overdentures was clip loosening, and the most common complication was clip fracture. There were 11 remakes required with the fixed prostheses, but only three with the overdentures. Relines were required in 32% (8 out of 25) of the

overdentures over the 5-year period. This study was the only one that determined that fixed complete dentures required more repairs than overdentures.

Tinsley et al⁴⁶ compared 21 patients with mandibular fixed complete dentures and 27 patients with mandibular overdentures. They separated maintenance/complications into those that occurred once, twice, and three or more times. Fixed maintenance/complications occurring only once included resealing the access channel (24%), remakes (24%), repair of opposing denture (13%), relines of opposing denture (31%), and remake of opposing denture (25%). Maintenance/complications occurring twice included relines of opposing denture (13%), and remake of opposing denture (13%). Those occurring three or more times included a need to reseal the access opening (19%), and repair of opposing denture (6%).

Removable prosthesis maintenance/complications occurring once included overdenture repair (4%), overdenture remake (33%), overdenture relines (22%), repair of opposing denture (4%), relines of opposing denture (15%), and remake of opposing denture (33%). Those occurring twice included remakes of the overdenture (15%), overdenture relines (4%), repair of opposing denture (4%), relines of opposing denture (4%), and remake of opposing denture (19%). Issues related to maintenance/complications occurring three or more times included repairs of overdenture (4%), overdenture relines (4%), repair of opposing denture (4%), relines of opposing denture (11%), and remake of opposing denture (4%). Maintenance for both groups was higher than expected and patients required more appointments in the removable group both during the first year and beyond.

Walton and MacEntee⁴⁷ published the results of a retrospective study comparing the follow-up care required with 12 fixed complete dentures and 20 implant overdentures. The incidence of repairs was significantly higher with removable prostheses (78% of the repairs occurred with the removable prostheses).

In 1994, Walton and MacEntee⁴⁸ published the results of a second retrospective study of implant-fixed complete dentures and implant overdentures based on records obtained from six general dentists and eight prosthodontists. The study evaluated maintenance associated with 156 patients after they had been wearing their prostheses for a mean time of 30 months. Complications for the fixed prostheses

included gold screw fracture (27%), denture tooth fracture (18%), acrylic resin fracture (14.4%), abutment screw or coping fracture (10%), porcelain fracture (7.2%), framework fracture (6.3%), with other fractures making up 17%. Maintenance/complications for the removable prostheses included lost or loose retentive clips (31.4%), relines (27.0%), fractured denture clip (8.8%), fractured denture tooth (7.3%), fractured acrylic resin (5.8%), fractured framework (5.1%), and other complication (14.6%). Patients expressed more satisfaction with their IFCDs than those who had IODs, except for the ability to clean where the removable prostheses were preferred. The implant overdentures required three times as many adjustments and twice as many repairs per prosthesis as the fixed prostheses.

A third study by Walton and MacEntee⁴⁹, published in 1997, was a prospective study of data obtained from eight private prosthodontic practices after an average post-placement time of 22 months. The study evaluated the number of adjustments, repairs, time, and the costs involved with maintaining 69 implant prostheses. The most common adjustments for the fixed prostheses included retightening of screws (27%), cleaning the prosthesis (18%), contour changes (14%), occlusion (14%), and other adjustments (27%). The most common adjustments for removable prostheses included contour changes (50%), tightening of abutment screws (32%), occlusion (11%), and other adjustments (7%). Fixed prostheses repairs included fractured restorative material (47%), resealing screw access openings (31%), and other repairs (22%). Removable prostheses repairs included replacement of retentive components (55%), other adjustments (35%), and relines (10%). On average, each removable prosthesis required 4 times as many adjustments and around twice as many repairs as the fixed prostheses. Most of the adjustments and repairs were required within the first year of service with removable prostheses and needed almost 3 times as much time as the fixed prostheses.

Watson et al³⁶ studied prosthetic maintenance/complications in 40 patients with 20 fixed complete dentures and 20 overdentures in the mandible, after a follow-up time of 5 years.

Fixed prosthesis complications included fractured abutments (10%), screw loosening (10%),

gold-alloy screw loosening (5%), acrylic-resin cracking (10%), fractured teeth (10%), soft tissue hyperplasia (35%), and opposing dentures needing maintenance (25%). Overdenture complications included the need to have a new abutment placed to improve cuff height and tissue health (10%), screw loosening (35%), gold-alloy screw loosening (30%), perforation or fracture of the base around an abutment requiring repair (25%), remaking or rebasing (35%), some sort of denture modification required (50%), fracture or looseness of the sleeve in the overdenture (25%), loss of retention (55%), soft tissue hyperplasia (55%), and opposing denture needed maintenance (30%). The mean number of maintenance visits (adjusted to avoid bias of non-attendance) was 16.3 for overdentures and 10.6 for the fixed prostheses.

In a 5-year prospective clinical study Makkonen et al³⁵ compared 13 mandibular 4-implant fixed complete dentures with 20 mandibular four-implant overdentures retained by Dolder bars. Fixed prosthesis complications included one loose screw, one framework fracture, one fixed prosthesis fracture, one infection/severe mucositis, and one bone loss greater than 1.0 mm/year. Overdenture complications included one bar fracture, a metal corrosion, and one clip fracture. Overall, very few complications and repairs were reported during the 5-year follow-up.

Katsoulis et al⁵⁰ evaluated 28 overdentures (16 with gold bars and 12 with titanium milled bars) and 12 fixed complete dentures, all of which were maxillary prostheses. Fixed prosthesis maintenance/complications included acrylic resin denture base fracture (38.5%), tooth fracture (61.5%), new denture or redesign (7.7%), sore spots (7.7%), relining (23.1%), occlusal corrections by remounting (38.5%), excessive wear (7.7%), mucosal hyperplasia (0%), and discoloration of acrylic resin (7.7%). Gold overdenture complications included attachment fracture (12.5%), attachment loss of retention (75%), fracture of bar (25%), acrylic resin denture base fracture (6.3%), denture tooth fracture (68.8%), sore spots (6.3%), relining (12.5%), occlusal corrections by remounting (37.5%), excessive tooth wear 0%, hyperplasia (68.8%), and discoloration of acrylic resin (0%). Titanium overdenture maintenance/complications included attachment fracture (0%), attachment loss of retention (58.3%), bar fracture (0%), acrylic resin denture base fracture (8.3%), denture tooth fracture

(0%), sore spots (33.3%), relining (16.7%), occlusal corrections and remounting (16.7%), excessive wear (0%), mucosal hyperplasia (8.3%), and discoloration of acrylic resin (25%). Fixed prostheses had a slightly lower number of maintenance visits (0.98 annual events) than titanium milled bar overdentures (1.36) and gold bar overdentures (1.24) but the difference was not significant. More adjustments were required during the first year with removable prostheses.

De Kok et al³⁸ evaluated 10 implant fixed complete dentures using three implants and 10 implant overdentures using two implants and ball abutments after a follow-up time of 1 year. There were 66 total maintenance/complications issues encountered during the year. The following percentage incidence data were provided: 55 of the 66 were prosthesis adjustments (83%), opposing arches denture reline (6.05%), denture tooth fracture (4.55%), ball attachment loosening (3.03%), prosthetic screw loosening (1.52%), and mandibular overdenture reline (1.52%).

■ Speech adaptation

A study by Walton et al⁴⁷ determined that five out of 29 patients (17.2%) noted mild to moderate speech difficulties, four of which were associated with overdentures and one with a fixed prosthesis.

Jacobs et al⁵¹ evaluated speech function in 138 edentulous patients wearing fixed or removable prostheses. Patients were divided into the following four groups: 1) maxillary denture opposing mandibular fixed complete denture; 2) maxillary fixed complete denture opposing mandibular natural dentition, 3) maxillary denture opposing mandibular two-implant overdenture, and 4) fixed complete denture in both jaws. The control group included patients with natural dentition in both jaws. Overall results showed that 84% of the implant prosthesis patients made one or more pronunciation errors, which were significantly higher than in the control group where 52% made one or more errors. Patients had the most difficulty with the pronunciation of "s" and "z" sounds and/or "t" and "d" sounds than in the control group. Speech differences were more pronounced with fixed complete dentures on maxillary implants since they had more difficulty with pronouncing the "s" and "z" sounds. Subjects with implant-fixed prostheses

opposing implant-fixed prostheses as well as maxillary dentures opposing implant-fixed prostheses experienced more problems with the pronunciation of “t” and “d” sounds.

Zitzmann and Marinello⁵² evaluated patients restored with maxillary implant-fixed prostheses and maxillary implant-supported overdentures. Patients restored with maxillary implant-supported overdentures reported higher general speech ratings than the fixed group. One fixed patient experienced speech issues related to space between the maxillary prosthesis and the soft tissue allowing air to escape during speech. The authors stressed the importance of being aware that fixed prostheses in the resorbed maxilla can have a negative effect on speech.

In a prospective study Van Lierde et al⁵³ evaluated the effect of 20 “all-on-4” fixed prostheses on articulation and speech. There were 11 maxillary prostheses and nine mandibular prostheses. Fifty-three percent of the patients mentioned problems with speech 7.3 months after prosthesis placement, although all were determined to have intelligible speech. Patients experienced two speech adaptation periods, with the first one occurring when the provisional prosthesis was placed and the other one when the final prosthesis was placed. Patients had most difficulty with “s” sounds.

■ Background information related to Residual Ridge Resorption (RRR)

A study of mandibular posterior RRR associated with implant overdentures was completed by de Jong et al⁵⁴, with the authors concluding there was more posterior bone resorption associated with two implants splinted with a round bar than with four implants splinted with a round bar. The change in posterior bone height over a 10-year period was determined to be 1.44 mm for the two-implant group and 0.74 mm for the four-implant group.

In comparing the two implant bar-clip retentive mechanism group with that of complete dentures after 5 years, Kordatzis et al⁵⁵ recorded an average mandibular residual ridge height reduction of 1.63 mm for the conventional complete denture group and 0.69 mm for the overdenture group. Female study participants had greater resorption than male participants.

Jacobs et al⁵⁶ compared the amount of bone resorption associated with maxillary complete dentures when they were opposed by either a mandibular complete denture, a mandibular implant overdenture with two implants, or a mandibular implant fixed complete denture attached to four to six implants. The maxillary bone resorption was more pronounced with the mandibular complete denture than the mandibular overdenture. The ridge resorption associated with the maxillary complete denture was greater with the fixed complete denture group than the overdenture group, but not significantly different.

■ RRR when both IFCDs and IODs were included in the same study

Jacobs et al⁵⁷ measured the mandibular posterior residual ridge resorption in 30 participants with mandibular overdentures (two implants connected by a bar) and compared that with 25 participants with implant fixed complete dentures attached to four to six implants. They also included 85 individuals with mandibular conventional complete dentures where no implants were present as controls. There was minimal resorption in the fixed prosthesis group, with more in the complete denture group and overdenture groups. The overdenture group had more resorption than the complete denture group in participants who were edentulous for less than 10 years, whereas there was no difference in the resorption between the overdenture and complete denture groups when individuals had been edentulous for more than 10 years.

Wright et al⁵⁸ compared the mandibular posterior RRR associated with 23 implant-fixed complete dentures attached to five or six implants and 21 implant overdentures attached to two implants splinted with a bar. The average decrease in the Posterior Area Index (PAI) of the overdenture group was 0.053, whereas the implant fixed complete denture group had an average bone gain of 0.046. In both groups, these changes represented an overall change in area of approximately 20 mm². When averaged over the residual ridge crest length, the PAI values represented about 0.5 mm loss for the overdenture group over a mean time period of 5 years, whereas there was about a 0.5 mm gain for the fixed complete denture group over a mean time period of 3 years.

■ Patient satisfaction and quality of life

Background information

Multiple studies have compared complete arch implant prostheses with conventional complete dentures where no implants were used. They identified improved patient satisfaction, positive psychological benefits, and improved quality of life^{25,59,60}, when dental implants were used.

Implant fixed complete dentures (IFCDs) and conventional complete dentures (CDs) compared

Cibirka et al²⁵ indicated that IFCD patients experienced significantly improved comfort, function, speech, aesthetics, self-image, dental health, and improved quality of life when mandibular CDs were replaced with IFCDs. Blomberg and Lindquist⁵⁹ determined that implant patients had more confidence and self-esteem, with improved social interactions, compared with CD patients. In addition, Hoogstraten and Lamers⁶¹ found wellbeing to be substantially better after implant-based treatment with both physical and social aspects being enhanced compared with complete dentures.

Implant overdentures and conventional complete dentures compared with use of vestibuloplasty

Raghoobar et al⁶² compared 32 patients with implant overdentures with 28 patients who received a surgical vestibuloplasty to enhance the mandibular residual ridge prior to receiving new dentures. A third group of 30 patients received new CDs without preprosthetic surgery. After 5 years, complaints about the mandibular prosthesis were significantly lower in the implant group than the other two groups. The favourable 1-year results for the preprosthetic vestibuloplasty decreased after 5 years and became comparable to the complete denture group.

Number of implants

When six maxillary implants splinted with bars were compared with four implants also splinted with bars in a 1-year randomised controlled trial⁶³, there were

no differences in patient satisfaction. However, both groups experienced significantly greater satisfaction with their maxillary overdentures compared with their pre-treatment maxillary complete denture.

Type of retentive mechanism

Using mandibular implant overdentures, Timmerman et al⁶⁴ compared two implants and ball attachments with two implants and a single bar and four implants with three bars. The participants completed a questionnaire about satisfaction and it was determined the retention and stability decreased significantly in the two-implant ball attachment group over time whereas the other two groups remained at the same level.

Naert et al⁶⁵ completed a 5-year prospective randomized clinical trial that compared patient satisfaction with two-implant mandibular overdentures made with either a bar, two individual ball attachments, or two individual magnets. After 5 years, there was similar general satisfaction, phonetics, and aesthetics recorded for all the groups, but the magnet group scored significantly lower relative to prosthesis stability and chewing comfort.

Walton et al⁶⁶ compared one midline ball attachment with two laterally positioned ball attachments. Similar satisfaction was reported, with both groups having increased satisfaction compared with their baseline satisfaction with complete dentures. Prosthodontic maintenance was similar for both groups.

Quality of life

Using a self-administered Oral Health Impact Profile (OHIP) in a randomised controlled clinical trial, Awad et al²⁷ concluded that patients who received implant overdentures experienced greater improvement in their perceived oral health than those who received complete dentures. In addition, Heydecke et al⁶⁷ determined there was significantly better Oral Health-Related Quality of Life with overdentures than complete dentures.

Beikler and Flemming⁶⁸ published a review from the European Association for Osseointegration (EAO) indicating that mandibular implant overdentures using two or four implants improved the Oral Health-Related Quality of Life compared with conventional complete dentures.

Implant overdenture design variations

Wismeijer et al⁶⁹ treated 110 patients with mandibular implant overdentures using the following three treatment methods: two implants and ball attachments; two implants and a bar attachment; and four implants with a triple bar attachment. A self-administered questionnaire was used to assess patient perception before they received their implant therapy and then at 16 months after treatment. No significant differences were found between the three treatment strategies, with an overdenture retained by two ball abutments judged to be sufficient.

■ Patient satisfaction and quality of life when both IFCDs and IODs were included in the same study

Effect of receiving the desired treatment

Allen et al⁶ compared edentulous participants who requested and received implants to stabilise a complete fixed or removable prosthesis, another group who requested implant prostheses, but received conventional dentures, and a third group who requested and received conventional dentures. The study participants who received their preferred treatment reported much greater satisfaction than those who did not receive their requested treatment. As a result, the authors indicated conventional complete dentures could be an effective means of treating edentulous patients when their expectations are encompassed by that treatment. The outcomes of patients who requested complete dentures supported this perception, since their satisfaction improved and they indicated being edentulous had little psychosocial impact upon their quality of life. Allen and McMillan⁷⁰ published a study showing that those who requested and received implant prostheses indicated chewing significantly improved, whereas those who had requested implant prostheses, but received complete dentures, reported no change or deterioration following treatment.

Studies reporting limited or no difference between IFCDs and IODs

Using a within-subject cross-over clinical study design, de Grandmont et al⁷¹ used a psychometric assessment to measure the perception of 15 patients who had worn either a fixed or removable complete arch prosthesis and were then switched to the other prosthesis design. After an adaptation period of at least two months, each patient completed a questionnaire three different times that assessed his or her perceptions of the first prosthesis. They had previously rated their existing complete dentures three times prior to treatment. The factors rated were general satisfaction, speaking ability, aesthetics, and ability to chew various foods. Higher scores were reported for the implant prostheses than for their complete dentures, but there were no significant differences between the two implant prostheses except for mastication of certain foods. The participants rated the fixed complete dentures as being better for chewing carrots, apples and sausages.

On the basis of 86 participants, Oh et al⁷² compared implant overdentures (27 participants), implant-fixed complete dentures (29 participants), and complete dentures (30 participants) relative to patient satisfaction and oral health-related quality of life (OHRQoL). After receiving their new prostheses, the patient satisfaction and OHRQoL were greater for both implant treatments compared with the complete dentures, but there were no significant differences between the two implant groups.

Zitzmann and Marinello⁵² compared 10 patients who received a maxillary fixed complete denture with 10 patients treated with implant overdentures on the basis of comfort, retention, function, aesthetics and appearance, taste, speech, and self-esteem. The participants completed a questionnaire after their first consultation and again 6 months after wearing their prosthesis. Both designs produced significant improvements in all the above factors.

A retrospective study by Zani et al⁷³ of 15 participants with implant overdentures and 15 with fixed complete dentures was completed at least 2 years following prosthesis placement. There were no significant differences in patient satisfaction or any significant differences in the condition of the prostheses as evaluated by the single prosthodontist examiner.

De Kok et al³⁸ treated 10 participants with an implant overdenture attached to two ball abutments and 10 individuals with fixed complete dentures attached to three implants. Participants responded to questionnaires before treatment and after 6 and 12 months following implant placement. There were no significant differences between the two groups, except for the ease of cleaning the mandibular denture, which was rated higher in the overdenture group. Regarding Oral Health-Related Quality of Life, there also were no significant differences between the groups but marginally better scores were reported for the fixed group relative to physical pain, physical disability, and functional limitations.

Studies reporting better results with IFCDs

Preciado et al⁷⁴ evaluated Oral Health-Related Quality of Life with implant overdentures and implant-fixed complete dentures using both a short questionnaire and the OHIP-20sp questionnaire. For the overdentures, four implants were used in the maxilla and two to four in the mandible. For the fixed prostheses, four to six implants were used in both arches. Participants with the fixed prostheses had the greatest quality of life based on oral pain and chewing difficulty, although the differences were not significant. The authors concluded that fixed prostheses were the preferred option related to pain and chewing compared with implant overdentures.

Castillo-Oyagüe et al⁷⁵ also used the short OHIP-20sp questionnaire to examine the Oral Health-Related Quality of Life of 38 participants with implant overdentures, 37 with fixed complete dentures, and a control group of 38 individuals with complete dentures. The participants with implant overdentures recorded lower functional and global satisfaction than those with fixed prostheses. The overdenture participants exhibited significantly lower quality of life related to physical pain. Based on this, the authors concluded that implant overdentures were the least predictable option.

Brennan et al⁷⁶ determined the Oral Health-Related Quality of Life of 37 participants with fixed complete dentures (nine maxillary and 28 mandibular prostheses) and 25 participants with implant overdentures (22 maxillary and three mandibular). Those with implant overdentures had significantly

lower overall satisfaction and lower satisfaction with their ability to chew, as well as the aesthetics of their prostheses. Individuals with a fixed prosthesis reported better OHRQoL, with the significant differences occurring in the domains of psychological discomfort and psychological disability.

Reasons for patients selecting IFCDs and IODs

A study by de Grandmont et al⁷¹ reported the results of asking 15 participants to choose their preferred prosthesis after previously wearing either a fixed or removable complete arch prosthesis and then being switched to the other prosthesis design. Eight of the 15 participants chose the fixed prosthesis and seven selected the removable prosthesis. While both groups reported significantly better mastication with the fixed prosthesis, those who preferred the removable prosthesis indicated ease of cleaning as the most important factor affecting their decision, followed by the aesthetic result and prosthesis stability. Participants who preferred the removable overdenture stated that it was as comfortable as the fixed complete denture, but was more aesthetic and easier to clean. Another participant reported feeling uncomfortable about not being able to remove the prosthesis. Those individuals who selected the fixed prosthesis indicated it could be cleaned in public whereas the removable one could not. It was also stated that while cleaning was more difficult with the fixed prosthesis, it was not a major problem. There were multiple comments from those who selected the fixed prosthesis about the removable prosthesis not being as stable. There was even a comment about being able to chew gum with the fixed prosthesis.

Heydecke et al⁶⁷ compared maxillary fixed complete dentures with implant overdentures in the same patients. After placing four to six implants and waiting for 6 months, two maxillary prostheses were fabricated for each patient by the same prosthodontist. After wearing their first prosthesis for 2 months, it was removed and the other one placed. After wearing each prosthesis, the participants rated their general satisfaction, comfort, ability to speak, stability, aesthetics, hygiene ease, occlusion, and their ability to chew seven types of food. In addition, they

were asked to choose their preferred prosthesis. The implant overdentures received significantly higher ratings for general satisfaction, ability to speak, and ease of cleaning than the fixed prostheses. No differences were recorded for comfort, stability, aesthetics, occlusion, and ability to chew the foods. Nine of the 13 participants chose the removable prosthesis. The factors that caused selection of an implant overdenture were speaking ability, oral hygiene ease, aesthetics, and general satisfaction. Those who chose the fixed prosthesis indicated their choice was based on comfort, ability to speak, stability, and general satisfaction.

■ Cost, time and cost-effectiveness: Background information

Implant overdentures and complete dentures compared

Zitzmann et al⁷⁷ compared the cost-effectiveness of an implant overdenture with four implants and bars, an overdenture with two implants and ball attachments, and a conventional complete denture group, with 20 participants in each group. The cost over 3 years was 9,100 Swiss Francs for the two-implant group and 19,800 Swiss Francs for the four implant group. Over the estimated 10-year period, the costs were reduced to 3,800 Swiss Francs for two implants and 7,100 Swiss Francs for four implants per quality-adjusted prosthesis year. The authors concluded that implant treatment becomes cost-effective over the 10-year time horizon with the two individual implants and ball attachments being the treatment of choice, assuming the patient is willing to pay at least 3,800 Swiss Francs per quality-adjusted prosthesis year gained.

Heydecke et al⁷⁸ compared the cost-effectiveness of two-implant mandibular overdentures with conventional mandibular dentures in 65 to 75-year-old edentulous participants. Thirty of the participants received conventional dentures and 30 received a two-implant overdenture with opposing maxillary complete denture. After 1 year, the average cost of the IOD was \$1600 Canadian dollars more than the CD. However, the annual cost in Canadian dollars was \$399 for the complete denture and \$625 for the implant overdenture, using an average patient life expectancy of 17.9 years for someone aged 65.

Beikler and Flemmig⁶⁸ published a review that evaluated the economics of implant-supported prostheses. The review, based on two studies, indicated that implant overdentures using two or four implants were cost-effective compared with conventional complete dentures when individuals were willing to pay the increased cost.

Cost-effectiveness of implant overdenture designs

Stoker et al⁷⁹ compared the 8-year follow-up costs of four implants and a triple bar, two-implants and a single bar, and two individual implants with ball attachments. The initial treatment costs comprised 71% to 78% of the total costs and were significantly higher in the four-implant-bar group compared with the other two groups. The mean total cost was €3,410 for the two individual implants, €3,563 for the two-implant-single bar group, and €4,548 for the four-implant-three-bar group. The ball attachment group needed to visit the prosthodontist more often between scheduled follow-up appointments to have the retentive mechanism re-activated. The authors concluded that two-implants connected by a single bar "might be the first treatment of choice" since it had high cost-effectiveness along with "efficacy and proven stability for a long-term period".

Slot et al⁸⁰ compared bar overdentures on four implants in the anterior maxilla (three bars connecting the four implants and a posteriorly cantilevered bar on each side) with overdentures supported by six implants (four anterior implants and two posterior implants with connecting bars and distal bar cantilevers) in a one-year randomised controlled trial. The authors concluded that both the four and six-implant overdentures provided comparable treatment outcomes but the results favoured the four-implant bar overdenture on the basis of cost-effectiveness.

Listl et al⁸¹ performed an economic evaluation based on a literature review of available evidence comparing four and six implants overdentures in the maxilla. They only found one article by Slot et al⁸⁰, reviewed above. The Slot et al study formed the basis for an extrapolated 10-year timeline where the authors concluded that bar-retained maxillary overdentures with six implants provide better patient

satisfaction than four-implant bar overdentures, but at considerably higher treatment cost.

■ **Cost-effectiveness when both IFCDs and IODs were included in the same study**

A study of implant treatment costs in Canada by MacEntee and Walton⁸² reported that implant overdentures with two implants were 7 times the cost of a conventional denture. They also indicated a fixed complete denture attached to five implants was 17 times more expensive than conventional complete dentures.

Tinsley et al⁸³ performed a 6-year prospective clinical trial that compared 21 participants with five-implant fixed complete dentures and 27 participants with an implant overdenture using two or three implants. The time required to complete treatment was comparable with a mean of eight visits for the fixed prosthesis and seven visits for the overdenture. The implant overdenture cost less than half the price of the fixed complete denture based on both time and implant component costs. However, the implant overdenture participants required more post-placement appointments during the first year and beyond.

Over a time period of 10 years, Attard et al⁸⁴ compared the cost of implant overdentures (two-implants used) and implant fixed complete dentures (five implants used) in patients treated during the early "pioneer" years with other patients also followed for 10 years, but treated subsequently to those treated during the pioneer years. The authors indicated there was a learning curve to the treatment with both the fixed prosthesis and overdenture pioneer groups requiring more maintenance during the "learning curve" years. The patients treated after the pioneer group had a 62% improved maintenance cost. The authors indicated the fixed complete denture design was more expensive to fabricate and maintain over the 10 years of observation, with the implant overdenture being the less expensive approach.

Palmqvist et al⁸⁵ compared the time and costs associated with the placement of three mandibular implants in 17 participants who had been followed for 1 to 2 years. Eleven of these patients received a fixed complete denture on their three implants and

seven received an implant overdenture with bars on their three implants with bilateral distal extensions and four clips. The mean number of clinical hours was 1 hour higher in the overdenture group, but five more laboratory hours were required with the fixed group. Based on using an equal number of implants, the authors indicated the fixed prosthesis could be provided for about the same cost as an overdenture.

A literature review by Vogel et al⁸⁶ evaluated the health economic implications and cost-effectiveness of dental implants and included 14 studies in their review based on the assessment of these studies using the Drummond checklist. The literature indicated that both implant-fixed complete dentures and implant overdentures were associated with high levels of patient satisfaction and Oral Health-Related Quality of Life compared with conventional complete dentures, even though the cost was greater. Also, the authors concluded that implant overdentures are likely to be a cost-effective option compared with conventional complete dentures. However, the review did not provide conclusions that directly related to a comparison of fixed complete dentures and implant overdentures but did review Attard's results⁸⁴, cited above, that determined overdentures were more cost-effective than fixed complete dentures.

■ **Masticatory performance: Background information**

Masticatory performance with implant-fixed complete dentures (IFCDs)

Haraldson and Carlsson⁸⁷ evaluated the oral function of 19 IFCD patients with an average of five implants and determined that all but one patient indicated they could chew as they wished. Similarly, Lundqvist⁸⁸ studied 21 consecutive patients with maxillary implant-fixed complete dentures and indicated there was a progressive increase in chewing efficiency and clenching force along with a subjective improvement in oral function.

Patients with implant-fixed complete dentures reported fewer problems with chewing, speaking, swallowing, kissing, laughing, and moving their tongue than patients with complete dentures⁸⁹.

In addition, implant overdentures were found to enhance the oral function of prostheses⁹⁰ and patients were able to chew foods they previously avoided⁹¹.

After receiving IFCDs, Blomberg and Lindquist⁵⁹ determined that 17 of 26 participants did not have to be cautious with what they ate or drank, whereas only two of the 26 complete denture patients said they had no challenges related to eating or drinking. Carlsson and Lindquist⁹² completed a 10-year longitudinal study of 23 patients who received mandibular IFCDs and concluded that those who were dissatisfied with complete dentures experienced a "rapid and dramatic improvement" in their masticatory ability and that some patients subsequently requested that a maxillary fixed prosthesis be placed. The benefits of the maxillary prosthesis were determined to be mainly psychological since the functional tests only produced minor improvements. Masticatory performance was compared by Mendonça et al⁹³ between a group of 21 complete denture participants, 16 individuals with fixed complete dentures, and 15 subjects with natural dentitions. After receiving mandibular fixed prostheses, the masticatory performance improved to a level that reached 61% of that recorded in those with natural dentitions. The individuals with complete dentures also improved their masticatory performance, but only by 31%.

Masticatory cycle comparisons

Jemt et al⁹⁴ tested the mandibular movements of 16 edentulous patients before and after receiving mandibular IFCDs and determined there was a wide variation in the number of chewing strokes required to reach the swallowing threshold (range of eight to 26 strokes). During mandibular opening, there was a significant increase in displacement and also in velocity after placement of the implant prostheses. The authors stated that rehabilitation with a mandibular implant-fixed complete denture produced a chewing pattern more like that of dentate patients previously tested by the authors. Lindquist and Carlsson⁹⁵ found there was a significant decrease in the chewing time from a little over 40 s, after new or optimised dentures were tested, to about 20 s after placement of implant

fixed complete dentures. The number of chewing strokes decreased from a mean of 50 after the new or optimised dentures were placed, to a mean of 28 when using the implant prostheses.

Masticatory performance with implant overdentures a comparison of retentive mechanisms

The masticatory function of three different implant overdenture retentive mechanisms (bar-clip, ball abutments, and magnet) attached to two implants was investigated by van Kampen et al⁹⁶ and compared with the function in complete dentures without the attachments present. All three attachments improved masticatory function compared with no attachments. There was slightly better masticatory performance with the bar-clip and ball abutments compared with the magnets.

Comparison of overdentures with complete dentures

Haraldson et al⁹¹ evaluated oral function before and after treatment with implant overdentures. When nine individuals wore complete dentures, they all avoided certain foods such as meats, nuts, and apples, but after receiving implant overdentures, only three of the nine patients indicated they now had to avoid certain foods.

Bakke et al⁹⁷ determined that patients felt their chewing and biting ability improved after implant placement, with all of them being able to chew hard and tough foods as determined by the ability to reach the threshold of swallowing and then swallow the food during a 2 min time period. Before implant treatment, only half the patients were able to pass this test. Geertman et al⁹⁸ also determined that participants with IODs produced significantly better food comminution than those with complete dentures who required 1.5 to 3.6 times more chewing strokes than the implant patients to achieve the same reduction in particle size. In contrast, Garrett et al⁹⁹ recorded no significant advantage for the implant overdenture group compared with the complete denture group, a finding the authors related to the patient population because the complete denture patients were able to comminute food exceptionally well.

Kimoto and Garrett¹⁰⁰ compared participants who received new complete dentures with those who received implant overdentures. The overdenture participants with a low mandibular residual ridge height (≤ 21 mm) had improved masticatory performance compared with the complete denture group with low ridge height. However, this improved masticatory performance with implant overdentures was not recorded for participants with moderate or high residual ridge heights. The authors concluded that patients with advanced residual ridge resorption were more likely to have improved masticatory performance with an implant overdenture than those with more bone height, and that clinicians should consider the amount of resorption before recommending implant overdenture treatment for patients who want to improve their chewing. Pera et al¹⁰¹ also compared the masticatory efficiency of complete denture participants with severe mandibular residual ridge resorption before and after they received two implants and an overdenture. Both the masticatory efficiency and degree of satisfaction improved in the 12 participants after treatment, but there was no correlation between the degree of satisfaction and the masticatory efficiency/oral function factors, a finding the authors attributed to the complexity of factors associated with patient satisfaction.

Boven et al¹⁰² systematically reviewed the literature related to masticatory performance and included studies that assessed function before and at least 1 year after treatment. Fifty-three articles met the inclusion criteria. The study concluded that treating complete denture participants by providing implant overdentures increased chewing efficiency.

Fontijn-Tekamp et al¹⁰³ administered chewing tests to patients with natural dentitions, complete dentures, implant overdentures, and patients with dentures overlaying the roots of natural teeth, but not attached to the roots by a mechanical attachment. The particle reduction of the test food was significantly better in the implant overdenture group than in the complete denture group with low mandibles (height between 9 and 15 mm) but not with the high mandible complete denture group (heights of 16 mm or more) or the group with overdentures on tooth roots. The chewing efficiency was best for the natural dentition group.

Masticatory cycle comparisons

Bakke et al⁹⁷ determined the chewing cycle duration generally decreased after IOD therapy both in those patients who were completely satisfied and those who were not. Jemt and Stablad¹⁰⁴ studied mandibular movements and determined the mean number of chewing strokes was 33 with a mandibular complete denture, and 24 after implant overdenture placement. The chewing rhythm increased significantly and there was a reduction in the duration of the chewing cycle. Pera et al¹⁰¹ compared 12 complete denture participants with severe mandibular residual ridge resorption before and after they received two implants and an overdenture. The chewing cycles increased in width by 92% and in height by 45% after implant treatment.

■ Masticatory performance when both IFCDs and IODs were included in the same study

Fueki et al¹⁰⁵ performed a systematic review of masticatory performance that included both implant fixed complete dentures and implant overdentures but they were not directly compared with each other but with complete dentures. Fixed complete dentures were compared with conventional removable partial dentures and also with complete dentures. Implant overdentures were compared with complete dentures. The authors concluded that implant-fixed complete dentures provided significantly better masticatory performance than mandibular complete dentures when individuals were not satisfied with their complete dentures. Also, mandibular implant overdentures opposed by a complete denture improved the masticatory performance compared with complete dentures in both arches when the patients had persistent functional problems with their mandibular complete denture and had severe mandibular residual ridge resorption, but not in those with less resorption.

Pjetursson¹⁰⁶ provided commentary on the Fueki study¹⁰⁵ and discussed the findings that the implant overdentures only improved masticatory performance in those individuals with severe resorption. He indicated this was a surprising result since two other studies compared implant overdentures with previously

worn complete dentures and reported significant masticatory improvement with implant overdentures. Two randomised controlled trials also concluded that implant overdentures improved masticatory performance compared with complete dentures.

In 1994 Feine et al¹⁰⁷ compared the masticatory function of 15 participants who were divided into two groups. Eight subjects first received a fixed complete denture and seven received an implant overdenture. After a two-month adaptation period, masticatory function was measured by mandibular movement and jaw muscle electromyographic activity recordings, as well as the chewing of standardised test foods. The authors concluded that long-bar overdentures “appear to be no less efficient than the fixed prosthesis” and they also stated that was contrary to what was expected.

Müller et al¹⁰⁸ studied chewing efficiency with both fixed complete dentures and implant overdentures. There were two control groups, one with complete dentures and the other with natural dentitions. The chewing efficiency of those with implant overdentures and implant-fixed complete dentures was better than the group with complete dentures, but not as good as the dentate group, with no significant difference between the two implant groups. It was interesting to note that participants from the fixed complete denture group who had experienced chipping of the veneer material or framework fracture exhibited significantly lower chewing efficiency and maximum bite force, causing the authors to conclude that a fracture experience may limit the functional benefit of fixed prostheses.

■ Conclusions

1. Studies reported high implant and prosthesis survival rates for traditional fixed complete dentures and overdentures. With “all-on-4” fixed complete dentures, implant and prosthesis survival rates were also high, with comparable implant survival rates reported for both upright and tilted implants.
2. A substantial number of prosthetic maintenance/complication issues have been reported with both implant fixed complete dentures and implant overdentures. More maintenance/complications were encountered with implant overdentures than with implant-fixed complete dentures.
3. With fixed complete dentures, resin tooth wear was a common sequela from usage, with one systematic review indicating 70% of prostheses presented with some form of wear and another review reporting this was the most common mechanical maintenance requirement with a 33% frequency at 5 years and 66% at 10 years. Other less frequently reported issues included screw-related and aesthetic complications.
4. With “all-on-4” fixed complete dentures, the major prosthetic complication was fracture of the all-resin conversion prosthesis.
5. With implant overdentures, the most common prosthetic maintenance requirement involved the retentive mechanism that frequently needed either an adjustment or replacement.
6. Only one study reported very few maintenance requirements or complications with fixed prostheses and overdentures, whereas all but one of the other studies reported more occurrences with overdentures than with fixed prostheses.
7. While the number of studies was limited, more residual ridge resorption was reported over time with implant overdentures than with fixed complete dentures.
8. Patients who received the specific treatment they desired had greater satisfaction.
9. Patient satisfaction was high with both types of prostheses.
10. Multiple studies reported limited or no difference in patient satisfaction between implant fixed complete dentures and implant overdentures, but three studies noted improved patient satisfaction with fixed complete dentures.
11. In two studies patients were permitted to wear both a fixed prosthesis and overdenture and then were asked to select their preferred prosthesis. In one of these two studies, an equivalent number of patients chose each type of prosthesis whereas most of the patients in another study preferred the overdenture. Reasons for selecting the fixed prosthesis included better mastication, increased stability, and greater comfort. Reasons for selecting the overdenture included ease of cleaning, aesthetics, and general satisfaction. It was interesting to note that

the patients in one study who preferred overdentures stated it was because of their “ability to speak” compared with fixed prostheses, while those who chose the fixed prosthesis in that study also indicated one of their reasons was the “ability to speak.”

12. Multiple studies reported that implant overdentures were more cost-effective than implant fixed complete dentures. However, one study indicated that fixed prostheses retained by three implants could be provided at about the same cost as implant overdentures that also used three implants.
13. When the masticatory performance of implant overdentures and implant-fixed complete dentures were individually compared with complete dentures, both types of prostheses improved the masticatory performance. However, both types of prostheses were only compared with each other in two studies and it was not possible to definitively determine which type of prosthesis was superior to the other.

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Clinical outcomes of full arch fixed implant-supported zirconia prostheses: A systematic review



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Aim: The primary aim of this systematic review was to study the clinical outcomes of one-piece fixed complete dentures (complete arch fixed implant-supported prostheses) made of zirconia for edentulous patients. The secondary aim was to compare the clinical outcomes of monolithic zirconia vs zirconia veneered with porcelain (conventional, minimal or gingival) for fixed complete dentures.

Materials and methods: Two investigators conducted an independent electronic search of the literature, using PubMed and Scopus search engines from January 1, 2000, to August 31, 2016. After application of pre-determined inclusion and exclusion criteria, the final list of articles was reviewed to meet the aims of this review.

Results: A total of 12 observational studies were identified that satisfied the inclusion criteria of this systematic review. Short-term results from a combined 223 patients with 285 one-piece zirconia fixed complete dentures showed a mean failure rate of 1.4% due to the fracture of four prostheses. Prosthetic complications occurred in 46 prostheses (16.1%). Out of these, 42 prostheses (14.7%) had minor complications exclusive to fracture of veneered porcelain.

Conclusions: Current evidence indicates that zirconia fixed complete dentures have a very low failure rate in the short term, but have a substantial rate of minor complications related to chipping of veneered porcelain. Use of monolithic zirconia with only gingival stains, or zirconia that is veneered only at the gingiva may offer promising results, but will need to be validated by future long-term studies.

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■ Introduction

Fixed complete dentures, also known as complete/full arch fixed implant-supported prostheses, are an excellent treatment option for edentulous patients¹⁻¹². A gamut of prosthetic materials and designs has been described in the literature¹³. They can be differentiated using four main parameters:

1. Mode of retention (screw-retained, cement-retained or a combination where a single milled bar has individual crowns cemented over it);

2. Framework design (one-piece, segmented or a combination);
3. Prosthetic material blend (metal-acrylic resin, metal-composite resin, metal-ceramic, monolithic zirconia or zirconia-ceramic)
4. Use of gingival material (denture base acrylic resin, gingival composite resin, gingival porcelain or gingival staining).

Metal-acrylic resin remains a popular choice for fixed complete dentures because of its long track record

in the literature, simplicity, reduced cost, easier reparability and clinicians' comfort level with this material over the years¹⁴. However, the high rate of prosthetic complications related to this material combination is also well known to clinicians. A long-term prospective cohort study of 24 metal-acrylic resin fixed complete dentures found that each prosthesis required resin maintenance work five to six times over a 10-year period¹⁴. Other such studies exist in the literature^{15,16}. This maintenance represents a significant inconvenience and financial investment for both the practitioner and the patient. Additionally, some patients with distal cantilevers, limited prosthetic space or parafunctional habits have even higher complication rates^{15,16}. Traditional alternatives to metal-acrylic resin fixed complete dentures are metal-composite resin or metal-ceramic, both of which are expensive, laborious to fabricate, difficult to repair, and technique sensitive, which precludes their use for a wide variety of patients¹³.

Zirconia is an emerging material for fixed complete dentures that has numerous purported advantages and disadvantages (Table 1). Zirconia has been used in dentistry for almost 15 years for varying indications, with a primary focus on improving aesthetics, due to its natural colour being white, as it is a crystalline oxide of zirconium²¹. Zirconia used in dentistry is yttria-stabilised tetragonal zirconia polycrystal (Y-TZP) and has a high fracture toughness ranging from 5 to 10 MPa·m^{1/2} and flexural strength ranging from 900 to 1400 MPa²². This is regarded as the highest of all dental ceramics presently available²¹. However, the primary clinical issue related to use of zirconia for fixed dental prostheses is the substantially high rate of veneered porcelain fracture ("porcelain chipping") reported in the scientific literature, ranging from 15% to 54%^{8,23}. The framework/core fracture itself is reported to be less than 1%²³. Purported reasons for veneered porcelain fracture include intrinsic mechanical properties related to the brand of zirconia itself, framework design and support for veneered porcelain and laboratory handling procedures^{6,8,10}.

Improved understanding of clinical performance and complications have led these issues to be successfully addressed by carefully selecting

good-quality zirconia blanks, carefully designing the framework digitally (including digital cut-back) to offer optimal support for veneered porcelain. Additionally, newer research related to adoption of slower heating and cooling rates during the firing of porcelain has shown to be beneficial in reducing stress and eventual fracture of veneered porcelain^{21,24}. Low temperature degradation has been noted to be an issue with zirconia during *in vitro* studies, but the clinical evidence for this issue is lacking^{6,21,25,26}.

Another emerging solution to entirely eliminate fracture of veneered porcelain is monolithic zirconia, with the addition of stains (tooth coloured or gingiva coloured) and internal coloration for aesthetics. However, monolithic zirconia presents a unique set of challenges. Denry and Kelly²¹ discussed challenges that emerge from the production of shaded zirconia, long-term chemical stability and the tribological behaviour of the material. They recommended that every step of the fabrication process, including blank fabrication, green machining, sintering process, and surface treatments (chemical, thermal, or mechanical), have to be carefully controlled to achieve expected mechanical and chemical properties²¹. Prudent manufacturers who ensure these processes are carefully controlled have now started to provide warranties ranging from 5 to 7 years on their zirconia restorations, including fixed complete dentures, which is significantly reassuring to both clinicians and patients¹⁸⁻²⁰. There is one systematic review that was recently published on "monolithic zirconia" fixed complete dentures²⁷. However, of the nine articles included in this systematic review, four articles were single-case reports with short-term follow-up. Furthermore, only one clinical study⁹ in this systematic review truly reported on "monolithic" zirconia, while the rest had some amount of veneered porcelain.

Therefore, the purpose of this systematic review was to analyse the clinical outcomes of zirconia fixed complete dentures for edentulous patients. The secondary objective was to compare the clinical outcomes of monolithic zirconia vs zirconia veneered with porcelain (conventional, minimal or gingival) for fixed complete dentures.

Table 1 Advantages and disadvantages of zirconia for use in fixed complete denture treatment of edentulous patients.

	Advantages	Disadvantages
1	Good dental and gingival aesthetics ^{1,6,8}	Inability to repair framework fractures
2	Superior strength and rigidity ⁶	Difficulty in adjusting and polishing ²¹
3	Excellent wear compatibility ^{6,8,17}	Heavier than metal-resin or metal-ceramic prostheses.
4	Fabrication requires CAD/CAM providing superior fit of the prosthesis	Low tolerance for minor inaccuracies in impression and can result in fracture of the prosthesis at the time of insertion.
5	Reduced laboratory cost due to less laborious nature of fabrication	High rate of chipping/fracture of veneering porcelain ²
6	Provision of warranty by dental laboratories and manufacturers against fracture ¹⁸⁻²⁰	Empirical reporting of occasional clicking sounds in double arch situations may be objectionable to some patients
7	Digital files can be stored permanently for fabrication of future prosthesis if necessary ⁹	Minimal long-term scientific data on clinical outcomes
8	Can be used in monolithic form with stains or with veneered porcelain (conventional, minimal or gingival)	
9	Allows fabrication and testing of prototype prosthesis in PMMA for patient approval and for future contingency use ^{1,6,9}	
10	Reduced staining compared to acrylic resin	
11	Good biocompatibility ⁸	
12	Reduced plaque accumulation and favourable soft tissue response ⁸	

Materials and methods

Two investigators conducted an independent electronic search of the literature, using PubMed and Scopus search engines. The specific search terms, search string, and limits are presented in Table 2. The population, intervention, comparison, outcome (PICO) questions of this systematic review were: for edentulous patients, do one-piece fixed complete dentures made of zirconia have good clinical outcomes?; and does monolithic zirconia compared with zirconia veneered with porcelain (conventional, minimal or gingival) or other prosthetic materials have superior clinical outcomes over each other? The period searched was from January 1, 2000, to August 31, 2016. The only search limits applied to the electronic search were the English language, search period and clinical studies.

The predetermined inclusion criteria were: 1) English language article in a peer-reviewed journal; 2) any clinical study published between January 1, 2000 and August 31, 2016; and 3) any clinical study on implant-supported zirconia fixed complete dentures with a minimum of five patients.

The predetermined exclusion criteria were:

1) articles that did not pertain to items described in the inclusion criteria; 2) articles that did not pertain to the objectives of the systematic review; 3) articles that did not clearly describe zirconia fixed complete dentures; 4) articles that described data on multiple piece fixed zirconia prosthesis; 5) review articles or technique articles without associated clinical study and data; 6) case reports or case series with fewer than 5 patients; 7) patients or data being repeated in other included articles; and 8) article description that would not allow extraction of qualitative or quantitative data related to objectives of the study.

The electronic search process using the PubMed and Scopus search engines was systematically conducted in three stages according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) format²⁸. In the filtering process this procedure helped to remove duplicate articles, as well as ensuring a systematic search process. In stage 1, the two investigators independently screened all relevant titles of the electronic search, and any disagreement was resolved by discussion.

Table 2 Description of the terms and search process used in the PubMed search engine.

Search	Query	Results
#1	("Zirconium"[Mesh] OR "Zirconium oxide"[Supplementary concept] OR zirconium[tiab] OR zirconia[tiab] OR "zirconium oxide"[tiab] OR "fixed zirconia"[tiab] OR "monolithic zirconia"[tiab] OR "minimally veneered zirconia"[tiab] OR "full arch zirconia"[tiab] OR "full-arch zirconia"[tiab] OR "full arch monolithic zirconia"[tiab] OR "full-arch monolithic zirconia"[tiab] OR "full arch prosthesis"[tiab] OR "full-arch prosthesis"[tiab] OR "full arch restoration"[tiab] OR "full-arch restoration"[tiab] OR "all-ceramic zirconia"[tiab] OR "all ceramic zirconia"[tiab] OR "complete arch zirconia"[tiab] OR "complete arch monolithic zirconia"[tiab] OR "full contour zirconia"[tiab] OR "solid zirconia"[tiab] OR "zirconia framework"[tiab] OR "zirconium-oxide fixed dental prosthesis"[tiab] OR "zirconium oxide fixed dental prosthesis"[tiab] OR "zirconia hybrid prosthesis"[tiab] OR "CAD CAM zirconia"[tiab] OR "CAD/CAM zirconia"[tiab] OR "CAD/CAM zirconia"[tiab] AND (implant[tiab] OR "dental implant"[tiab] OR "Dental Implants"[Mesh] OR implant prosthe*[tiab] OR "Dental Prosthesis, Implant-Supported"[Mesh] OR "Dental Prosthesis"[Mesh] OR dental prosthe*[tiab] OR "full arch restorations"[tiab] OR "full arch restoration"[tiab])	2541
#2	#1 + English	2436
#3	2000-2017	2278

In situations where the application of the exclusion criteria was unclear, the controversial article was included for consideration in the abstract stage. In stage 2, the investigators independently analysed the abstracts of all selected titles, and disagreements were resolved by discussion. In situations of uncertainty, the abstract was advanced for the full-text stage. After the application of the exclusion criteria, the definitive list of articles was screened at stage 3 by the investigators to extract qualitative and quantitative data. Authors of three clinical studies^{2,3,6} were contacted by email for further clarification of data, and all the authors responded and successfully clarified missing data. A supplemental electronic search for articles from the Cochrane database, along with a hand search of references of all included articles, was conducted using systematic methods. Additionally, articles that had a lag time before appearing on the PubMed search engine were also screened for the three stages, as part of the supplemental search. Data from all included studies were then tabulated, analysed, and compared to satisfy the objectives of the systematic review. In this systematic review, the authors defined failure as fracture of any part of a zirconia prosthesis that required removal and remake of a new prosthesis or alteration of treatment. Prosthetic complication was defined as an unanticipated event that affected the prosthesis and required an intervention or none, but without replacement and remake of new zirconia prosthesis.

■ Results

The initial electronic search using the specific search terms from PubMed (2278) and Scopus search engine (871, after removal of duplicates from PubMed) resulted in a combined total of 3149 titles, out of which 35 abstracts were applicable to the study. Reviewing the abstracts resulted in 21 full-text articles being appropriate for further review. Incorporating a supplemental electronic search process resulted in 249 additional titles from PubMed and Scopus. Systematic examination eventually resulted in the inclusion of 12 full text articles, all of which reported data on zirconia fixed complete dentures for edentulous patients (Fig 1). These 12 studies were included for qualitative data extraction and analysis (Table 3).

All 12 articles were observational in nature (three prospective and nine retrospective studies). All of them were published in the past 5 years, with eight of them being published in the past 2 years. Seven studies were conducted in a university setting and five were conducted in a private practice. The total number of implants per arch to support the one-piece zirconia prosthesis ranged from as low as three implants to as high as 15 implants, with a majority of studies using at least four implants per arch. Only one study reported on an entirely monolithic zirconia fixed prosthesis, where the gingival region was not veneered with porcelain, but simply characterised with gingival stains⁹. The

remaining 11 studies all had zirconia veneered with porcelain (conventional, minimal or gingival). Out of these, six studies reported conventional veneering of porcelain; five studies reported "minimal" veneering of porcelain that was restricted to the facial surfaces of anterior teeth and/or the gingival region only. Zirconia from various manufacturers were used across the 12 studies, with four studies using Nobel Procera Zirconia (Nobel Biocare, Yorba Linda, CA, USA), four studies using Prettau Zirconia ((Zirkonzahn, South Tyrol, Italy) and the remaining four studies each using zirconia from unique manufacturers (Table 3). The opposing jaw characteristics were all heterogeneous, but 10 studies reported that at least a few patients in their study had fixed complete dentures made of various materials (zirconia, metal-resin, metal-ceramic). One study⁹ reported that the opposing maxilla was restricted to a complete denture, while another study⁷ did not report on the opposing jaw characteristics. A total of nine studies reported that some sort of cantilever extension was present in the prostheses, while two studies^{4,10} did not clarify on the presence of cantilevers, but it is likely that at least some of the prostheses in these two studies had distal cantilevers, given the number of implants per arch reported in these two studies^{4,10}.

A total of 223 patients with 285 one-piece zirconia fixed complete dentures were included in these 12 studies (Table 4). The sample size ranged from nine to 40 patients per study, which was the same for the number of zirconia prostheses per study. The reported range of follow-up of patients varied from as low as 0.1 years (2 months) to 8 years. Most studies had a follow-up of 1 year, but six studies (96 prostheses) reported up to 3 years, five studies (55 prostheses) reported up to 4 years, three studies reported up to 5 years (42 prostheses) and only one study (nine prostheses) reported up to 8 years. This finding was anticipated at the start of the systematic review given that zirconia fixed complete dentures are a relatively new treatment. Most studies did not specify how many patients were followed up at each time interval. In total, eight studies reported on zirconia fixed complete dentures being used for single arch and/or double arch rehabilitation, four studies were exclusively for single arch rehabilitation and one study did not report this data.

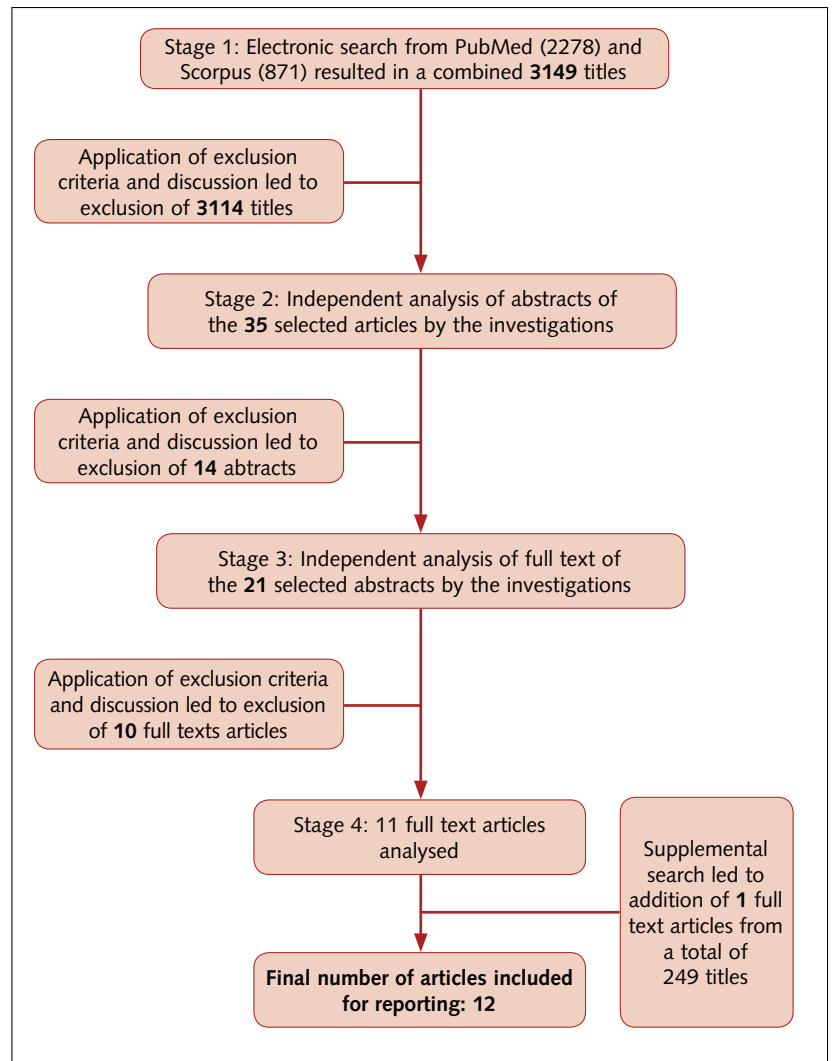


Fig 1 Flowchart of the systematic search process.

The pooled data from 285 zirconia fixed complete dentures showed a total of four reported failures due to fracture of the prosthesis (mean failure 1.4%). The four fractures occurred in various types of zirconia^{2,7,9}. A total of 46 prostheses (16.1%) had prosthetic complications and 42 of these (14.7%) had complications exclusive to chipping of veneered porcelain. The four prostheses with complications other than chipping of veneered porcelain included two fractured abutments⁹ and two loose abutments^{9,12}. One study also reported on six chippings of denture teeth in the opposing jaw⁹, which was not counted towards prosthetic complications in this systematic review. Two studies reported on complications related to the use of primary and secondary components, which again did not count towards prosthetic complications

Table 3 Descriptive data from the 12 included studies that reported on one-piece zirconia fixed complete dentures.

Study Name	Year	Nature of the study	Setting of the study	Composition of material of the fixed complete denture	Opposing jaw characteristics	Zirconia Manufacturer Information	Study support/ Conflict of interest reported
Rojas-Vizcaya ¹	2016	Retrospective study	Private practice	PFZ (veneering was restricted to gingiva)	Zirconia fixed complete dentures	Zirconia: Prettau Zirconia, Zirkonzahn; Veneering porcelain: ICE Zirkon Ceramics, Zirkonzahn	Author reported no conflict of interest
Tartaglia et al ²	2016	Retrospective study	Private practice	PFZ	Fixed complete dentures made of zirconia or metal-resin, natural teeth	Zirconia: Zirite, Keramo Spa; Veneering porcelain: CZR, Noritake	Authors reported no conflict of interest
Sannino et al ³	2016	Retrospective study	University	PFZ	Fixed complete dentures made of zirconia or metal-resin, restored natural teeth, removable partial denture, complete denture	Zirconia: Procera; Nobel Biocare; Veneering porcelain: Carabien Zirconia, Kuraray, Noritake Dental	Authors reported no conflict of interest
Carames et al ⁴	2015	Retrospective study	University	PFZ (veneering was restricted to facial surfaces of teeth and gingiva)	Fixed complete dentures made of zirconia, complete dentures, restored natural teeth	Zirconia: Prettau Zirconia, Zirkonzahn; Veneering porcelain: ICE Zirkon Ceramics, Zirkonzahn	Authors reported no conflict of interest
Venezia et al ⁵	2015	Retrospective study	Two private practices	PFZ (veneering restricted to incisal and facial aspects of anterior teeth)	Fixed complete dentures made of zirconia, natural teeth	Zirconia: Sagemax Zr; Sagemax Bioceramics Inc); Veneering porcelain: E-max Ceram; Ivoclar Vivadent AG	Not reported
Moscovitch ⁶	2015	Prospective study	Single Private practice	PFZ (veneering was restricted to facial surfaces of teeth and gingiva);	Fixed complete dentures made of zirconia, natural teeth	Zirconia: Prettau Zirconia, Zirkonzahn; Veneering porcelain: VITA VM9, VITA Zahnfabrik	Author reported no conflict of interest
Worni et al ⁷	2015	Retrospective study	University	PFZ	NR	Zirconia: Procera; Nobel Biocare; Veneering porcelain: Not specified	Not reported
Pozzi et al ⁸	2015	Retrospective study	University	PFZ	Fixed complete dentures, complete denture, natural teeth	Zirconia: Procera; Nobel Biocare; Veneering porcelain: CZR, Noritake	Not reported
Limmer et al ⁹	2014	Prospective study	University	Monolithic zirconia prostheses with gingival staining	Complete denture	Zirconia: Prettau Zirconia, Zirkonzahn; Veneering porcelain: None (only gingival stains were used)	Dentsply (Molndal, Sweden) & Zirkonzahn (Gais, Italy) provided test materials.
Larsson et al ¹⁰	2013	Prospective study	University	PFZ (cement retained)	Fixed complete dentures (metal-ceramic), restored natural teeth, removable partial denture	Zirconia: Cercon, DeguDent; Veneering porcelain: Cercon ceram S, DeguDent	Authors reported no conflict of interest
Papaspapiridakos et al ¹¹	2013	Retrospective study	University	PFZ	Fixed complete dentures made of zirconia or metal-ceramic, restored natural teeth, removable partial denture, complete denture, over-denture	Zirconia: Procera; Nobel Biocare; Veneering porcelain: Not specified	Authors reported no conflict of interest
Oliva et al ¹²	2012	Retrospective study	Private practice	PFZ (veneering was restricted to facial surfaces of teeth)	Fixed complete dentures made of zirconia, natural teeth	Zirconia: (CeraCrown system, Oral Ice-berg) Veneering porcelain: Not specified	Authors reported no conflict of interest

PFZ: Porcelain fused/fired to zirconia

Table 4 Clinical outcomes data from the 12 included studies that reported on one-piece zirconia fixed complete dentures.

Study Name	Number of patients with one-piece zirconia fixed complete dentures.	Total number of one-piece zirconia prostheses in the study	Range of follow-up in years	Range of implants per arch	Distribution of patients (single arch vs double arch)	Total number of prosthetic failures reported	Total number of prostheses with various complications	Total number of prostheses with complications exclusive to porcelain chipping
Rojas-Vizcaya ¹	10	19	2 to 7 years	4 to 8 implants	Double arch (10)	0	0	0
Tartaglia et al ²	32	48	0.1 to 5 years	4 implants	Single arch (16) and double arch (16)	2	19	19
Sannino et al ³	40	40	3 years	4 implants	Single arch (33) and double arch (7)	0	1	1
Carames et al ⁴	14	26	0.25 to 3.5 years	4 to 9 implants	Single arch (2) and double arch (12)	0	1	1
Venezia et al ⁵	18	26	0.83 to 3 years	5 to 7 implants	Single arch (10) and double arch (8)	0	3	3
Moscovitch ⁶	21	25	0.1 to 5.6 years	5 to 15 implants	Single arch (17) and double arch (8)	0	0	0
Worni et al ⁷	11	11	2 to 7 years	NR	Single arch (11)	1	1	1
Pozzi et al ⁸	22	26	3-5 yrs	4 to 10 implants	Single arch (18) and double arch (4)	0	3	3
Limmer et al ⁹	17	15	1 yr	4 implants	Single arch (17)	1	3	0
Larsson et al ¹⁰	9	9	8 yrs	4 implants	Single arch (9)	0	8	8
Papaspyridakos et al ¹¹	14	14	2-4 yrs	5 to 8 implants	Not reported for one-piece prostheses	0	5	5
Oliva et al ¹²	15	26	5 yrs	3 to 6	Single arch (3) and double arch (12)	0	2	1

in this systematic review, as those samples were excluded^{1,9}. Only two studies in this systematic review reported absence of any failures or prosthetic complications in the analysed samples^{1,6}. Due to paucity of sample size, extremely low number of reported failures, absence of long-term follow-up and inadequate of reporting on when failures and prosthetic complications actually occurred, construction of a life table and subsequent computation of cumulative survival rates was not possible. Therefore, no further statistical analysis was performed. There were no adverse effects reported on implants, opposing natural dentition, hard and soft tissues, temporomandibular joints or patient dissatisfaction due to use of zirconia fixed complete dentures on single or double jaw rehabilitations.

■ Discussion

The aim of this systematic review was to analyse the clinical outcomes of one-piece zirconia fixed complete dentures for edentulous patients and to compare monolithic zirconia vs zirconia veneered with porcelain (conventional, minimal or gingival). Zirconia is a relatively new material in dentistry, with its popularity only emerging in the past decade, and zirconia fixed complete denture is a relatively novel application of this material. As a result, the authors did not attempt to analyse long-term survival as it was anticipated before the systematic review began that such data would be unavailable. Therefore, this review was designed to assess only the short-term survival rate of zirconia fixed complete dentures, to help understand the clinical potential and prognostic nature of this material in the long term.

It is remarkable that only four out of 285 zirconia fixed complete dentures (1.4%) exhibited failures (fractures requiring prosthesis remake) in this systematic review. The four failures were restricted to three studies^{2,7,9}. Tartaglia et al² reported two fractures that required a remake of the prostheses. In this study, the authors clarified that the fit of the frameworks were passive and the connectors were designed with a minimum dimension of 10 mm², with no more than a 2 mm space for veneered porcelain. This indicates that these fixed complete dentures were all made as “dentition-only” replacements without any gingival prosthesis¹³. Despite proper precautions, two prostheses fractured and 19 prostheses had chipping of veneered porcelain indicating that this may either be an issue with intrinsic properties of the chosen zirconia itself, or perhaps that zirconia fixed complete dentures may require increased prosthetic space for increased thickness of zirconia for sufficient strength. This can be attained by appropriate bone reduction and incorporating gingival prosthesis for proper aesthetics and tooth proportions. There was no mention of the use of an occlusal device or the parafunctional habits of these patients, although the authors clarified that they used a slower heating and cooling protocol during the firing of porcelain. Worni et al⁷ reported one prosthesis fracture on a 12-unit fixed dental prosthesis on a patient who exhibited bruxism (among other framework fractures in partially edentulous arches). The fractured prosthesis was a “dentition-only” replacement without any gingival prosthesis, once again suggesting that zirconia fixed complete dentures may require increased prosthetic space for increased thickness of zirconia. Limmer et al⁹ reported one fracture of a monolithic zirconia prosthesis (with staining used for gingival aspect) 6 months after insertion. The authors clarified explicitly that the fracture occurred vertically through the entire body of the prosthesis immediately distal to the terminal abutment, resulting in the loss of the distal cantilever segment on the affected side. Authors reported that inadequate prosthetic space, cantilever length or intrinsic properties of the zirconia may have caused the fracture. In summary, an analysis of the four fractures from all three studies indicated that reduced prosthetic space may be a risk factor for fracture of zirconia

fixed complete dentures and warrants careful case selection or appropriate bone reduction for optimal prosthetic space.

Commonly reported complications of zirconia-based restorations typically involve fracturing or delamination of the veneered porcelain. This study is no different. A total of 42 out of 285 prostheses (14.7%) from nine studies, reported chipping of veneered porcelain. Although this number is lower than the fracture of veneered resin/denture teeth typically seen in metal-resin prostheses, this number is substantial because of the expensive and complex nature of porcelain repair procedures in the dental laboratory. It is remarkable that none of the chipping of veneered porcelain required a remake or replacement of the prosthesis across all studies. One study even reported that many patients were unaware of the fractures of the veneered porcelain at follow-up and concluded that the importance of fractures of the veneered porcelain should not be overstated¹⁰. Use of an occlusal device (night guard) was reported to have aided in risk reduction for fracture of veneered porcelain, by multiple authors^{3,4, 9,11,12}. Chairside polishing and adjustment was performed for most porcelain chippings, and in some situations a laminate was fabricated.

Except for one recent study by Tartaglia et al², which reported an abnormally high rate of fracture of veneered porcelain, most studies had a minimal number of fractures (range 1 to 8).

However, it is important to note that compared with newer studies, the older studies or those with a longer follow-up period had higher numbers of veneered porcelain fracture, indicating that the older studies may not have adopted slower heating and cooling rates during the firing of porcelain, which is regarded as important to minimise veneered porcelain fracture^{21,24}. It is also interesting to note that zirconia prostheses that had conventional veneering and minimal veneering both reported fracture of veneered porcelain, indicating that minimal veneering may not help reduce the risk of porcelain chipping, but may help to reduce a patient's dissatisfaction once the fracture has occurred. Additionally, chipping of veneered gingival porcelain was not reported as a complication in any of the studies, perhaps because this is located in a non-functional and non-load bearing area. In summary, an analysis

of the 42 porcelain chippings from nine studies indicates that fracture of veneered porcelain may be a minor complication in zirconia fixed complete dentures and clinicians and patients are less likely to have the prosthesis remade or repaired in the laboratory. Furthermore, use of monolithic zirconia with gingival stains, or zirconia with only veneered gingival porcelain, may aid in risk reduction for failures and complications with the material, but further studies are needed.

Despite the lack of long-term clinical evidence, the popularity of zirconia fixed complete dentures is likely to continue growing, as many dental manufacturers and dental laboratories in the United States now offer a warranty against any prosthetic complications. The warranty period varies between laboratories/manufacturers, provided there is sufficient prosthetic space to allow for adequate zirconia thickness¹⁸⁻²⁰. The warranty concept is not only based on the fidelity of the material, but also due to the reduced cost of fabrication due to CAD/CAM technology and reduced labour. The clinician's labour and time in removing fractured zirconia prosthesis and replacement with an interim (prototype) resin prosthesis is minimal, due to the screw-retained nature of the prosthesis. Thus, the warranty reassures the patient and clinician of indemnification of a fractured prosthesis, and having a digital file permanently stored allows fabrication of a new monolithic zirconia prosthesis, to mimic the original prosthesis. Additionally, the patient can continue to wear the prototype prosthesis (milled from the same scan using resin-based materials) during the fabrication of a new prosthesis.

Although this systematic review satisfied most PRISMA guidelines, there were some limitations to this review: 1) some aspects of the results section were not applicable or amenable to the PRISMA checklist; 2) due to the nature of the topic and PICO questions posed in this systematic review, the authors did not find significant quantitative data for construction of a life table and subsequent computation of cumulative survival rates was not possible. Therefore, no further statistical analysis was performed; 3) only one study identified in this systematic review compared the clinical outcomes of zirconia fixed complete dentures with another material (metal-resin)². This study concluded that

prosthetic material did not influence the complication risk. However, both prostheses were not equally divided in this study, and further bias was introduced against zirconia because authors stated that one of the criteria for patients to be provided with zirconia prostheses was occurrence of fractures in the interim prosthesis. Additionally, the zirconia prostheses were all "dentition-only" replacement without any gingival prosthesis, implying reduced prosthetic space; 4) there were no studies identified that compared monolithic zirconia fixed prostheses with zirconia fixed prostheses with veneered porcelain (conventional, minimal or gingival). In fact, only one study in this systematic review was identified that had truly monolithic zirconia fixed prostheses (with gingival staining)⁹. Many studies claimed to use "monolithic zirconia", but study descriptions clearly indicated that some level of porcelain was veneered to the zirconia. Future studies should adhere to the definition of monolithic and make this aspect clearer to the reader to allow a fair assessment and comparison of prostheses. Finally, we did not include studies or samples within the included studies that described zirconia fixed complete dentures which were not one-piece by design^{1,9,11}. We deemed that segmented fixed dental prostheses (multiple units of crown and bridge) or fixed complete dentures with primary and secondary components like a veneer or crown cemented over the access opening, have different biomechanical and prosthetic considerations, impeding a fair comparison with the typical one-piece prostheses.

Despite an exhaustive search process, it is possible that the authors failed to identify some articles in the search process²⁹, as in most systematic reviews. Grey literature (information that falls outside the mainstream of published journal and monograph literature) was not considered here because articles of this type are usually non-peer reviewed, with a potential for biased information or information that is restricted for use³⁰. Additionally, published trials tend to be larger and show an overall greater treatment effect than grey trials³¹. However, it is unknown whether incorporation of these omitted articles would change the conclusions of this systematic review.

Unanswered questions from this systematic review that will hopefully be answered by future

investigators include differences in clinical outcomes of zirconia fixed complete dentures between: 1) single arch vs double arch prostheses; 2) distal cantilever vs non-cantilever prostheses; 3) maxilla vs mandible; 4) monolithic vs veneered zirconia prostheses; 5) various types of veneering porcelain (conventional vs minimal vs gingival); 6) implant level vs abutment level prostheses; 7) indirect zirconia interface (bonded to metal cylinders) vs direct zirconia interface with abutments; and 8) different thickness of zirconia for different prosthetic space requirements based on prosthetic designs.

■ Conclusions

Within the limitations of this systematic review, the following conclusions were drawn:

1. One-piece zirconia fixed complete dentures have a very low failure rate in the short term, but have a substantial rate of chipping of veneered porcelain. Reduced prosthetic space was associated with all fractures.
2. Chipping of veneered porcelain did not require the remake of any prostheses, but only required chairside polishing and adjustment or, in some cases, a porcelain laminate veneer was fabricated, indicating that this generally may be regarded as a minor complication.
3. Chipping of veneered gingival porcelain was not reported as a complication in any of the samples in the included studies.
4. Use of monolithic zirconia with gingival stains, or zirconia with only veneered gingival porcelain, may offer promising results for fixed complete dentures, but will need to be validated by future long-term studies.
5. There were no adverse effects reported on implants, hard and soft tissues, temporomandibular joints or patient dissatisfaction due to use of zirconia fixed complete dentures on single or double jaw rehabilitations.
6. Most of the studies evaluated were short-term and there is a need for long-term data to provide more definitive conclusions.

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Impact of prosthetic material on mid- and long-term outcome of dental implants supporting single crowns and fixed partial dentures: A systematic review and meta-analysis

Key words *fixed partial dentures, implants, material selection, meta-analysis, single crowns, systematic review*

Aim: The impact of prosthetic material selection on implant survival is not clear. The current criteria for choosing a prosthetic material seem to be based on clinician preferences. This systematic review aims to evaluate the impact of restorative materials on the mid- and long-term survival of implants supporting single crowns and fixed partial dentures.

Materials and methods: Hand and MEDLINE searches were performed to identify relevant literature for single crowns (SC) and fixed partial dentures (FPD). Further inclusion criteria were a mean follow-up period of at least 3 years, the inclusion of at least 10 patients in a relevant study cohort, and a clear description of prosthesis type and prosthetic material.

Results: A total of 63 studies for the SC group and 11 studies for the FPD group were included. Full arch restorations were not included. The materials utilised in the SC group were metal-ceramic (precious and non-precious), lithium-disilicate, veneered zirconia, veneered alumina, and nanoceramics. The materials used in the FPD group were metal-ceramic (precious), veneered titanium, metal-resin (precious), and veneered zirconia. No significant impact on the prosthetic material relating to mid- or long-term implant survival was identified. Furthermore, there were no statistically significant differences between the survival rates of the dental prostheses made from different materials (SC and FPD group). Single crowns made of nanoceramics showed a higher risk for decementation relative to other materials (0.80, 95% CI [0.67; 0.89]; $P < 0.0001$), whereas metal-resin FPDs showed a higher risk for chipping (0.36, 95% CI [0.23; 0.52]; $P = 0.0072$).

Conclusion: The current evidence suggests that prosthetic material selection has no influence on mid- and long-term survival of implants restored with single crowns and fixed partial dentures. Similarly, the prosthetic material seems to have no significant impact on prosthetic survival rates. Further research is required to provide more evidence regarding the impact of the prosthetic material on long-term outcome.

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

■ Introduction

The use of oral endosseous implants for the replacement of missing teeth has become a routine clinical procedure¹. Today, oral implants are being used

to treat various clinical situations, in particular partially and completely edentulous jaws. For implant-supported dental rehabilitations, several prosthetic solutions and materials are available². In fact, clinicians have a wide variety of materials available for



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prosthetic solutions. With the progress of CAD/CAM techniques and improvements to the aesthetic characteristics of contemporary materials, new possibilities for both fixed and removable rehabilitations are continuously being introduced. For example, high-strength ceramics can be used today as a framework material for veneered restorations, as well as for a final monolithic restoration. With such a wide spectrum of available materials and restorative options, clinicians are often confused about selecting the ideal prosthetic material, which facilitates ideal aesthetics, biocompatibility, and long-term stability. Apparently, material selection for the definitive prosthesis seems to depend not only on mechanical properties and anatomic and patient-related factors, but also on a clinician's individual preferences³.

The influence of many factors on the long-term outcome and on technical or biological complication rates of implant-borne fixed partial dentures (FPDs) is well described in scientific literature. For example, retention mechanisms seem to have an influence on technical and biological complication rates^{4,5}. On the one hand, screw-retained single crowns and fixed partial dentures seem to have a higher risk for technical complications than cement-retained single crowns or fixed partial prostheses. On the other hand, when all fixed restorations (regardless of the restoration type) are compared, significantly fewer complications were observed with screw retention⁴. This demonstrates that factors such as the retention mechanism can have different effects on various restoration types.

Another potential factor influencing the long term-outcome in partially edentulous patients is the length of the utilised implants. A recently published systematic review comparing short vs standard-length implants found that there were no significant differences in marginal bone loss, complication, or prosthesis failure rates. However, implants with lengths of less than 8 mm presented a higher risk of implant failure⁶. Another 5-year follow-up of a randomised controlled trial showed similar survival and success rates, and no statistically significant complication rates in partially edentulous cases, when 6 mm implants were compared with 10 mm implants⁷.

There appear to be several factors influencing the long-term survival and success rates of implant-borne dental restorations, including, but not necessarily

limited to, restoration type, retention mechanism, and implant length. For example, the choice of the prosthetic material is an additional factor to be considered in combination with the aforementioned variables, as it might play a role in determining long-term outcome⁸.

While many studies have reported on implants and factors affecting their survival, little knowledge is available about the impact of the prosthetic material. For example, it is not clear whether an all-ceramic crown would lead to an improved outcome for the implant relative to a metal-ceramic crown. Also, the influence of the restorative material on the clinical outcome of the implant-borne prosthetic rehabilitation is unclear. So far, studies addressing the outcome of implant rehabilitations made of different materials primarily compared two materials. Moreover, varying study designs make it difficult to assess the outcome and impact of a specific material. An evaluation of the impact of the prosthetic material on implant survival would enhance clinical knowledge and provide clinicians with guidelines regarding material selection.

Therefore, the aim of this systematic literature review and meta-analysis is to examine whether a correlation exists between the type of restorative material and the clinical outcome of implants, as well as the associated prosthetic rehabilitations.

■ Materials and methods

■ Study protocol

The study protocol was set in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement⁹. The focused leading question was set according to the PICO model for clinical questions. This model aids the discovery of clinically relevant evidence in literature by dividing the leading question into four subcategories (population, intervention, comparison, and outcome). The four criteria for this study were as follows:

- Population: Partially edentulous patients receiving fixed implant-supported restorations;
- Intervention: Prosthodontic rehabilitation by means of implant-supported single crowns (SCs) or fixed partial dentures (FPDs);

- Comparison: Performance of various prosthetic materials used for each type of restoration;
- Outcome: Implant and prosthetic survival, as well as technical complications related to the restorative material and the type of prosthesis.

After analysing the different points of this model, the resulting PICO question was: "Does the choice of restorative material influence the mid- and long-term outcome of implants and/or fixed partial dentures?"

■ Definitions

Prior to the systematic search, several terms were defined: "Implant survival" was defined as implants that were still *in situ* at the point of observation. Implant conditions such as surrounding bone, soft tissue, or signs of inflammation were not parameters considered in the evaluation of survival. "Prosthetic survival" was defined as prostheses that were still *in situ*, even if repairs of any kind were necessary (e.g. renewal of the veneering material). "Technical complications" were subdivided into four distinct categories: abutment fracture, chipping, screw loosening, and decementation of the superstructure.

■ Inclusion and exclusion criteria

For the systematic literature search, the following inclusion and exclusion criteria were compiled:

Inclusion criteria

- Human clinical studies (randomised controlled trials, controlled trials, prospective studies, retrospective studies, case series);
- Fixed implant-supported prostheses and single crowns;
- Titanium implants;
- Partially edentulous patients;
- Documentation of prosthetic material;
- Documentation of restoration type;
- Number of patients/ study arm or cohort ≥ 10 ;
- Mean follow-up period ≥ 3 years;
- Publication in English.

Table 1 Key words for initial database search.

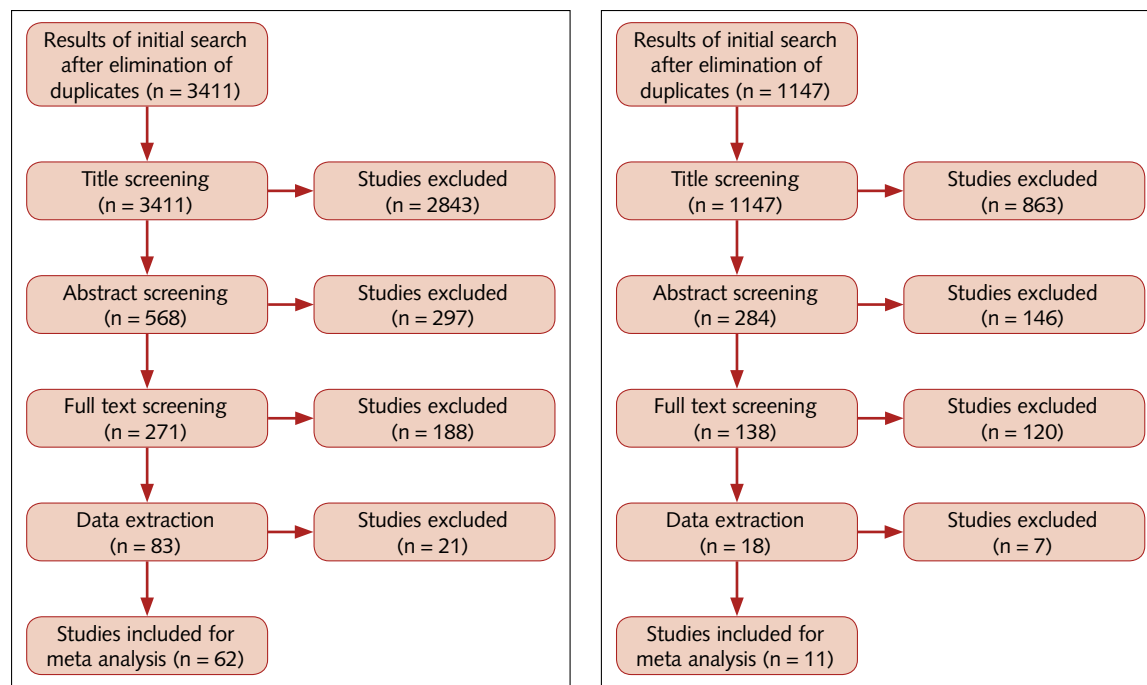
Group	Search Terms	Initial hits
SC	("crown" OR "crowns" OR "partially edentulous" OR "single Crown" OR "single Crowns") AND ("implant" OR "implants" OR "dental implant" OR "dental implants")	3411
FPD	("fixed partial prostheses" OR "fixed partial prosthesis" OR "partially edentulous" OR "implant bridge") AND ("implant" OR "implants" OR "dental implants")	1147

Exclusion criteria

- *In vitro* or animal studies;
- Removable partial denture;
- Ceramic implants;
- Edentulous patients;
- Insufficient documentation of prosthetic material;
- No documentation of restoration type;
- Fewer than 10 patients in relevant study arm/cohort;
- Mean follow-up period less than 3 years;
- Publications not written in English;
- Combined tooth-implant-supported restorations;

■ Search strategy and study selection

For the initial electronic search in the MEDLINE library (via PubMed), the types of dental restorations were divided into two different groups: single crowns (SC group) and fixed partial dentures (FPD group). For each group, a separate initial search of literature without any filters was performed using distinct key words (Table 1). Furthermore, reference lists of review articles with similar topics were systematically screened, and potentially relevant articles were added to the results of the electronic search. After elimination of duplicates, the titles of the remaining articles were checked for adequacy, according to the inclusion criteria. Irrelevant titles (e.g. *in vitro* studies) were excluded. When the relevance of studies was uncertain according to the title, the studies were included for abstract screening. When the relevance of the studies remained unclear after reading the



Tables 2a and 2b Study selection process for single crowns (SCs) and fixed partial dentures (FPDs).

abstract, they were included for full text screening, resulting in a selection of possibly eligible full texts. After reviewing the full texts, irrelevant articles were excluded, and data of the remaining articles was extracted whenever possible. Study selection and data extraction were performed for each group independently by two reviewers (SA and MS). Afterwards, every disagreement regarding the inclusion of specific articles was solved by discussion. Tables 2a and 2b illustrate the study selection process for each group. For data extraction, identical study forms for each group were designed, including the following parameters: authors, title, year of publication, study design, study period, number of patients, number of implants in the study, implant system, implant lengths, implant diameters, implant material, abutment material, timing of implant placement, loading protocol, number of implants per prosthesis, number of prostheses in total, jaw, number of cantilevers, length of cantilever, type of retention, bone augmentation, soft tissue augmentation, CAD/CAM workflow, mean radiographic bone loss, implant loss before loading, prosthetic survival rate, screw loosening, decementation, chipping, prosthesis fracture, framework fracture, abutment fracture, peri-implantitis, mucositis, implant fracture, and superstructure material.

■ Risk of bias within the studies

For quality assessment, six quality categories were implemented to evaluate the included studies¹⁰: “fair” for retrospective studies, “average” for prospective case studies, “good” for prospective studies with historical control, “better” for prospective studies with concurrent controls, “best” for double-blind randomised controlled trials, and “unknown” for studies not fitting one of the other five criteria. Due to the high degree of heterogeneity observed in study design and in results of the different studies that were considered, a decision was made to include all studies that were rated at least “fair”.

■ Risk of bias across the studies

In most of the studies, primary outcomes differed from our leading question. The choice of prosthetic material was often considered as a marginal note. Therefore, a potential risk of bias might be introduced via extracting and evaluating data from studies that do not refer to the influence of the prosthetic material.

■ Statistical analysis

For evidence synthesis using meta-analysis, the open source statistical environment R (version 3.2.0)¹¹ with the R packages “meta”¹² and “metafor”¹³ was used. The random effects model was used throughout. The outcomes were the proportion of surviving implants, the prosthetic survival proportion, the proportion of screw-loosening events by number of implants, the proportion of abutment fractures by the number of implants, the proportion of chipping by the number of prostheses, and the proportion of decementation by the number of prostheses. Proportions were pooled using the logit transformation. In addition, loss of implants was measured as an incidence rate per average follow-up time. For all outcomes, the impact of material was analysed using meta-regression¹³. The generally poor reporting in the primary studies made it impossible to adjust for potential intrasubject correlation due to the varying unit of analysis (patients, implants, prostheses).

■ Synthesis of results

Most of the included studies did not compare multiple restorative materials directly, but described, for example, different augmentation techniques.

Data were extracted whenever the restorative material was mentioned and the study met the inclusion criteria. For simplification, not all of the columns of the study form had to be completed, if certain information was not provided in a given study (e.g. implant lengths). Whenever implant or prosthetic survival rates were not reported, studies were not included for data extraction, but taken into consideration for strengthening or weakening results of the meta-analysis. If multiple study arms or cohorts were identified in the same study, data from each group was recorded separately. This resulted in a higher number of study populations than indicated by the number of included studies.

The primary outcome of the meta-analysis was to evaluate the implant and prosthetic survival rates as functions of the restorative material and restoration type. Therefore, restorations were divided into metal-based and all-ceramic restorations, and secondly, whenever possible, divided into groups according to the exact restoration material (e.g. glass

ceramics or ceramic-veneered precious alloy). Hence, several studies did not describe the exact restoration material, but only whether an all-ceramic or metal-based restoration was used, such that the number of included studies was higher for the comparison between metal-based and all-ceramic materials than for the comparison of the exact materials used.

Furthermore, to be able to compare the results of the included studies, despite the variable follow-up periods, the implant loss rate per 10 implant years was calculated. This rate describes the risk of an implant loss regarding one single implant for a period of 10 years, or the risk of an implant loss of two implants over 5 years. Additionally, the incidence rates for screw loosening, decementation of superstructures, chipping, and abutment fractures were calculated.

■ Results

■ Literature search

As previously described, an initial literature search via MEDLINE and a manual search were performed for each group separately (Table 1). 3411 studies were included for the SC group, while 1147 studies were included for FPDs. After title-, abstract-, and full text screening, 83 studies remained in the SC group, and 18 remained in the FPD group for data extraction. During data extraction, 21 further studies from the SC group and seven from the FPD group were excluded, resulting in a final number of included studies of 62 for the SC group and 11 for the FPD group (Tables 2a and 2b). Reasons for exclusion during data extraction are listed in Tables 3a and 3b. The results for the two groups are henceforth described separately.

■ Study characteristics

Most of the included studies were prospective studies, but RCTs, retrospective studies and case series were also included. The type of study and quality assessment of each study is shown in Tables 4a and 4b. The majority of the studies had an observation period between 3 and 10 years. Studies with longer observation periods were scarce. In the SC

Table 3a Reasons for study exclusion (SC group).

Study	Reason for exclusion
Bergenblock et al. 2012 ¹⁴	Pooled results
Bianchi et al. 2004 ¹⁵	Pooled results
Branzen et al. 2015 ¹⁶	Pooled results
Dierens et al. 2016 ¹⁷	Pooled results
Ekfeldt et al. 2011 ¹⁸	Pooled results
Grassi et al. 2015 ¹⁹	Zirconia implants
Hälg et al. 2008 ²⁰	Pooled results
Hosseini et al. 2013 ²¹	Pooled results
Lops et al 2012 ²²	Pooled results
Mangano et al. 2010 ²³	Pooled results
Mangano et al. 2015 ²⁴	Pooled results
Moberg et al. 1999 ²⁵	Pooled results
Özkan et al. 2011 ²⁶	Pooled results
Özkan et al. 2007 ²⁷	Pooled results
Passos et al. 2016 ²⁸	Pooled results
Spies et al. 2015 ²⁹	Zirconia implants
Spies et al. 2015 ³⁰	Zirconia implants
Tartaglia et al. 2015 ³¹	Pooled results
Thoma DS et al. 2015 ³²	Different target variables
Vigolo et al. 2000 ³³	Pooled results
Walton 2015 ³⁴	Pooled results

group, 76 study populations across 62 studies and in the FPD group, 15 populations across 11 studies were investigated. Various implant types with different surface modifications were placed in these studies. Several types of prosthetic materials were used in the studies (all types of metal-ceramic, metal-resin and all-ceramic materials). Screw-retained, as well as cemented restorations were analysed. Differences in time of implant placement, loading protocols, augmentation procedures, number of implants per prosthesis, abutment materials, implant lengths, implant diameters, number of cantilevers, and lengths of cantilevers were not taken into consideration for the meta-analysis.

■ Single crowns

All-ceramic vs metal-based SCs

For the analysis of implant survival, the results of 24 study cohorts of the all-ceramic group and 53 of the metal-based group were used for the meta-analysis (Tables 5 and 6). The implant survival rate in

Table 3b Reasons for study exclusion (FPD-group).

Study	Reason for exclusion
Astrand et al. 2004 ³⁵	No implant/ prosthetic survival rates reported
Becktor et al. 2007 ³⁶	No implant/ prosthetic survival rates reported
Bornstein et al 2010 ³⁷	Pooled results
Felice et al. 2014 ³⁸	No implant/ prosthetic survival rates reported
Maló P et al 2013 ³⁹	Pooled results
Nissan J et al. 2011 ⁴⁰	Unclear statistics
Ortorp A et al. 1999 ⁴¹	Pooled results

the all-ceramic group (included studies $n = 23$) was 0.97 (95% CI [0.95; 0.98]) with a mean observation period of 5.4 years, and 0.96 (95% CI [0.95; 0.97]) among metal-based SCs with a mean observation period of 5.6 years. This difference was not statistically significant ($P = 0.1724$). The meta-regression-analysis showed no impact on the different observation periods for the two groups ($P = 0.5976$). The calculated implant loss rate per 10 implant years was 0.06 (95% CI [0.04; 0.08]) for the all-ceramic and 0.07 (95% CI [0.05; 0.10]) for the metal-based group. This difference was not statistically significant ($P = 0.3737$).

Prosthetic survival rates were 0.95 (95% CI [0.94; 0.97]) in the all-ceramic (included studies $n = 19$) and 0.97 (95% CI [0.96; 0.98]) in the metal-based group ($n = 27$). The difference was not significant ($P = 0.0872$). Subgroup analyses for the incidence rates of screw loosening, decementation, abutment fractures and chipping revealed no statistical differences between the two groups.

■ Exact restorative materials

For the meta-analysis of implant survival rates, the results of two study cohorts of veneered non-precious alloys, 11 of veneered precious alloys, 10 of veneered zirconia, five of veneered alumina, four of glass ceramics, and one for nanoceramics, were included. The veneering material was ceramic. For the analysis of the prosthetic survival rates, three study cohorts of veneered precious alloys, 12 of veneered zirconia, four of veneered alumina, four of glass ceramics, and one of nanoceramics, were included. For veneered non-precious alloys, no

Table 4a Quality assessment of included studies (SC group).

Authors	Type of study	Quality assessment
Balshi TJ et al. ⁴²	Prospective	good
Berberi AN et al. ⁴³	Prospective	good
Bilhan H et al. ⁴⁴	Retrospective	fair
Bonde MJ et al. ⁴⁵	Retrospective	fair
Buser D et al. ⁴⁶	Prospective	good
Calandriello R & Tomatis M ⁴⁷	Prospective	good
Cannizzaro G et al. ⁴⁸	RCT	best
Cannizzaro G et al. ⁴⁹	RCT	best
De Bruyn H et al. ⁵⁰	Prospective	better
Cosyn J et al. ⁵¹	Prospective	good
Covani U et al. ⁵²	Prospective	good
Covani U et al. ⁵³	Prospective	good
Davis DM ⁵⁴	Prospective	good
Donati M et al. ⁵⁵	Prospective	good
Enkling N et al. ⁵⁶	RCT	best
Fenner N et al. ⁵⁷	Prospective	better
Glauser R et al. ⁵⁸	Prospective	good
Gotfredsen K et al. ⁵⁹	Prospective	better
Guarnieri R et al. ⁶⁰	Prospective	good
Ioannidis A et al. ⁶¹	RCT	best
Jemt T ⁶²	Retrospective	fair
Jemt T & Pettersson P ⁶³	Retrospective	fair
Khraisat A et al. ⁶⁴	Prospective	good
Kolgeci L et al. ⁶⁵	Prospective	good
Lai HC et al. ⁶⁶	Retrospective	fair
Lang LA et al. ⁶⁷	Prospective	good
Lops D et al. ⁶⁸	Prospective	better
Mangano C et al. ⁶⁹	Retrospective	fair
Mangano FG et al. ⁷⁰	Prospective	good

Authors	Type of study	Quality assessment
Mangano FG et al. ⁷¹	Retrospective	fair
Mericske-Stern R et al. ⁷²	Retrospective	fair
Montoya-Salazar V. et al. ⁷³	RCT	best
Nejatidanesh et al. ⁷⁴	Retrospective	fair
Palmer RM ⁷⁵	Prospective	good
Perelli M. et al. ⁷⁶	Prospective	good
Pieri F et al. ⁷⁷	Prospective	better
Proussaefs P & Lozada J ⁷⁸	Prospective	good
Rinke S et al. ⁷⁹	Retrospective	fair
Rinke S et al. ⁸⁰	Retrospective	fair
Rocuzzo M et al. ⁸¹	Prospective	good
Romanos GE et al. ⁸²	RCT	best
Romeo E et al. ⁸³	Prospective	good
Rossi F et al. ⁸⁴	Prospective	good
Rossi F et al. ⁸⁵	RCT	best
Schepke U ⁸⁶	Prospective	good
Schropp L et al. ⁸⁷	RCT	best
Schropp L et al. ⁸⁸	RCT	best
Sorrentino R et al. ⁸⁹	Retrospective	fair
Turkyilmaz I et al. ⁹⁰	Prospective	better
Vanioglu AB et al. ⁹¹	Prospective	better
Vigolo P et al. ⁹²	Prospective	better
Visser A et al. ⁹³	Prospective	good
Weber HP et al. ⁹⁴	Prospective	good
Worni A et al. ⁹⁵	Prospective	good
Zarone F et al. ⁹⁶	Prospective	good
Zembic A et al. ⁹⁷	RCT	best
Zembic A et al. ⁹⁸	Prospective	good
Zhao X et al. ⁹⁹	Retrospective	fair

Table 4b Quality assessment of included studies (FPD-group).

details regarding prosthetic survival rates could be found. Implant and prosthetic survival rates, as well as the 95% CI, can be seen in Table 7. The differences in implant and prosthetic survival rates were not statistically significant (implant survival: $P = 0.4061$; prosthetic survival: $P = 0.8580$). The meta-regression-analysis showed no impact of the different observation periods on the comparison between any of the groups (implant survival: $P = 0.2120$; prosthetic survival: $P = 0.9622$). The calculated implant loss rate per 10 implant years showed no statistically significant differences among all groups ($P = 0.6502$).

Authors	Type of study	Quality assessment
Barnea E et al. ¹⁰⁰	Retrospective	fair
Brägger U et al. ¹⁰¹	Prospective	good
Francetti L et al. ¹⁰²	Prospective	good
Göthberg C et al. ¹⁰³	RCT	best
Jemt T et al. ¹⁰⁴	Retrospective	fair
Kreissl ME et al. ¹⁰⁵	Prospective	good
Mangano F et al. ¹⁰⁶	Prospective	good
Pozzi A et al. ¹⁰⁷	Prospective	better
Romeo E et al. ¹⁰⁸	Prospective	good
Romeo E et al. ¹⁰⁹	Prospective	good
Romeo E et al. ⁷	RCT	best

Table 5 Included studies in the all-ceramic single crown group.

Study	Study period (years)	Patients (n)	Implants (n)	Prostheses (n)	Superstructure material	Abutment material	Implant survival (%)	Prosthetic survival (%)	Abutment fracture (%)	Chipping (%)	Screw loosening (%)	Decementation (%)
Berberi AN et al. ⁴³	3	20	20	20	Veneered Zirconia	Ti	100					
Bonde MJ et al. ⁴⁵	10	42	46	46	All ceramic (non defined)	Ti	93.5	93.5				
Buser D et al. ⁴⁶	3	20	20	20	Veneered Zirconia	Ti	100	100				
Calandriello R & Tomatis M ⁴⁷	5	33	40	40	Veneered Alumina	Ti	95	100	0	0	0	0
De Bruyn H et al. ⁵⁰	5	55	55	55	Veneered Alumina	Ti	94.6					
De Bruyn H et al. ⁵⁰	5	58	58	58	Veneered Alumina	Ti	98.3					
Fenner N et al. ⁵⁷	7.2	13	13	13	All ceramic (non defined)	Al	100	100	0	0	0	0
Glauser R et al. ⁵⁸	4.1	18	36	36	Glass ceramics	Zr	100	97.2	0	8.3	5.6	0
Guarnieri R et al. ⁶⁰	5	21	21	21	All ceramic (non defined)	Zr	95.2		0	0	0	4.8
Jemt T ⁶²	10	15	18	18	All ceramic (non defined)	Ti	100		0	0	16.7	0
Kolgeci L et al. ⁶⁵	3.3	67	120	120	Veneered Zirconia	Zr	98.3	95.8	0			
Lops D et al. ⁶⁸	5	37	37	37	Veneered Zirconia	Zr	100	100	0	10.8	2.7	0
Nejatidanesht et al. ⁷⁴	4.9	122	232	232	Veneered Zirconia	Ti	99.2	97.5		1.6		
Pieri F et al. ⁷⁷	5	29	29	29	Veneered Zirconia	Ti/Zr	100	100	0	7	0	3.5
Rinke S et al. ⁷⁹	6.5	27	42	42	Veneered Zirconia	Zr	100	97.6	2,3	11.9	4.7	9.5
Schepke U et al. ⁸⁶	1.1		50	50	Nano Ceramic	Zr	100	94				80
Sorrentino R et al. ⁸⁹	6	48	81	81	Veneered Alumina	Ti/Al	97.6	95.1		0.9	0	0
Vanioglu AB et al. ⁹¹	5	6	11	11	Glass ceramics	Zr	100	100	0	0	9.1	0
Vanioglu AB et al. ⁹¹	5	6	12	12	Glass ceramics	Ti	100	100	0	0	0	0
Visser A et al. ⁹³	5	93	92	92	Veneered Zirconia	Ti	96.7	88	0	1.1	2.2	0
Worni A et al. ⁹⁵	5		70	70	Veneered Zirconia	Zr	98.6	94.2				
Zarone F et al. ⁹⁶	4		58	58	Veneered Alumina	Al/Ti	100	98.3				
Zembic A et al. ⁹⁷	5.6	18	18	18	All ceramic (non defined)	Zr	88.9	100	0	0	0	0
Zembic A et al. ⁹⁸	11.3	16	23	23	Glass ceramics	Zr	100	100		9.7	6.5	

Table 6 (cont. next 2 pages) Included studies in the metal-ceramic single crown group.

Study	Study period (years)	Patients (n)	Implants (n)	Prostheses (n)	Superstructure material	Abutment material	Implant survival (%)	Prosthetic survival (%)	Abutment fracture (%)	Chipping (%)	Screw loosening (%)	Dece- menta- tion (%)
Balshi TJ et al. ⁴²	5.5	140	164	164	Metal-Ceramic (precious)	-	95.7					
Bilhan H et al. ⁴⁴	3	80	122	122	Metal-Ceramic (non-defined)	-	91.8					
Cannizzaro G et al. ⁴⁸	4	30	29	29	Metal-Ceramic (non-defined)	-	96.7					
Cannizzaro G et al. ⁴⁸	4	30	31	31	Metal-Ceramic (non-defined)	-	96.8					
Cannizzaro G et al. ⁴⁸	4	30	29	29	Metal-Ceramic (non defined)	-	96.7					
Cannizzaro G et al. ⁴⁹	3	20	52	52	Metal-Ceramic (non-defined)	-	100	100	0	3.8	1.9	0
Cannizzaro G et al. ⁴⁹	3	20	56	56	Metal-Ceramic (non-defined)	-	100	100	0	3.6	0	0
Cosyn J et al. ⁵¹	3	25	25	25	Metal-Ceramic (non-defined)	-	96	100	0	0	0	4
Covani U et al. ⁵²	10	91	159	159	Metal-Ceramic (non-defined)	-	91.8	100	0	1.3	5.7	0
Covani U et al. ⁵³	5	47	47	47	Metal-Ceramic (non-defined)	Ti	95.7					
Davis DM ⁵⁴	5	20	23	23	Metal-Ceramic (non-defined)	-	87			13	18.2	52.2
Donati M et al. ⁵⁵	12	31	35	35	Metal-Ceramic (non-defined)	Ti	90.9		0	5.7	11.4	
Enkling N et al. ⁵⁶	3	25	25	25	Metal-Ceramic (non-defined)	Ti	100					
Enkling N et al. ⁵⁶	3	25	25	25	Metal-Ceramic (non-defined)	Ti	100					
Fenner N et al. ⁵⁷	7.2	15	15	15	Metal-Ceramic (non-defined)	Ti	100	100	0	13.3	0	0
Gotfredsen K et al. ⁵⁹	10	10	10	10	Metal-Ceramic (non-defined)	Ti	100	90		15	10	10
Gotfredsen K et al. ⁵⁹	10	10	10	10	Metal-Ceramic (non-defined)	Ti	100	90		15	10	10
Ioannidis A et al. ⁶¹	3	15	15	15	Metal-Ceramic (non-defined)	-	100		0	5.9	5.9	0

Study	Study period (years)	Patients (n)	Implants (n)	Prostheses (n)	Superstructure material	Abutment material	Implant survival (%)	Prosthetic survival (%)	Abutment fracture (%)	Chipping (%)	Screw loosening (%)	Dece- mentation (%)
Ioannidis A et al. ⁶¹	3	17	17	17	Metal-Ceramic (non-defined)	-	100		0	5.9	0	0
Jemt & Petterson ⁶³	3	49	69	69	Metal-Ceramic (non-defined)	-	98.5				44.9	
Jemt T ⁶²	10	13	15	15	Metal-Ceramic (non-defined)	Ti	100	100	0	0	20	0
Khraisat A et al. ⁶⁴	3	12	12	12	Metal-Ceramic (non-defined)	-	100					
Khraisat A et al. ⁶⁴	3	12	12	12	Metal-Ceramic (non-defined)	-	100					
Lai HC et al. ⁶⁶	10	168	231	231	Metal-Ceramic (non-defined)	-	98.3	95.2	0.4	2.6	5.6	3.9
Lang LA et al. ⁶⁷	5	10	10	10	Metal-Ceramic (non-defined)	-	100					
Lops D et al. ⁶⁸	5	44	44	44	Metal-Ceramic (non-defined)	Ti	100	100	0	6.8	2.3	0
Mangano C et al. ⁶⁹	3	20	20	20	Metal-Ceramic (non-defined)	-	100	100				
Mangano FG et al. ⁷⁰	5.6	191	212	212	Metal-Ceramic (non-defined)	-	98.5	100	0	0.9	0.5	0
Mangano FG et al. ⁷¹	10		482	482	Metal-Ceramic (non-defined)	-	99.2	99.2	0	0	0.6	20
Mericske-Stern R et al. ⁷²	4.3	72	109	109	Metal-Ceramic (precious)	Ti	97.3	95.8	4.2	1.4	26.4	1.4
Montoya-Salazar V. et al. ⁷³	3	18	18	18	Metal-Ceramic (non-precious)	Ti	94.4					
Montoya-Salazar V. et al. ⁷³	3	18	18	18	Metal-Ceramic (non-precious)	Ti	100					
Palmer RM ⁷⁵	5	14	14	14	Metal-Ceramic (non-defined)	-	100	100	0	7.1	0	7.1
Perelli M. et al. ⁷⁶	5	87	110	110	Metal-Ceramic (non-defined)	-	90	93.1	0	0.9	1.8	
Proussaefs P & Lozada J ⁷⁸	3	10	10	10	Metal-Ceramic (non-defined)	-	100	100				
Rinke S et al. ⁸⁰	6.8	65	112	112	Metal-Ceramic (precious)	-	100	97.3	0	8.9	3.6	14.3

Study	Study period (years)	Patients (n)	Implants (n)	Protheses (n)	Superstructure material	Abutment material	Implant survival (%)	Prosthetic survival (%)	Abutment fracture (%)	Chipping (%)	Screw loosening (%)	Dece- menta- tion (%)
Rocuzzo M et al. ⁸¹	10	30	36	36	Metal-Ceramic (precious)	-	100					
Romanos GE et al. ⁸²	12.1	10	36	36	Metal-Ceramic (non-defined)	-	100	100				
Romanos GE et al. ⁸²	12.4	10	36	36	Metal-Ceramic (non-defined)	-	100	100				
Romeo E et al. ⁸³	7	103	176	176	Metal-Ceramic (precious)	-	96.8					
Rossi F et al. ⁸⁴	5	45	60	60	Metal-Ceramic (precious)	Ti	86.7					
Rossi F et al. ⁸⁴	5	45	60	60	Metal-Ceramic (precious)	Ti	96.7					
Rossi F et al. ⁸⁵	5	35	40	40	Metal-Ceramic (non-defined)	Ti	95					
Schropp L et al. ⁸⁷	5	18	18	18	Metal-Ceramic (non-defined)	-	88.9	88.9	0	0		0
Schropp L et al. ⁸⁷	5	16	16	16	Metal-Ceramic (non-defined)	-	93.7	93.7	0	0		0
Schropp L et al. ⁸⁸	10	18	18	18	Metal-Ceramic (non-defined)	-	90.9					
Schropp L et al. ⁸⁸	10	40	37	37	Metal-Ceramic (non-defined)	-	97.6					
Turkyilmaz I et al. ⁹⁰	4	29	34	34	Metal-Ceramic (precious)	Ti	94.4					
Turkyilmaz I et al. ⁹⁰	4	10	23	23	Metal-Ceramic (precious)	Ti	95.7					
Vigolo P et al. ⁹²	4	20	40	40	Metal-Ceramic (precious)	Au/Ti	100	100	0	0	0	0
Weber HP et al. ⁹⁴	3		152	152	Metal-Ceramic (non-defined)	-	100	100	0	0	0	0
Zembic A et al. ⁹⁷	5.6	18	10	10	Metal-Ceramic (non-defined)	Ti	90	100	0	30	0	0
Zhao X et al. ⁹⁹	6.2	45	45	45	Metal-Ceramic (precious)	Ti	100	100	0	4.4	0	0

Table 7 Results for exact restorative materials (SC group).

Material	Number of studies included	Implant survival rates + 95% CI	Implant loss per 10 implant years	Number of studies included	Prosthetic survival rates + 95% CI	Decementation + 95% CI
Veneered metal-ceramics (non-precious)	2	0.96 [0.81; 0.99]	0.15 [0.03; 0.73]	-	-	-
Veneered metal-ceramics (precious)	11	0.96 [0.93; 0.98]	0.07 [0.04; 0.13]	4	0.97 [0.94; 0.98]	0.03 [0.01; 0.15]
Veneered zirconia	10	0.98 [0.97; 0.99]	0.04 [0.02; 0.07]	9	0.96 [0.93; 0.97]	0.04 [0.02; 0.09]
Veneered alumina	5	0.97 [0.93; 0.98]	0.07 [0.03; 0.13]	3	0.96 [0.92; 0.98]	0.01 [0.00; 0.06]
Glass ceramics	4	0.97 [0.87; 0.99]	0.06 [0.01; 0.31]	4	0.97 [0.91; 0.99]	0.03 [0.01; 0.13]
Nano Ceramics	1	0.99 [0.86; 1.00]	0.09 [0.01; 1.45]	1	0.94 [0.83; 0.98]	0.80 [0.67; 0.89]

Subgroup analyses for the prosthetic complication rates showed no statistically significant differences for screw loosening, abutment fractures, or chipping between any of the groups. The incidence rate for decementation was significantly higher for the nanoceramic group relative to all of the other groups ($P < 0.0001$). Incidence rates and 95% CI can be seen in Table 7.

■ Fixed Partial Dentures

All-ceramic vs metal-based FPDs

For the analysis of implant survival, the results from one study cohort of the all-ceramic group, two of the metal-based FPDs with resin facings, and eight of metal-based FPDs veneered with ceramics were included in the meta-analysis (Table 8). The survival rate of the all-ceramic group was 0.96 (95% CI [0.89; 0.99]) with a mean observation time of 3 years, 0.97 (95% CI [0.94; 0.99]) in the group of the metal-based FPDs with resin facings with a mean observation time of 5 years, and 0.96 (95% CI [0.94; 0.98]) in the ceramic-veneered group with a mean observation period of 5.9 years. The differences were not statistically significant ($P = 0.835$). The calculated implant loss rate per 10 implant years was 0.12 (95% CI [0.04; 0.38]) for the all-ceramic, 0.05 (95% CI [0.03; 0.11]) for the metal-based group with resin facings, and 0.06 (95% CI [0.03; 0.15]) for the ceramic-veneered group. The differences were not statistically significant ($P = 0.4840$).

Prosthetic survival rates were 0.99 (95% CI [0.82; 1.00]) for the all-ceramic, 0.99 (95% CI [0.93; 1.00]) for the metal-based group with resin facings,

and 0.96 (95% CI [0.91; 0.98]) for the ceramic-veneered group. The difference was also not significant ($P = 0.3695$).

Subgroup analyses for the incidence rates of screw loosening ($P = 0.0641$) and abutment fractures ($P = 1$) revealed no statistical differences among the three materials. Data concerning prosthesis fracture and decementation was only available for the metal-ceramic group. The incidence rate for chipping was significantly higher ($P = 0.0072$) in the metal-resin group (0.36; 95% CI [0.23; 0.52]), compared with the metal-ceramic (0.09; 95% CI [0.02; 0.31]) and the all-ceramic group (0.08; 95% CI [0.03; 0.22]).

■ Types of restorative materials

For the meta-analysis of implant survival rates, the results of three study cohorts from ceramic-veneered precious alloy FPDs group, two from ceramic-veneered and titanium based FPDs group, two from precious alloy-resin FPDs, and one from veneered zirconia FPDs, were included. For the analysis of the prosthetic survival rates, two study cohorts from the ceramic-veneered precious alloy FPDs group, two from precious alloy-resin FPDs, and one from veneered zirconia FPDs, were included. For the ceramic-veneered titanium group, no details regarding the prosthetic survival rates could be found. Implant and prosthetic survival rates, as well as the 95% CI, are given in Table 9. The differences in implant and prosthetic survival rates were not statistically significant (implant survival: $P = 0.8249$; prosthetic survival: $P = 0.9486$). The meta-regression-analysis showed no impact of the different observation periods for any of the groups (implant survival:

$P = 0.5270$; prosthetic survival: $P = 0.6558$). The calculated implant loss rate per 10 implant years showed no statistically significant differences among the groups ($P = 0,1534$).

Subgroup analyses for the incidence rates of screw loosening ($P = 0.0641$) showed no statistically significant differences between the used materials. Data regarding prosthesis fracture, abutment fracture, and decementation was only available for the metal-ceramic group. The incidence rate for chipping was significantly higher ($P = 0.0176$) in the metal-resin group (0.36; 95% CI [0.23; 0.52]), compared to the metal-ceramic (0.11; 95% CI [0.01; 0.56]) and the veneered zirconia group (0.08; 95% CI [0.03; 0.22]).

Discussion

Summary of evidence

The aim of this systematic review and meta-analysis was to analyse whether the choice of prosthetic material for fixed implant-supported restorations has an impact on the survival rates of oral endosseous implants. Furthermore, additional analyses for dental prosthesis survival rates and the incidence rates of prosthetic complications were performed.

Current data regarding the influence of prosthetic materials on implant survival is unsatisfactory. To our knowledge, there is not a single study investigating the impact of the prosthetic material on implant survival. There are several reviews dealing with implant and prosthetic survival rates for all kinds of fixed prostheses, but each of these posed a different scientific question, e.g. restoration types or implant lengths, while none of them addressed the prosthetic material during data collection^{7,110-116}. Therefore, the evidence for the influence of the prosthetic material has to be evaluated as nonexistent. Furthermore, even the abutment material as well as the abutment shape might play a role in implant survival. The most commonly used abutment material in the present study was titanium, but zirconia, alumina or gold alloy abutments were also used for the different types of restoration.

Even more interesting than the implant or prosthetic survival rates, are the associated success rates.

Table 8 Included studies in the FPD group.

Study	Study period (years)	Patients (n)	Implants (n)	Prostheses (n)	Superstructure material	Abutment material	Implant survival (%)	Prosthetic survival (%)	Abutment fracture (%)	Chipping (%)	Screw loosening (%)	Decementation (%)
Barnea E et al. ¹⁰⁰	4.86	29	29	29	Metal-Ceramic (non-defined)	-	93.10	100				
Barnea E et al. ¹⁰⁰	4.86	29	29	29	Metal-Ceramic (non-defined)	-	89.60	100				
Brägger U et al. ¹⁰¹	10	29	69	33	Metal-Ceramic (non-defined)	-	93.9	93.9				
Francetti L et al. ¹⁰²	6		39	18	Metal-Ceramic (precious)	Ti	100	100				
Göthberg C et al. ¹⁰³	3	26	78	26	Titanium-Ceramic	Ti	94.87					
Göthberg C et al. ¹⁰³	3	24	72	24	Titanium-Ceramic	Ti	97.22					
Jemt & Lekholm ¹⁰⁴	5		101	36	Metal-Resin	-	97.2	100		44.44	36.11	
Jemt & Lekholm ¹⁰⁴	5		158	58	Metal Resin	-	97.2	100		29.31	8.62	
Kreissl ME et al. ¹⁰⁵	5		159	66	Metal-Ceramic (precious)	Ti				6.06	3.03	
Mangano F et al. ¹⁰⁶	10		636	242	Metal-Ceramic (non-defined)	-	98.4		0	2.8		1.6
Pozzi A et al. ¹⁰⁷	3	27	81	37	Veneered Zirconia	Ti/Zr	96.3	100	0	8.1	0	
Romeo E et al. ¹⁰⁸	7		295	137	Metal-Ceramic (precious)	Ti	96.1			2.92	2.19	3.65
Romeo E et al. ¹⁰⁹	8.2	45	105	45	Metal-Ceramic (precious)	Ti/Au	100	100		48.89		6.6
Romeo E et al. ⁷	5	9		9	Metal-Ceramic (non-defined)	Ti		90	0	11.11		33.33
Romeo E et al. ⁷	5	9	9	9	Metal-Ceramic (non-defined)	Ti		100	0	11.11		22.22

Table 9 Results for exact restorative materials (FPD-group).

Material	Number of studies included	Implant survival rates + 95% CI	Implant loss per 10 implant years	Number of studies included	Prosthetic survival rates + 95% CI	Chipping + 95% CI
Metal-ceramic (precious)	3	0.98 [0.92; 0.99]	0.03 [0.01; 0.12]	2	0.98 [0.89; 1.00]	0.11 [0.01; 0.56]
Titanium-ceramic	2	0.96 [0.91; 0.98]	0.14 [0.06; 0.31]	---	---	
Metal-resin	2	0.97 [0.94; 0.99]	0.05 [0.03; 0.11]	2	0.99 [0.93; 1.00]	0.36 [0.23; 0.52]
Veneered zirconia	1	0.96 [0.89; 0.99]	0.12 [0.04; 0.38]	1	0.99 [0.82; 1.00]	0.08 [0.03; 0.22]

As there are several criteria for measuring implant success or the related success of the restorations, all of these distinct criteria are used in the analysed literature, which by itself makes finding a useful comparison method challenging; some authors did not even explicitly discuss the applied criteria. Therefore, it was decided not to analyse success, but rather survival rates. A main criterion for the analysis of implant success is the marginal bone loss. Generally, there are two different possible dates to evaluate the baseline value for bone loss: the day of implant placement or the day of the insertion of the definitive restoration. Furthermore, there are several possibilities for measuring marginal bone loss (e.g. the distance between implant shoulder and crestal bone margin). Apparently, a unified method to evaluate bone loss in combination with the description of the restorative material has not been used. For this reason, evaluation of the marginal bone loss was not included in the current meta-analysis.

For a meta-regression analysis, there are two commonly used statistical models: the random and the fixed effects model. For meta-regression and subgroup analyses, the random effects model is the most often recommended model¹¹⁷. In the present review, there were meta-analyses showing statistically significant differences between study groups when using the fixed effects model, but the random effects model showed no statistical significance (implant survival of all-ceramic SCs vs metal-ceramic SCs; screw loosening in all analysed study groups).

The calculation of implant loss rate per 10 implant years makes the assumption that the probability of implant loss is constant over the time after placement. This type of analysis might be questionable, but it enables the inclusion and comparison of studies with different observation periods, and has been applied in previous studies¹¹⁸. Furthermore,

the results can also be interpreted as the average implant loss rate during a period of 10 years.

To obtain an acceptable number of included studies, RCTs, controlled clinical trials, prospective studies, retrospective studies, and case series with at least 10 patients were included. In many studies, no information about the restoration material was provided. This led to the exclusion of several studies. Despite the inclusion of retrospective studies and case series, there are study groups in the present meta-analysis consisting of a single study cohort (e.g. veneered zirconia FPDs). The significance of the results concerning these groups is at least questionable.

In the SC group, 75 study populations in 61 study groups were initially investigated. Furthermore, one study was included in the tables, although it did not fit into the inclusion criteria (due to a follow-up period shorter than 3 years), but it was the only study that dealt with nanoceramics as the restorative material⁸³. The study showed a significantly higher incidence rate for decementation of the nanoceramic single crowns, compared with the other materials, even though the observation period was lower.

Considering the focused leading question, the prosthetic material selection seems to have no influence on the survival rates of dental implants or fixed partial dentures. Among single crowns, the incidence rates for decementation were significantly higher in the nanoceramic group (0.80; 95% CI [0.67; 0.89]) relative to all the other groups, even with the shorter follow up-period. In the FPD group, the incidence rate for chipping was significantly higher in the metal-resin group (0.36; 95% CI [0.23; 0.52]).

■ Limitations

The results of this meta-analysis must be regarded to consider the following limitations:

Data was mostly extracted from non-comparative studies. This was done because there were no studies comparing the influence of various restorative materials on implant survival. Especially due to the fact that the use of implants is a relatively new in dentistry, it is challenging to find comparative studies for every aspect. Many factors that have been considered to be more important have been investigated in randomised studies with different study cohorts.

It is worth mentioning that the primary questions of each of the included RCTs and prospective studies did not regard the choice of restorative material. Therefore, the level of evidence might be lower than assumed by regarding the quality assessment of the included studies. The scarcity of RCTs led to a lack of high-quality studies that could be included in this meta-analysis.

As the restorative material was not the key point of the included studies, heterogeneity among them was high. Furthermore, in many studies it was not clearly stated whether the baseline was the time of implant placement or the time of prosthesis delivery. Therefore, the mean calculated observation in the study groups could be different from reality.

The glass ceramic restorations of the SC group comprised different types of glass ceramic materials. In two studies the single crowns were made of leucite ceramics and in the two other studies, the crowns were made of lithium-disilicate ceramics^{58,91,98}. Although the material properties are different, we decided not to separate them into distinct groups as the crowns were all fabricated in a monolithic way. This seemed to have no influence on our outcome measures.

Further factors with a possible influence on survival, such as implant type, implant material, implant diameter, implant length, abutment material, location of implants, soft- or hard tissue grafting, biological complications, time of implant placement, loading protocols, type of retention, existing cantilever, or the number of implants per prosthesis, were not taken into consideration. Many of these factors are known to have an influence on implant survival and/or on the prosthetic outcome. However, due to

the aforementioned heterogeneity, it was not possible to include these factors in the present meta-analysis.

Full-arch implant-supported prostheses were not included in the study. The heterogeneity of variables within this type of restoration was too large for the analysis performed here (e.g. the number of implants per prosthesis). Further research on the influence of the prosthetic materials, especially on this type of prosthesis, would be interesting, as there are no remaining teeth in full arch prostheses. Therefore, bite forces are directly transferred to the bone by the implant and the prosthetic restoration, without any buffering by teeth or the periodontal ligaments, and the impact of the restorative material on implant survival might be significant in this group. But for a representative analysis, a closer selection of inclusion criteria must be performed than was required for this study.

■ Conclusions

A wide range of literature is available to analyse the impact of prosthetic material selection on implant and prosthetic survival rates in fixed dental restorations. However, most of the studies investigate single crowns rather than fixed partial dentures. Despite the limitations discussed above, the following conclusions can be made:

- The choice of prosthetic material seems to have no influence on implant survival rates in fixed restorations;
- The prosthetic material seems to have no influence on prosthetic survival rates of fixed implant-borne restorations;
- Nanoceramic SCs seem to have a higher risk of decementation relative to other materials, and;
- Metal-resin FPDs seem to have higher risk of chipping relative to other materials.

For future research, controlled clinical trials are essential to minimise the heterogeneity of literature concerning material selection, thereby enhancing our knowledge about the influence of restorative material on implant survival.

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Influence of implant abutment fabrication method on clinical outcomes: a systematic review



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Key words CAD/CAM, clinical outcome, conventional abutment, implant abutment, systematic review

Aim: The aim of this systematic review was to evaluate and synthesise the existing evidence on the effect of the prosthetic implant abutment design and fabrication process on mechanical, biological and aesthetic clinical outcomes.

Materials and methods: Two electronic databases (PubMed and Embase) were searched in August 2016 to identify clinical studies evaluating the clinical outcomes of CAD/CAM abutments. The studies were screened and two reviewers used the full text to extract data independently. A qualitative synthesis was performed on the extracted data and summary tables were prepared. Due to heterogeneity in the studies included, no meta-analysis was performed.

Results: Twenty-four studies were included in this review. Of these, 13 studies focused solely on CAD/CAM abutment and did not include a control group, or a comparison with conventional implant abutments. Eleven studies compared clinical outcomes of CAD/CAM abutments with conventional abutments. There were only three clinical trials and the majority of the studies were observational or case series studies. The most commonly reported clinical outcomes measured were soft tissue volume and aesthetic scores, survival and success rates, and marginal bone levels.

Conclusion: The results of the review demonstrate that CAD/CAM abutments had overall good survival and success rates and that they provide comparable, if not better, clinical outcomes when compared with conventional abutments. However, existing evidence is weak as few randomised control trials were conducted and follow-up periods were, in general, short.

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Introduction

The restoration of dental implants requires the use of carefully designed prosthetic abutments to retain the final restoration. The abutment must be made of a biocompatible material that can endure the harsh oral environment. It must possess adequate

mechanical and physical properties to withstand occlusal forces and to distribute the load favourably along the supporting implant¹. As such, the long-term success of implant abutments heavily depends on abutment material properties.

Prosthetic abutments can be fabricated using various materials, including titanium, gold and

ceramics. These materials exhibit different degrees of biocompatibility and harmony with soft tissues². Titanium has been traditionally preferred because of its strength, biocompatibility, reliability, and machinability³⁻⁵. Zirconia prosthetic abutments are increasingly used as they tend to evoke better colour response of peri-implant mucosa and superior aesthetic outcomes compared with titanium abutments, as measured by the Pink Esthetic Score (PES), especially in subjects with thin mucosal phenotype^{6,7}.

The long-term success of implant abutments is not only dependent on material choice, but it is also dependent on design and manufacturing process as these may significantly influence abutment material properties. For example, physical and mechanical properties of zirconia are heavily influenced by preparation technique and the design of prosthetic components⁸⁻¹⁰. Indeed, the design and geometry of the prosthetic abutment significantly affects stress distribution in implant-retained restorations, which, in turn, impacts clinical outcomes¹.

A successful prosthetic implant abutment must also support the peri-implant mucosa. This will allow for the fabrication of a restoration endowed with optimum contours and a proper emergence profile. This will ultimately result in a restoration that is functional, aesthetic and cleansable. The design and manufacturing process also influences abutment contours and finish, which are factors directly influencing aesthetic outcomes.

In addition, abutment design and manufacturing process have critical biological consequences. For example, the accumulating body of evidence suggests that the use of stock prosthetic abutments for cement-retained restorations should be avoided, as they may complicate cement removal¹¹⁻¹³. Thus, abutment design and contours may affect the ability of clinicians to remove excess cement. This further highlights the importance of abutment design and fabrication technique in affecting the clinical outcomes of implant restorations.

With the recent explosion of digital technology and the increased use of computer-aided design and computer-aided manufacture (CAD/CAM) processes in the fabrication of implant prosthetic abutments, it is important to assess if the design and fabrication method affects clinical treatment outcomes. While previous systematic reviews focused on the effect

of abutment materials on clinical outcomes, none investigated CAD/CAM abutments and how they compared with conventional abutments. Therefore, the objective of this review was to analyse the literature relating to the use of CAD/CAM prosthetic implant abutments to address the following PICO question¹⁴: In subjects treated with fixed implant-supported restorations, what is the effect of using CAD/CAM abutments, compared with conventional abutments, on mechanical, biological and aesthetic treatment outcomes.

■ Materials and methods

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines¹⁴.

■ Eligibility criteria

Clinical studies examining humans of any age, race/ethnicity, or gender were eligible for this review. Studies reporting on the clinical outcomes of CAD/CAM abutments in implant-supported restorations were included. Also included were studies comparing CAD/CAM abutments with conventional abutments. Clinical outcomes were broadly categorised as mechanical, biological and aesthetic outcomes. Conventional abutments were defined as those fabricated using non-digital methods, including stock abutments, prefabricated abutments and customised abutments. Case reports with fewer than five cases, conference abstracts, non-systematic reviews, letters, opinion articles and animal studies were excluded.

■ Source and search methods

Two different electronic databases were searched using search strategies designed for each database – PubMed and Embase. There were no language or date restrictions in the electronic search. The literature search was first performed on 3 March, 2016, and then updated on 21 August, 2016. The following is a brief description of the strategy used in the PubMed search: The MeSH term “computer-aided design” was combined with MeSH terms: “dental

implants", "dental implantation", "dental abutments", "dental implant-abutment design", "dental implantation, endosseous/methods", or "dental prosthesis, implant-supported". In addition, the text words "CAD", "CAM", "customized abutment*", "computer-generated", "computer-assisted manufacture*", "computer-assisted designed manufactured", "Computer-assisted design*", "computer-aided manufacture*", "Computer-aided design*", "computer assisted", "cad-cam", "CAD/CAM", "sirona", "procera", "e4d", or "atlantis abutment*" were combined with the text words: "abutment*", "dental prosthesis implant-supported", "implant abutment*", "implant dentistry", "implant-supported abutment*", "single implant*", or "dental implant*". The filter for excluding animal studies was also applied. The complete search strategy for both databases is described in the appendices – (appendix 1: PubMed; appendix 2: Embase). In addition to searching electronic databases, a manual search was conducted to identify additional relevant literature. The National Institutes of Health Research Portfolio Online Reporting Tools (RePort) and search engines, such as "Google" and "Google Scholar", were also used to search for grey literature, unpublished studies and ongoing clinical trials. Only manuscripts with full text were included in this review.

■ Selection of studies

Two authors independently screened the titles and abstracts from the electronic and manual searches. Abstracts were initially classified as relevant, maybe relevant or not relevant. For abstracts labelled relevant or maybe relevant, full-text copies of the manuscripts were obtained. Two authors independently assessed each article and determined whether to include, exclude or designate each study as a "maybe". After the end of independent review, agreement between the reviewers was documented and conflicts were resolved through discussion or consultation with the third author.

■ Data collection

Two authors independently extracted the data. The following study characteristics were extracted: study design, CAD/CAM abutment system and material

used, conventional abutment type and material used, clinical outcomes, loss to follow-up, and follow-up period.

To assess the risk of bias for clinical trials, the Cochrane Risk of Bias tool was used¹⁵. To evaluate the reporting quality of observational studies, the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist¹⁶ was used. For case series studies, the Case Reporting (CARE) checklist¹⁷ was used. All of the 21 STROBE domains and 14 CARE topics were assessed. Risk of bias assessments for observational studies and case series studies were not conducted due to the heterogeneous quality of reporting in these studies.

■ Synthesis of results

The manuscripts were divided into studies that only investigated CAD/CAM abutments, and studies that compared CAD/CAM abutments with conventional abutments. A "summary of findings" table was produced describing the commonly reported outcomes from these studies. Because of the extreme clinical and methodological heterogeneity among these studies, a meta-analysis of the results was not feasible.

■ Results

The study selection process is illustrated in Figure 1. During the title and abstract screening process, studies were excluded if they did not examine humans or did not examine clinical outcomes of CAD/CAM abutments in fixed implant-supported restorations. Reasons for exclusion during the full-text review included: limited reporting such as abstracts, letters, opinion articles; treatment irrelevant for the present review: implant-supported facial reconstruction; patient population irrelevant for the present review: edentulous patients. A total of 24 studies were included in this review (Fig 1).

Thirteen studies used CAD/CAM abutment only and did not utilise conventional abutments. The study design, type of CAD/CAM abutments used, and main study outcomes of these studies are listed in Table 1. Among these studies, six were descriptive studies (case series), one was a cross-sectional

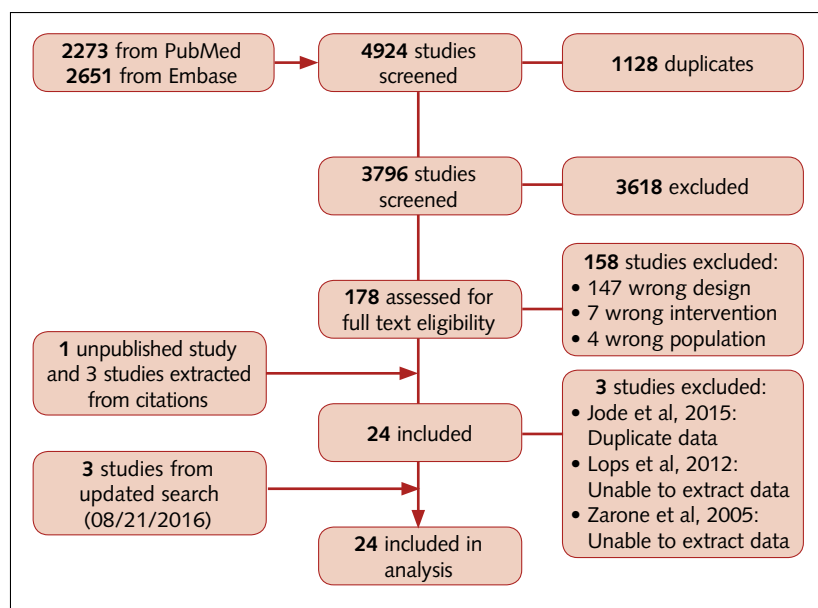


Fig 1 Manuscript review and selection process.

study, there were five cohort studies, and only one randomised clinical trial (RCT). These studies lacked a comparison to conventional abutments, as they were not primarily designed to compare CAD/CAM vs conventional abutments. Instead, they were designed to test differences between different CAD/CAM abutment materials and systems. Nonetheless, these studies yielded valuable information regarding clinical outcomes of CAD/CAM abutments.

Among these 13 studies, four investigated the Atlantis abutment system, six studies evaluated Procera abutments (including one on CeraOne abutments), one study investigated Straumann abutments, one evaluated Everest abutments, and one study did not include information on the system used, but only elaborated on the materials. The follow-up period of these studies ranged from 1 to 7 years. Five studies only had a 1-year follow-up and

Table 1 Studies solely investigating CAD/CAM abutments.

Study	Study design	CAD/CAM abutment used	Main outcome	Follow-up period (years)
Borges, 2012 ²²	Cross-sectional	Atlantis; Zirconia; Gold; Titanium	PES, bone level, success rate	2
Cooper, 2016 ⁴⁸	Cohort	Atlantis; Zirconia	Mechanical and biological complication rates	2.4
Ekfeldt, 2011 ²⁹	Cohort	Procera; Zirconia	Cases presenting with mechanical complication, bone level, PD, aesthetic score, self-evaluated VAS	1-5
Ferrari, 2016 ²⁵	Clinical trial	Atlantis; Titanium; Titanium nitride and Zirconia	Success rate	3
Furze, 2012 ²⁴	Case series	Straumann; Zirconia	PES, WES, Survival rate, success rate	1
Henriksson, 2003 ¹⁹	Cohort	Procera; Ceramic	Bone level, papilla index, cumulative survival rate	1
Henriksson, 2004 ²⁰	Cohort	CeraOne; Procera; Ceramic	Bone level, papilla index, cumulative survival rate	1
Kolgeci, 2014 ²⁷	Case series	Unreported; Zirconia	Cumulative survival rate	2-7
Kutkut, 2015 ²⁸	Case series	Procera; Titanium, Zirconia	Mechanical and biological complication rates, survival rate, aesthetic satisfaction	1
Pozzi, 2012 ²⁶	Cohort	NobelProcera; Zirconia and Titanium	Survival rate, bone level, success rate	1-3
Zhu, 2013 ³⁰	Case series	Everest; Zirconia	Incidence of bleeding upon probing, patient satisfaction	1
Wasiluk, 2016 ¹⁸	Case series	Atlantis; Titanium and Gold Hue	Presence of residual cement	N/A
Furhauser, 2016 ²³	Case series	NobelProcera; Zirconia	PES, thickness of buccal bone, gingival biotype, presence of periodontal disease	5

PES: Pink Esthetic Score; WES: White Esthetic Score; PD: Probing depth; VAS: Visual Analogue Scale

Table 2 Success and survival rates of CAD/CAM abutments based on the system used.

Parameter	CAD/CAM abutment	Outcome at 1-year follow-up	Number of abutments	Number of studies	Comments
Success rate	Atlantis	See comments	109	2 ^{22,25}	82.2% to 100% success rate reported at 2-year or 3-year time point
	Procera	See comments	91	1 ²⁶	91.9% cumulative success rate reported at 3-year time point
	Straumann	100%	10	1 ²⁴	
Survival rate	Straumann	100%	10	1 ²⁴	
	Procera	96.3%–100%	164	4 ^{19,20,26,28}	3 implants failed in study ²⁶
	CeraOne	100%	10	1 ²⁰	

Table 3 Success and survival rates of CAD/CAM abutments based on abutment material.

Outcomes	CAD/CAM abutment	Outcome at 1-year follow-up	Number of abutments	Number of studies	Comments
Success rate	Zirconia	See comments	41	3 ^{22,24,25}	82.2% success rate reported at 3-year time point in study ²⁵ . Others reported 100% success rate.
	Titanium	100%	78	2 ^{22,25}	100% success rate was also reported at 2-year or 3-year time points.
	Ceramic	100%	24	1 ¹⁹	
Survival rate	Zirconia	97.4%–100%	91	2 ^{24,26}	7-year cumulative survival rate was reported as 96.4% in study ²⁷ .
	Titanium	95.2%	42	1 ²⁶	
	Ceramic	100%	9	1 ²⁰	

seven studies had a follow-up of more than 1 year (Table 1). There was one study¹⁸ with no follow-up, because the outcome (presence of residual cement) was measured immediately after the restoration was delivered.

Of the 13 studies solely focussing on CAD/CAM abutments, five reported on changes in the papilla index of tissues surrounding the CAD/CAM abutment, including reporting on soft tissue volume^{19,20}, soft tissue response using a special four-point scale²¹, PES^{22–24}, and White Esthetic Score²⁴. Four of the 13 studies investigated the success rate of CAD/CAM abutments^{22,24–26}, which was defined, in the majority of studies as the proportion of restorations that remained *in situ* without any modification. Six out of 13 studies investigated the survival rate of CAD/CAM abutments^{19,20,24,26–28}, which was defined, in the majority of studies, by the proportion of restorations that remained clinically acceptable *in situ*, even if they received modifications²⁵. However, each study had its own predefined criteria for success and survival assessment. Only three of the 13 studies

reported patient-centred outcomes^{26,28,29}, including aesthetic and functional satisfaction. The success and survival rates of the various CAD/CAM abutments at 1 year of follow-up based on the system and materials used are presented in Tables 2 and 3 respectively.

For the only clinical trial²⁵ investigating clinical outcomes of CAD/CAM abutments, risk of bias assessment was performed according to the Cochrane Risk of Bias Assessment Tool¹⁵. The clinical trial had a low risk of selection bias because a computer-generated random list and allocation concealment were performed. However, it might be subject to information bias because of the subjective nature of the outcomes measured.

The reporting quality of observational studies was evaluated according to the STROBE checklist¹⁶. All of the six observational studies (cross-sectional and cohort) included exhibited good reporting quality in the title, abstract and introduction sections. However, half of the studies did not clearly articulate the study design and eligibility criteria,

Table 4 Studies investigating CAD/CAM vs conventional abutments.

Study	Study Design	CAD/CAM Abutment		Conventional Abutment		Main Outcome	Follow up Period (years)
		System, material	Number	Type, material	Number		
Borges, 2014 ³⁹	Cohort	Atlantis, Zirconia, Gold Titanium	25	Custom, Metal	12	PES, bone level, survival rate	1
Choquet, 2001 ⁴⁰	Cross-sectional	Procera, N/A	11	Customised, Titanium and Ceramic; Standard, N/A (CeraOne)	16	PES, bone level, PD, soft tissue height	Minimum of 0.5
Dierens, 2013 ⁴⁹	Case series	CeraOne, N/A	N/A	Customised, N/A	N/A	PES, WES, bone level, PD, soft tissue height	16-22
Joda, 2014 ³¹	Case series	Straumann, Titanium	3	Prefabricated, Titanium	3	Time, cost, WES	N/A
Joda, 2015 ³²	Cohort	Straumann Titanium	20	Prefabricated, Titanium	20	Time, cost, CMA	N/A
Joda, 2015 ³³	Cohort	Straumann, Titanium	20	Prefabricated, Titanium	20	Fitting and adjustment time	N/A
Korsch, 2015 ³⁷	Cohort	Atlantis, N/A	96	Prefabricated, N/A	312	Loosening rate, survival rate	2
Lops, 2015 ³⁴	Cohort	Atlantis, Zirconia	36	Stock, Zirconia and Titanium	36	Success rate, survival rate, soft tissue recession	2
Schepke, 2015 ³⁵	Case series	Atlantis, Zirconia	25	Stock, Zirconia	25	Survival rate, success rate	1
Borzangy, 2015 ³⁸	RCT	N/A, Zirconia	15	Prefabricated, Titanium	15	PES, WES, success rate, plaque score, bleeding score, PD, bone change	1
Schepke, 2016 ³⁶	RCT	Atlantis, Zirconia	25	Stock (ZirDesign), Zirconia	25	Bone change, plaque index, calculus formation, bleeding score, PD, soft tissue recession, patients' satisfaction	1

RCT: Randomised Clinical Trial; PES: Pink Esthetic Score; WES: white Esthetic Score; PD: Probing depth; CMA: clinical productivity rate/cost minimization; N/A: not reported.

and only one study included matched subjects. Five of the six studies suffered from missing follow-up data, and none of the studies addressed the missing data or performed sensitivity analysis¹⁶. None of the studies discussed external validity of the presented results and only two studies reported the source of funding.

The reporting quality of case-series studies was evaluated according to the CARE checklist¹⁷. Among the six case series studies, five studies indicated the study type in the title. However, none of these studies included "case report" or "case series" in the key words. All studies exhibited good reporting quality in their abstracts, introductions, interventions, outcomes and discussions. None of the studies included a timeline that indicated specific dates and times in a table, figure or graphic. Only half of the studies described the specific reasons and conditions of

patients who received implant treatment. Half of the studies reported on the evaluation of patients before treatment. Two of the six case-series studies reported patient perspective of the experience^{28,30}. Two^{18,28} did not report on the informed consent process and whether it was obtained from patients, and only two studies included an acknowledgements section.

■ Systematic review of studies comparing CAD/CAM abutments with conventional abutments

Eleven studies compared clinical outcomes of CAD/CAM abutments with conventional abutments. The study design, type of CAD/CAM abutment, type of conventional abutment, and main study outcomes are summarised in Table 4. Among these 11 studies, three were descriptive studies (case series), one was

Table 5 Outcomes of CAD/CAM vs conventional abutments.

Outcomes	1-year results without significant difference		1-year results with significant difference (CAD/CAM showing better performance)		Comments
	No. of total abutments	No. of studies	No. of total abutments	No. of studies	
Success rate	79	2 ^{35,38}	0	0	
Survival rate	87	2 ^{35,39}	0	0	Study ³⁷ reported less crown loosening on CAD/CAM abutment at 2-year follow-up time.
PES	29	1 ³⁸	37	1 ³⁹	
WES	29	1 ³⁸	0	0	
Crest bone level	116	3 ^{36,38,39}	0	0	
Soft tissue recession	50	1 ³⁶	0	0	Study ³⁴ reported less soft tissue recession from CAD/CAM abutments at 2-year follow-up time.

a cross-sectional study, five were cohort studies, and two were RCTs.

Three studies³¹⁻³³ comparing CAD/CAM and prefabricated Titanium abutments (Straumann) used the same patient cohort, but each reported on different outcomes. Two studies compared the survival rate and success rate of Atlantis zirconia abutments to stock zirconia abutments^{34,35}, but the study design and follow-up period were different between the studies. The follow-up time of these 11 studies ranged from six months to 22 years (Table 4). There were three studies³¹⁻³³ with no follow-up because the outcome measured did not require one.

Of the 11 studies, only one³⁶ reported patient-centred outcomes. Three studies³¹⁻³³ reported cost-effective outcomes, such as comparative time and economical analysis. In Table 5 a summary of the systematic review is presented when all CAD/CAM abutments are grouped in one category, regardless of the system and material used, and the same for conventional abutments. The table was produced for outcomes after 1 year of follow-up. However, two of the 11 studies reviewed reported outcomes after a 2-year follow-up. Overall, the studies reported no significant differences in the majority of outcomes between CAD/CAM and conventional abutments after 1 year of follow-up. However, when studies investigating the 2-year follow ups were considered; one study³⁴ reported a significantly better soft tissue reaction (less recession) around CAD/CAM abutments (n = 36) compared with conventionally

fabricated abutments (n = 36). In another study³⁷, although the survival rate was not significantly different between CAD/CAM (n = 96) and prefabricated abutments (n = 312), CAD/CAM abutments with single crown restorations suffered from significantly less crown loosening than restorations retained by conventionally fabricated abutments over a 2-year follow-up.

The Risk of Bias assessment of the two clinical trials included^{36,38} revealed they were vulnerable to selection bias, as both provided incomplete descriptions of the randomisation process. They were also subject to some information bias, as allocation concealment was not performed. Detailed risk of bias assessment for each study is summarised in Table 6.

All six observational studies (cross-sectional and cohort studies) exhibited good reporting quality in title, abstract, and introduction sections. Half of the studies clearly presented the study design. Of the six studies, five described the eligibility criteria, but no study was a matched study. Two studies^{39,40} had missing follow-up data, but they did not address the missing data or perform sensitivity analysis. In one study, subgroup analysis was performed³⁹. No study discussed the external validity of the study results, and only two studies^{32,33} reported the source of funding.

Reporting quality for the three case series studies was also assessed. Two studies indicated the study type in the title, but none of the studies included "case report" or "case series" in the key words.

Table 6 Risk of bias in clinical trials comparing outcomes of CAD/CAM and conventional abutments.

	Schepke, 2016 ³⁶	Borzangy, 2015 ³⁸
Random sequence generation (Selection bias)	?	?
Allocation concealment (Selection bias)	?	+
Blinding of participants, personnel (Information bias)	?	?
Incomplete outcome data (Information bias)	+	?
Selective outcome reporting (Information bias)	?	+
Other sources of bias	?	+

+: low risk of bias; -: high risk of bias; ?: unclear risk of bias.

All studies had a good report quality in abstracts, introductions, interventions, outcomes and discussions. However, no study created a timeline that indicated specific dates and times in a table, figure or graphic. Two studies described the specific reasons and conditions of patients who received implant treatment, and two studies reported on how subjects were evaluated before treatment. None of the studies reported on patient perspective of experience, and one study³¹ did not report on the informed consent procedure from patients. Two studies included an acknowledgements section.

■ Discussion

The 24 studies included in this review represent research conducted on the clinical outcomes of CAD/CAM abutments used in implant-supported restorations compared with conventional abutments. These studies demonstrated substantial heterogeneity regarding the systems and materials of abutments examined, specific clinical outcomes observed, as well as the design of studies and measurement techniques employed.

The results of studies that solely examined CAD/CAM abutments showed an overall high survival rate at the 1- and 3-year follow-ups (Table 1). For studies comparing CAD/CAM abutments with conventional abutments, there was no significant difference in most of the clinical outcomes at 1-year follow up. However, one study³⁹ showed better interproximal

papilla PES in Atlantis CAD/CAM zirconia and gold titanium abutments compared with custom metal abutments. In addition, two studies^{34,37} reported higher survival rate and less tissue recession when Atlantis CAD/CAM abutments were compared to conventional abutments after 2 years of follow-up. Among the 24 included clinical studies, there were only three RCTs^{25,36,38}. Two compared CAD/CAM abutments with conventional stock abutments^{36,38}. However, both studies used a different material of stock abutments in the control group. Therefore, data from the two trials could not be combined for further analysis. The results for plaque index, bleeding score, probing depth, and change in marginal bone levels were reported as not significantly different in both of these RCTs. More RCTs with long-term follow-ups are needed to determine if the use of CAD/CAM abutments results in improved clinical outcomes when compared with conventional abutments. If RCTs are not feasible, cohort studies with adequate sample size and long follow-up periods are encouraged.

Reporting quality assessment for observational and descriptive studies revealed that about 40% of the studies did not describe the patient population in detail; none discussed the impact of missing data; more than half omitted to report the funding sources of the research; and less than 20% stated patient-reported outcomes. Detailed population description, including specific chief complaints and other relevant medical history, could help researchers and readers evaluate the external validity of the studies⁴¹. Missing data could have a great impact on the outcomes of observational studies, especially when the sample size is small⁴². Funding sources and the role of the funders could have potential conflict of interest and may lead to bias in reporting the results⁴³. Therefore, it is recommended that researchers report selection criteria and characteristics in detail, conduct qualitative or quantitative analysis taking in account missing data, and report and acknowledge funding sources.

Some outcomes evaluated in the reviewed manuscripts were not completely objective, such as aesthetic evaluation of restorations. To test aesthetic outcomes, several standards were adopted, and in different interproximal sites relative to the restoration. Thus, it is recommended that researchers try

to provide a detailed description of the methods of assessment and sources of data, including specifying the system, materials, measurement methods and specific sites tested and assessed. To enhance the quality and transparency of research, as well as the searchable characteristic, accurate reporting of literature is a critical consideration. It is recommended that researchers consult EQUATOR-network.org⁴⁴ for appropriate reporting guidelines to report their studies.

When risk of bias assessment is considered, none of the RCTs discussed blinding of subjects. In studies reporting objective clinical outcomes, such as bone level reduction through measurements on radiographs, subject blinding may have little impact on the outcomes. However, it may have significant influence on subjective outcomes, such as patient-reported outcomes⁴⁵. However, it is important to note that the literature reviewed showed little emphasis on patient-reported outcomes. Patient-reported outcomes provide important information regarding treatment alternatives, and inform the research process^{46,47}. Research on CAD/CAM abutments would benefit greatly from studies that are patient-outcome centred.

This systematic review is subject to some limitations. Firstly, unpublished results uncovered using the NIH RePORT and grey literature searches were not included, as full texts were not publically available. Secondly, an overall quality assessment of included studies was not conducted, however, reporting quality assessment for observational and descriptive studies and risk of bias assessment for clinical trials was conducted. These assessment processes are among several considerations contributing to a study's overall quality and are in line with Cochrane guidelines⁴³.

■ Conclusions

The results of the review suggest that CAD/CAM abutments have overall good survival and success rate and provide comparable, if not better, clinical outcomes when compared with conventional abutments. However, available studies comparing CAD/CAM and conventional abutments are few and the majority of studies included are short term.

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■ Appendix 1

■ PubMed search strategy

Implant abutment key terms:

((dental implants[MeSH Terms]) OR dental implantation[MeSH Terms]) OR ((endosseous implant*[Text Word]) OR (((((((((((Dental Abutments[MeSH Terms]) OR Dental Implant-abutment design[MeSH Terms]) OR Dental implantation, endosseous/methods[MeSH Subheading]) OR Dental prosthesis, implant-supported[MeSH Terms]) OR abutment*[Text Word]) OR dental prosthesis implant-supported[Text Word]) OR implant abutment*[Text Word]) OR implant dentistry[Text Word]) OR implant-supported abutment*[Text Word]) OR single implant*[Text Word]) OR dental implant*[Text Word]))

CAD/CAM key terms:

((((((((((((((CAM[Text Word]) OR CAD[Text Word]) OR customized abutment*[Text Word]) OR computer-generated[Text Word]) OR computer-assisted manufactur*[Text Word]) OR ((computer-assisted designed[Text Word] AND manufactured[Text Word]))) OR Computer-assisted design*[Text Word]) OR computer-aided manufactur*[Text Word]) OR Computer-aided design*[Text Word]) OR computer assisted[Text Word]) OR cad-cam[Text Word]) OR CAD/CAM[Text Word]) OR Computer-aided design[MeSH Terms])) OR sirona) OR procera) OR e4d) OR atlantis abutment*

Not animal studies filter:

NOT("animals"[MeSH Terms]) NOT("humans"[MeSH Terms]) AND "animals"[MeSH Terms])

■ Appendix 2.

■ Embase search strategy

Implant abutment key terms:

'dental abutment'/exp OR 'dental abutment' OR 'dental abutments' OR 'dental implant abutment design' OR 'dental implant-abutment design' OR 'tooth implant'/exp OR 'dental implant' OR 'dental

implants' OR 'dental implants, single-tooth' OR 'implant, teeth' OR 'implant, tooth' OR 'implants, teeth' OR 'implants, tooth' OR 'teeth implant' OR 'teeth implants' OR 'tooth implant' OR 'tooth implants' OR 'tooth implantation'/exp OR 'dental implantation' OR 'dental implantation, endosseous' OR 'dental implantation, endosseous, endodontic' OR 'dental implantation, subperiosteal' OR 'immediate dental implant loading' OR 'tooth implantation' OR 'tooth prosthesis'/exp OR 'dental prostheses' OR 'dental prosthesis' OR 'dental prosthesis repair' OR 'dental prosthesis, implant-supported' OR 'prostheses, dental' OR 'prosthesis, dental' OR 'prosthesis, tooth' OR 'tooth prosthesis' OR 'tooth, artificial' OR abutment*:ab,ti OR 'dental implant':ab,ti OR 'dental implants':ab,ti OR 'dental prosthesis implant-supported':ab,ti OR 'endosseous implant':ab,ti OR 'endosseous implants':ab,ti OR 'implant abutment':ab,ti OR 'implant abutments':ab,ti OR 'implant dentistry':ab,ti OR 'implant-supported abutment':ab,ti OR 'implant-supported abutments':ab,ti OR 'single implant':ab,ti OR 'single implants':ab,ti

CAD/CAM key terms:

'computer aided design'/exp OR 'computer aided design' OR 'computer assisted design' OR 'computer-aided design' OR 'design, computer assisted' OR 'cad/cam':ab,ti OR cad:ab,ti OR 'cad cam':ab,ti OR cam:ab,ti OR 'computer assisted':ab,ti OR 'computer-aided design':ab,ti OR 'computer-aided manufacture':ab,ti OR 'computer-aided manufacturing':ab,ti OR 'computer aided manufacturing' OR 'computer-assisted design':ab,ti OR 'computer-assisted designed and manufactured':ab,ti OR 'computer-assisted manufacture':ab,ti OR 'computer-assisted manufacturing':ab,ti OR 'computer generated':ab,ti OR 'customized abutment':ab,ti OR 'customized abutments':ab,ti OR 'computer-aided design and manufacturing':ab,ti OR 'atlantis abutment' OR 'atlantis abutments' OR 'procera abutment' OR 'procera abutments' OR 'procera' OR sirona:ab,ti OR e4d

Not animal studies filter:

NOT 'animal'/exp NOT ('animal'/exp AND 'human'/exp)

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Immediate loading of zygomatic implants: A systematic review of implant survival, prosthesis survival and potential complications



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Key words *immediate load dental implant, zygoma, zygomatic implant*

Statement of problem: Zygomatic implants have been utilised for the treatment of the severely atrophic maxilla since 1998. However, few articles exist as to the success of zygomatic implants and immediate loading of its prosthesis.

Aim: To systematically review the outcome of immediate loaded zygomatic implants.

Materials and methods: An electronic PubMed search was performed to identify case reports, prospective and retrospective studies of immediately loaded zygomatic implants with a mean follow-up of 12 months. Assessment of the identified studies was performed using the Delphi method. Reviewers independently assessed the articles for inclusion, with a facilitator coordinating responses. A consensus was reached on the articles that were included.

Results: The search provided 236 titles for immediately loaded zygomatic implants and resulted in 106 abstracts for analysis. Full-text analysis was performed on 67 articles, resulting in the inclusion of 38 articles for this systematic review.

Conclusion: Based on the present systematic review, the authors report that immediately loading zygomatic implants for the restoration of the severely atrophic maxilla presents a viable alternative for treatment of the atrophic maxilla.

■ Introduction

The maxillary atrophic edentulous patient may require multiple surgeries and bone augmentation to achieve a fixed result. The introduction of zygomatic implants by PI Brånemark in 1988 enabled the utilisation of the facial skeleton as anchorage for oral rehabilitation. Ten years later, after proven clinical success, this implant was made available to the dental profession¹.

This graft-less approach was initially intended for patients who presented with an atrophic maxilla, and for a variety of reasons could not undergo “traditional” sinus elevation, grafting, and implant placement. It was also indicated for those who preferred

to avoid multiple surgeries, sinus lifts and bone placement. The latter extended treatment times for healing and subsequent implant placement. It also eliminated the need to employ a long-term transitional prosthesis prior to fabrication of the final prosthesis.

The initial Brånemark protocol called for the placement of two zygomatic implants bilaterally in the posterior maxilla, and additional root form implants in the anterior maxilla. All implants were splinted with a rigid prosthesis at the time of stage 1 surgery. Following the recommended healing phase of 6 months, a final fixed dental prosthesis was fabricated. This approach enjoyed a high surgical success rate of 94% and a prosthetic success rate of 96% after 5 years¹.

Despite its success, a limitation of the early zygomatic procedure included the emergence of the abutment interface medial to the residual alveolar ridge, with encroachment on the hard palate. This resulted in patient complaints of tongue irritation and difficulty in maintaining routine daily hygiene. This surgical approach also necessitated traversing the maxillary sinus and, in 15 to 20% of subjects, a potential for abnormal radiological findings without clinical symptoms⁴.

As surgical procedures became more refined, the zygomatic implant was placed so that its emergence was through the alveolar ridge and within the tooth alveolar envelope. This results in a prosthesis that is anatomically closer to the normal position of the missing dentition, and allows for improved, aesthetics, function and hygiene.

Further developments led to the use of a purely zygoma approach, which places two implants in each zygoma and a full arch fixed prosthesis on four zygomatic implants ("Quad zygoma"). This favourable anterior posterior distribution negates the need for anterior implants and satisfies the biomechanical requirements that would otherwise demand multiple implants. The emergence is on the alveolar ridge, thus mimicking the natural dentition²⁶.

The purpose of this systematic review was to report on the outcome of immediately loaded zygomatic implant scenarios, the surgical and prosthetic success, and complications from 1990 until June 2016.

■ Materials and methods

■ Search strategy

An electronic PubMed search was performed from January 1990 until June 2016 searching for "zygoma implants," "zygomatic implants," "immediate load zygoma," "quad zygoma implants," "immediate function zygoma implants," and "zygomaticus implants."

■ Inclusion criteria

Case reports with at least 12 months' follow-up after immediate loading; immediately loaded zygomatic implants attached to anterior implants; immediately

loaded zygomatic implants not attached to anterior implants.

■ Exclusion criteria:

Non-English journals; non-peer reviewed journals; articles prior to 1990; studies with fewer than 12 months' follow-up after immediate loading; zygomatic implants not immediately loaded; pterygoid implants; maxillofacial treatment; technique articles.

■ Selection of studies:

Titles were initially screened by two reviewers (LW, FJT) for possible inclusion in this systematic review. Abstracts were then reviewed by four independent reviewers (LW, FJT, JN, EB) to assess their validity for inclusion. Any disagreements were resolved using the Delphi method, with LW and FJT acting as the facilitators.

■ Results

■ Study characteristics:

Titles were reviewed by LW and FJT. Of the 236 that were initially included, LW and FJT sent 106 abstracts to four independent reviewers (LW, FJT, JN, EB) to assess their validity for inclusion. Any disagreements were resolved using the Delphi method, with LW and FJT acting as the facilitators. From those 106 abstracts, a consensus of 67 was chosen for full-text analysis. After analysing the complete articles, 38 met the inclusion criteria. The articles excluded the use of dental implants for facial plastic surgery or in maxillofacial rehabilitation as skeletal anchorage, pterygoid implants, studies that had less than 12 months' follow-up, or situations in which there was no immediate loading.

■ Immediate load survival:

The success of implants and prostheses ranged from 96% to 100%.

■ Complications:

Complications of immediately loaded zygomatic implants include: failure of the implant and/or prosthesis, fracture of the implant, screw loosening (abutment and prosthetic), soft tissue inflammation around the implant abutments, speech complications, hygiene difficulties, chronic rhino-sinusitis.

In order to summarise the available information about immediately loaded zygomatic implants, all studies that met the inclusion criteria were utilised in this systematic review. This included randomised controlled studies, retrospective studies and case studies.

Brånemark reported on 81 patients with 132 zygomatic implants immediately loaded and connected to anterior endosseous implants, with a success rate of 97%¹. In 2000, Higuchi reported on 86 patients with 162 zygomatic implants and 258 conventional implants. Ten patients had unilateral zygomatic implants all immediately loaded. His suggestions were that all implants needed to be anchored to at least two conventional anterior implants to control torsional forces; the palatal bone offered little to no support; the sinus needed to be disease free; and the procedure should be performed under general anaesthesia².

Consistent with this, Davo et al (2007)³ reported on 36 immediate loaded zygomatic and conventional implants in 18 maxillas. The patients were followed for 29 months with an average follow-up of 14 months. All prostheses were inserted within 48 h of the surgical placement. No zygomatic implants were lost. The conventional implants had a 95.5% success rate. The only complication relating to the zygomatic implant was one case of sinusitis that was resolved with antibiotic therapy³. Davo published specifically on sinuses that same year and found that when sinuses are penetrated by zygomatic implants, the sinuses maintain their normal physiology. There are cases where radiologically the sinuses will appear compromised, but there are no clinical symptoms⁴.

In a prospective study by Aparicio et al⁵, a cohort (69 patients/69 prostheses) of patients with atrophic maxillas were restored with 435 implants (131 zygomatic) and followed for a period of up to 5 years. Two conventional implants failed, whereas no failures were seen with zygomatic implants. There were

three cases of sinusitis, which were resolved with antibiotic therapy. He reported screw loosening in nine out of 69 patients, one gold screw fracture, one out of 69 prosthesis fractures, and the fracture of four prosthetic teeth. Of interest was the prosthetic design: 57 FDPs were screw retained and 12 FDPs were cement retained. The screw-retained restorations were removed at all recall appointments and Periotest (Siemens AG, Bensheim, Germany) values were recorded. The Periotest values of zygomatic implants decreased over time indicating increased density of bone and higher levels of integration⁵.

A retrospective study by Bedrossian published the same year showed similar results⁶. Immediate function zygomatic implants had a success rate of 100% followed by a minimum of 12 months' follow-up. This was attributed to the high initial stability of the zygomatic implants.

Duarte (2007)⁷ reported on the treatment of the severely atrophic maxilla with immediate load using the "Quad zygoma" approach and no anterior endosseous implants. Twelve patients received a total of 48 zygoma implants loaded immediately with a rigid provisional. They were followed for 6 to 30 months. One zygomatic implant was lost. The surgery used in this case was a palatal approach. There were no other complications reported⁷. In 2008, Mozzati et al⁴ reported on 14 zygomatic implants and 34 endosseous anterior implants followed for 24 months. All zygomatic implants were either anchored to four or five anterior implants. There was a 100% survival rate of all implants and prostheses and the authors suggested that the use of anterior implants gave more predictable results⁸.

Davo (2008)⁹ reported on 42 patients (19 male and 23 female), with an average follow-up of 20.5 months. In total, 37 patients were completely edentulous and five presented with partial edentulism. A total of 81 zygomatic and 140 conventional implants were inserted. All prostheses were loaded within 48 h. 100% of the zygomatic implants, and 97% of the conventional implants survived. 100% of the prostheses were in place, with one reported case of sinusitis⁹. Davo et al⁴ also reported on a radiographic analysis of the maxillary sinus in 26 patients with 52 immediate loaded zygomatic implants (44 machined surface and 27 TiUnite) followed for 3 to 20 months. There was no evidence

Table 1 Complications of immediately loaded zygomatic implants.

Author	Success Rate	Success, CI	Prosthetic Complications	Sinusitis
Aparicio C et al (2006) ⁵	100%	99%	Loosening of ZI gold screws (9/69 patients) Fracture of gold screw (1/69) Fracture prosthesis (1/69) Fracture anterior prosthetic teeth (4/69)	3/69 patients
Bedrossian E et al (2006) ⁶	100%	Not reported	No fractures/loosening of screws Fracture of denture (2/14 patients)	Not reported
Duarte LR et al (2007) ⁷	97.9%	Not reported	No prosthetic failures/complications	No sinusitis
Davo R et al (2007) ³	100%	95.60%	No prosthetic failures/complications	Not reported
Davó R et al (2008) ⁴	Not reported	Not reported	Not reported	15 to 20% had radiological findings without clinical symptoms
Davó R et al (2008) ⁹	100%	97%	No prosthetic failures/complications	1/42 patients
Mozzati M et al (2008) ⁸	100%	100%	No prosthetic failures/complications	No sinusitis
Maló P et al (2008) ¹⁰	98.50%	100%	Not reported	Not reported
Balshi SF et al (2009) ¹²	96.37%	Not reported	No prosthetic failures/complications	Not reported
Aparicio C et al (2010) ¹⁵	100%	Not reported	No prosthetic failures/complications	No sinusitis
Chow J et al (2010) ¹⁶	100%	Not reported	Not reported	No sinusitis
Davo R et al (2010) ³⁹	100%	Not reported	No prosthetic failures complications	No sinusitis
Kuabara MR et al (2010) ¹⁷	100%	Not reported	No prosthetic failures/complications	No sinusitis
Stiévenart M, Malevez C. (2010) ¹³	96%	Not reported	Not reported	1/20 patients
Bedrossian E. (2010) ³⁶	2/74 ZI failed & were replaced with 100% success	Not reported	Not reported	3/36 patients
Aparicio C et al (2010) ¹⁴	100%	99.20%	Fracture of 1 abutment screw Fracture anterior teeth (5/25 patients)	Not reported
Ferreira EJ et al (2010) ¹¹	Not reported	Not reported	Not reported	Not reported
Cordero EB et al (2011) ¹⁹	100%	Not reported	Not reported	Not reported
Migliorança RM et al (2011) ⁴⁰	98.70%	99.30%	No prosthetic failures/complications	No sinusitis
Sartori EM et al (2012) ¹⁸	100%	100%	Fracture of prosthetic screw Loosening of prosthetic screw Loosening of abutment screw Wear of teeth	Not reported
Balshi TJ et al (2012) ²⁰	96.50%	Not reported	Not reported	Not reported
Maló P et al (2012) ²¹	100%	100%	No prosthetic failures/complications	5/39 patients
Migliorança RM et al (2012) ²²	97.50%	95.90%	Metal bar broken	No sinusitis
Davó R, Pons O. (2013) ²⁶	100%	Not reported	Fracture of abutment screw 1/17 patients Fracture of prosthesis 2/17	2/17 patients
Davó R et al (2013) ²⁵	98.50%	94.90%	Not reported	Not reported
Farret MM et al (2013) ²⁷	100%	100%	Not reported	Not reported
Aparicio C et al (2014) ²⁸	Not reported	Not reported	Not reported	Not reported

Author	Success Rate	Success, CI	Prosthetic Complications	Sinusitis
Aparicio C et al (2014) ³⁵	95.12%	97.71%	One patient fractured framework 2× loose/ fractured screws 11/22 patients occlusal material fractured 7/22 patients	2/22
Goiato MC et al (2014) ⁴¹	97.86%	Not reported	Not reported	
Maló P et al (2014) ³⁰	98.80%	Not reported	Fracture of acrylic prosthesis 2/39 patients One ceramic crown fracture on metal sub- structure Three screw loosening	5/39 patients
Rajan G et al (2014) ⁴²	100%	100%	Not reported	No sinusitis
Maló P et al (2015) ²⁴	98.20%	97.90%	Not reported	7% "maxillary sinus path- ology"
Bertolai R et al (2015) ³⁷	98%	100%	Not reported	2/31 patients
Davó R, Pons O (2015) ³⁴	100%	Not reported	Fracture of abutment screw 1/17 patients fracture of prosthesis 2/17	2/17 patients
Mozzati M et al (2015) ³³	100%	Not reported	No prosthetic failures/complications	Not reported
Rajan G et al (2015) ³²	100%	Not reported	Not reported	Not reported
Padovan LE et al (2015) ³¹	100%	100%	Not reported	Not reported

of sinusitis or sinus pathology in any of these patients. In a pilot study (Malo et al 2008)¹⁰ of 29 patients (21 female, eight male) utilising an extra-maxillary approach to place zygomatic implants, implant survival was 98.5% and prosthesis survival was 100% after 6 to 18 months. Of further interest was the primary focus of the study to assess soft tissue health. They reported normal soft tissue health and probing depths consistent with conventional implant therapy¹⁰.

In a case report, Ferreira et al (2010)¹¹ followed one patient with an "all on four" approach in the maxilla (two zygomatic implants and two anterior conventional implants). After 2 years all implants and the prosthesis were functioning without complications¹¹. Balshi (2009)¹² reported on 56 patients with 110 zygomatic implants treated between 2000 and 2006. Four zygomatic implants failed, resulting in a success rate of 96.3%, however all prostheses remained in function. Of the implants that failed, this happened within the first 4 months of loading¹².

In 2010 Stievenart et al¹³ tested the concept of immediate load "Quad zygoma" with a consecutive cohort of 20 patients (19 female, one male). The first 10 patients had a two-stage procedure and the remaining 10 had a one-stage procedure. There was a cumulative survival rate of 96% (77/80). Implant failure occurred between 7 and 9 months. Of note

was the incidence of sinusitis, which ranged from 14% to 30%¹³.

Aparicio et al (2010)¹⁴ followed 25 consecutive patients (12 female and 13 male) with 47 zygomatic implants and 129 conventional implants for a minimum of 2 years, and up to 5 years. He reported a 100% survival rate, with 19 patients loaded in 24 h and six within 5 days. In total, 23 prostheses were screw-retained and two were cement retained. Complications included the fracture of one abutment screw and anterior teeth in five patients. Smokers had an equal success to non-smokers. He quoted a previous study on 1,143 zygomatic implants observed for 6 months to 10 years, with an overall success rate of 98.2%.

In another paper published the same year¹⁵, Aparicio reported on 20 patients restored with 36 zygomatic implants and 104 endosseous implants, who were followed for up to 48 months using the extra-sinus approach. Zygomatic implants were splinted to anterior conventional implants, with 16 patients treated with zygomatic implants bilaterally, and four patients treated unilaterally. At 41 months all implants were in place and functioning¹⁵. Chow et al (2010)¹⁶ utilising an extended sinus lift technique and zygomatic implants placed external to the maxillary sinus, reported 100% success of zygomatic implants and

prostheses, with no incidence of sinusitis. This was in 16 patients restored with 37 zygomatic implants followed for up to 24 months. He concluded that this approach could potentially reduce the incidence of sinusitis¹⁶. In a single case report with a 20-month follow-up, Kuabara found 100% success rate of his immediately loaded "Quad zygoma", with no complications¹⁷.

In 2012, Sartori et al¹⁸ reported on patient satisfaction with immediate loaded prostheses on zygomatic implants. Sixteen patients were followed from 2005 to 2009 and surveyed with a questionnaire. Half of the patients were completely satisfied with their prosthesis. The other 50% had complaints that fell into the categories of hygiene, aesthetics, phonetics and the ability to chew. All prostheses were in place. They reported fracture of a prosthetic screw, loosening of prosthetic and abutment screws and wear of the prosthetic teeth. Some of these patients' concerns could be addressed or eliminated with the lateral approach to zygoma placement and the emergence of new materials for restorative options¹⁸. Using the Stella and extra-sinus techniques, Cordero¹⁹ had a 100% success rate.

Balshi et al (2012)²⁰ evaluated the bone to implant contact of 173 zygomatic implants in 77 patients, 62% of the patients were female. He reported that 35.9% with a variable of 11.7% of the implant had contact with bone. Males had an average of 16.5 mm and females 14.7 mm. Malo (2012)²¹ reported on a 3-year follow-up of 39 patients restored with a combination of zygomatic implants (92) and conventional implants (77), all immediately loaded. No implants were lost in the population that was followed, but about 10% of the patients were lost from the study. There were five cases of sinusitis but all patients reported sinus disease prior to surgery. There were no prosthetic failures noted²¹. Miglioranca (2012)²² immediately loaded zygomatic implants and with an 8-year follow up had a success rate of 97.5%. The conventional implants, on the other hand, had a success rate of 95.9% and the definitive prosthesis a 95.2% success. There was one prosthetic complication of a metal bar fracture in one patient. There were no reports of screw loosening or fracture. All patients were free of sinus symptoms and disturbances²².

Chrcanovic and Bruno (2013)²³ performed a literature search and reported on complications in

12 studies of zygomatic implants with immediate function. There were 70 cases of sinusitis, 15 cases of paresthesia, and 17 of oroantral fistulas. In addition, there were 48 reports of soft tissue infection. Overall, the cumulative success rate of the zygomatic implants was 96.7%²³.

Malò (2013)²⁴ reported on 352 completely edentulous patients who received 747 zygomatic implants in combination with 795 conventional implants, all immediately loaded. The surgical procedure was modified to have an extra maxillary approach. A total of four patients lost seven zygomatic implants, producing an overall success rate of 98.2%; 10 patients lost 17 conventional implants for a success rate of 96.7%. He also reported on 156 "mechanical complications", of which one-third were in patients with a history of bruxing. Two out of the 17 prostheses fractured and one abutment screw fractured²⁴. Davo²⁵ presented data (2013) on 42 patients with a total of 81 zygomatic implants and 140 conventional implants followed for 5 years. The success rate for the zygomatic implant was 98.5% and the conventional implants 94.9% with all implants immediately loaded. All prostheses were in place²⁵. In another study published the same year²⁶, Davo looked at 3 years of prospective data of immediately loaded zygomatic implants. He had a 100% success rate of the zygomatic implants. In a questionnaire administered regarding oral health related quality of life, Davo et al found that patients who had immediately loaded implants had an improved quality of life.

In a clinical case report, Farrett described using zygomatic implants in conjunction with conventional implants to support a fixed maxillary prosthesis²⁷. After 8 years, he reported excellent results, with optimum tissue health. There was no mention of any prosthetic complications.

Aparacio et al (2014)²⁸ described a zygomatic success code and established criteria/protocol for successful implementation of the immediate loaded zygomatic implant. The success code has four criteria that are used to determine if the final result is successful: zygomatic implant stability, sinus pathology, soft tissue peri-implant tissue health, and prosthetic offset. Each is then graded 1 to 4, with specific criteria. He concluded that when compared with conventional grafting procedures, the zygomatic approach had distinct advantages, reduced

healing time, fewer surgical procedures, and expedited treatment time. One patient twice experienced a fractured framework. There were reports of screw loosening in 11 out of 22 patients and fracture of the occlusal material in seven out of 22 patients²⁸.

Rajan (2014)²⁹ followed two patients with generalised periodontal disease and loss of all teeth that had full mouth rehabilitation with two zygomatic implants and four anterior implants immediately loaded and converted to final restorations after 6 months. All implants were in place and the most common complication was gingival inflammation, which was readily managed conservatively²⁹.

Malo's 5-year retrospective (2014)³⁰ consisting of 39 patients, 92 zygomatic implants, and 77 conventional implants, had a 98.8% success rate for the zygomatic implants. He did not report on the success rate for conventional implants. Two of the 39 acrylic prostheses fractured, as well as one metal ceramic crown. He had a 100% success rate for the prostheses, concluding that immediately loading zygomatic implants alone or in conjunction with conventional implants was satisfactory³⁰.

Padovan et al (2015)³¹ followed one patient for 55 months with an immediate loaded prosthesis with three zygomatic implants on one side, one zygomatic on the contra-lateral side, and one anterior conventional implant – all splinted. In a case report by Rajan et al (2015)³² of a patient with an immediately loaded prosthesis supported by quad zygomatic implants and followed for 3 years, a 100% success rate was reported for all implants. No prosthetic complications were reported.

Mozzati (2015) reported on a new surgical protocol for the insertion of zygomatic implants using an ultrasonic technique³³. With 30 to 32 months of follow up, he had a 100% success rate for these implants and their associated prostheses. According to the authors this technique gives the surgeon better surgical visualisation in comparison to drilling protocols, better tissue management, and better healing.

In 2015, Davo et al, in a 5-year outcome of cross arch immediately loaded zygomatic implants using the quad zygoma approach in 14 patients (original cohort of 17 patients), reported one abutment screw fracture and two prostheses fractures³⁴. In the 14 patients there was 100% survival of the zygomatic implants and the prostheses. Half of the patients had

complications (screw loosening, abutment fracture, soft tissue inflammation etc) that were managed with routine post insertion care. The patients were asked about their overall satisfaction using the OHIP-14. The average score was 3.8, which is consistent with that of the overall population³⁴.

All studies demonstrated excellent survival and success of the immediate loaded zygomatic implant. Complications were few, but were defined as catastrophic when either an implant was lost or a prosthesis was compromised or lost due to implant failure. The most significant complication was implant failure and/or fracture.

■ Discussion

The use of zygomatic implants for the edentulous maxilla has been well documented since Brånemark's first report in 1988. The original protocol called for the placement of two zygomatic implants bilaterally and two to four anterior endosseous implants splinted. This approach yielded a 94.9%²⁵ to 100% success rate for endosseous implants and a 95.12%³⁵ to 100% success rate for zygomatic implants. The prosthetic complications reported were screw-loosening, fracture of prosthetic and abutment screws, wear or loss of the prosthetic teeth and fracture of the prosthesis.

The original protocol had zygomatic implants traversing the maxillary sinus and engaging the palatal bone in the coronal aspect, providing there was sufficient volume and the zygoma in the apical aspect. The thought process was to achieve bi-cortical stabilisation. This, however, yielded prosthetic designs that had less than ideal access for hygiene purposes. One author reported that 50% of patients had concerns about speech, hygiene, phonetic and the ability to chew¹⁸. Malo et al reported that 44.3% of patients (156/352) had experienced mechanical complications, including prosthesis fracture, prosthetic and abutment and prosthetic screw loosening/fracture²⁴. Of note was that these were all in patients with a history of bruxing. There were also multiple reports of maxillary sinusitis^{5,9,13,21,24,26,30,34-37}. Of note was a report of complications from 12 studies that included 70 cases of sinusitis, 15 cases of paresthesia, and 17 oroantral fistulas²³.

With the evolution of the surgical technique and a large data pool of successful zygomatic implant placements, there was a shift in focus to move the implant to a more lateral and vertical position, negating the need to traverse the maxillary sinus. One author has reported that this approach has zero incidences of sinusitis and 100% of implant/prosthetic success without complications¹⁶. The emergence of the zygoma was now closer to the residual alveolar ridge and in the “tooth alveolar” envelope.

Further surgical initiatives led to the use of four zygomatic implants, with two in each zygoma. The immediate load protocol was also employed in this approach. The reported success rate of the zygomatic implants ranged from 96% to 100%^{34,35}. The reported prosthetic complications were prosthetic and abutment screw loosening, fracture of abutment screws, fracture and wear of prosthetic tooth replacement and fracture of the prosthesis. The lateralised approach to the zygoma placement created a different soft tissue concern. The lack of attached tissue in the buccal aspect of the residual ridge, in specific clinical presentations resulted in mucosal irritation due to the movement of the tissue on the implant surface. To help resolve this problem, the buccal fat pad was used to wrap around the implant surface and ameliorate the issue³⁸.

■ Conclusions

Based on the present systematic review, the authors recommend immediately loading and splinting zygomatic implants for the restoration of the severely atrophic maxilla with or without anterior conventional implants. The complication rates are relatively few, rarely catastrophic, and easily managed. Further randomised clinical trials should be conducted.

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Prosthetic protocols in implant-based oral rehabilitations: A systematic review on the clinical outcome of monolithic all-ceramic single- and multi-unit prostheses

Key words *dental implants, dental restoration failure, humans, implant-supported, single tooth, survival rate*

Aim: The purpose of this systematic review was to assess the clinical performance of implant-supported monolithic all-ceramic single- and multi-unit restorations.

Materials and methods: The electronic databases of MEDLINE via PubMed, the Cochrane Library (CENTRAL) and EMBASE were searched for clinical studies on monolithic all-ceramic single and multi-unit implant-supported fixed dental prostheses. Human studies with a mean follow-up of at least 2 years and published in English or German language peer-reviewed journals up until August 2016 were included. Two independent examiners conducted the literature search and review process.

Results: The search resulted in 2510 titles and of these, 57 studies were selected for full-text evaluation. Three studies were included on the basis of the pre-determined criteria. Two articles reported on monolithic lithium disilicate implant-supported single crowns (SC) and revealed a survival rate of 97,8 and 100% after 3 years. One study investigated implant-supported monolithic zirconia SCs and fixed partial dentures (FPD) and showed a survival rate of 100% after 5 years. No studies could be identified on the clinical performance of monolithic resin matrix ceramic restorations. Clinical studies are lacking on the long-term outcome of implant-supported monolithic all-ceramic single- and multi-unit restorations.

Conclusions: Preliminary clinical data indicate high short-term survival for implant-supported monolithic lithium disilicate and zirconia single- and multi-unit restorations. Randomised clinical studies and observations with a longer duration are necessary to validate the broad application of this therapy.

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



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■ Introduction

Therapeutic concepts for the prosthetic rehabilitation of various types of edentulism have changed significantly over past decades due to the high survival of dental implants reported in the literature. Implant-supported single crowns and fixed dental prostheses are recognised as a reliable treatment option for partial edentulism, with an implant survival rate well above 90%^{1,2}.

Clinicians face challenges with the choice of materials available today for implant prosthodontics. The survival rates of implant-supported metal-ceramic single crowns and FPDs are high; 96.3% for single crowns and 95.4% for FPDs after 5 years are reported^{1,2}. However, technical problems, such as fractures of the veneering material, abutment or screw loosening and loss of retention of cemented restorations, are described as major limitations for bilayer gold acrylic and porcelain veneered metal-based

restorations. Moreover, poor gingival aesthetics has been reported with these metal-based restorations over short- and long-term observations^{1,2}.

Thus, alternative prosthetic solutions evolved. Several all-ceramic systems were developed over past decades to meet increased clinician and patient demand for metal-free restorations³.

In the early 1990s the lost wax press technique was introduced to the dental market as an innovative processing method for all-ceramic restorations. A pressable leucite-reinforced glass-ceramic evolved (IPS Empress, Ivoclar Vivadent, Schaan, Liechtenstein) and further enhancements of this system led to the introduction of a lithium disilicate glass-ceramic system (IPS Empress II, Ivoclar Vivadent), which started in 1998, with a significantly increased strength. A consecutive pressable lithium disilicate glass-ceramic (IPS e.max Press, Ivoclar Vivadent) with improved physical properties and translucency through different firing processes was then launched, followed by a CAD/CAM version of this lithium disilicate glass-ceramic (IPS e.max CAD, Ivoclar Vivadent).

In 2013, IPS e.max CAD blocks for the chairside fabrication of implant crowns with pre-fabricated screw access holes and insertion grooves for the corresponding titanium base were introduced. Hence, hybrid implant abutments, as well as full-contour hybrid implant abutment crowns, which are adhesively bonded to a titanium base (Ti Base, Dentsply Sirona, York, USA), are now available.

As the market share of lithium disilicate ceramics increased enormously over recent years, several manufacturers developed novel glass ceramic systems. The zirconia-reinforced lithium silicate material (VITA SUPRINITY, Vita Zahnfabrik, Bad Säckingen, Germany; CELTRA, CELTRA DUO, Dentsply Sirona, York, USA), which was launched in 2013, is one example.

In addition, a novel material class – resin-matrix-ceramics – has been introduced for the CAD/CAM fabrication of fixed restorations. These resin matrix ceramics are composed of inorganic glasses, porcelains or glass-ceramics that are clustered and embedded in a cross-linked resin matrix³. They reveal a modulus that simulates the modulus of dentine and are easier to CAD/CAM mill and to adjust. According to their inorganic composition they can be divided into resin nano ceramics (Lava Ultimate, 3M ESPE,

Neuss, Germany), glass ceramic in a resin interpenetrating matrix (Vita Enamic, Vita Zahnfabrik), and zirconia-silica ceramic in a resin interpenetrating matrix (e.g. Shofu Block HC, Shofu, Kyoto, Japan)³.

Polycrystalline ceramics, such as alumina oxide ceramics (e.g. Procera Alumina, Nobel Biocare, Kloten, Switzerland), were first introduced in the mid-1990s. They were commonly applied for implant restorations, but became less important with the increased use of zirconia and lithium disilicate restorations³.

In the early 1990s yttrium oxide partially-stabilised tetragonal zirconia polycrystal (Y-TZP) was introduced to dentistry as a core material for all-ceramic restorations. Due to a transformation, toughening mechanism Y-TZP exhibits superior mechanical properties compared with other all-ceramic systems³. Zirconia ceramics have been used in dentistry as copings and frameworks for bilayered restorations with porcelain veneers, for implants, implant abutments, posts and cores, as well as for orthodontic brackets.

The introduction of computer-aided design and computer-aided manufacturing of all-ceramic restorations provided new approaches for addressing restorative challenges in implant dentistry.

The high reliability of zirconia as abutment, as well as framework material for implant-borne crowns and fixed dental prostheses⁴, was confirmed in several clinical studies^{5,6}. However, the clinical success of zirconia-based implant-supported restorations is limited by veneering porcelain fractures (chipping), exhibiting the most common technical complication⁷⁻⁹. Attempts were made to reduce the incidence of chip fractures with zirconia-based restorations. Anatomical core design for adequate support for the veneering ceramic and slow cooling firing protocols for the veneer application were proposed in the dental literature¹⁰. However, it is well known that higher functional impact forces, impaired feedback from periodontal neural receptors, and rigidity of osseointegrated implants put implant supported restorations at higher risk for porcelain fracture¹¹.

To overcome the limitations of bilayer systems with a weak veneering layer, several systems such as resin matrix ceramics¹², lithium disilicate¹³ and zirconia ceramics¹⁴ are increasingly used in monolithic application. The advantages of monolithic vs bilayer

restorations are well described in the dental literature¹³. *In vitro* data evaluating the potential of monolithic resin matrix ceramic¹⁵, lithium disilicate¹⁶⁻¹⁸ and zirconia¹⁹ systems for the fabrication of implant-supported restorations are promising. Various short- and mid-term clinical reports on monolithic and minimally veneered zirconia implant supported full-arch restorations have shown a favourable performance by these full-contour restorations²⁰. However, the clinical performance of monolithic all-ceramic systems for implant-supported single- and multi-unit restorations is currently not well described in the dental literature.

Therefore, it was the aim of this systematic review to analyse the clinical outcome of implant-supported monolithic all-ceramic single- and multi-unit restorations.

■ Materials and methods

■ Search strategy

The following databases for articles published until August 22nd, 2016, in the dental literature were searched: MEDLINE via PubMed, the Cochrane Central Register of Controlled Trials (CENTRAL) and EMBASE. Furthermore, an additional manual search was carried out for reference lists of all full-text publications, as well as for selected recently published reviews relating to this topic (see “list of reviews”). Moreover, the websites of clinicaltrials.gov, the World Health Organization (WHO) and the German Register for Clinical Trials (DRKS – Deutsches Register Klinischer Studien) were checked.

The search was conducted according to Cochrane guidelines for systematic reviews. PICOS question were defined as follows:

- **P** (population) compromised patients who received one or more dental implants (titanium or ceramic);
- **I** (intervention) included monolithic single crowns (SC: cemented or screw-retained) or short implant supported fixed-dental prosthesis (FPD, 3-5 units);
- **C** (comparison) was not applicable in this review;
- **O** (outcome and study design) was survival or success rate;
- **S** (study type) compromised randomised controlled trials (RCT), clinical follow-up studies (prospective and retrospective studies) and case series.

Search terms:

In each database the following search combinations and terms were applied:

- Population AND Intervention AND (Outcome OR Study type)
- Intervention AND (Outcome OR Study type)
- Population: dental implant OR oral implant OR bone screw* OR endosseous implant
- Intervention: dental restoration OR dental crown OR dental bridge OR cantilever OR restoration OR FPD OR fixed prosthesis; (dental prosthesis AND implant supported) OR (restoration AND implant supported); CAD CAM OR digital OR CEREC OR computer aided) OR (monolithic OR full contour)
- Outcome and study type: clinical evaluation OR RCT OR clinical performance OR failure OR clinical study OR clinical trial OR follow up study OR survival OR longevity OR success OR survival rate

The search strategy is displayed in Figure 1.

■ Inclusion criteria:

As there were no randomised controlled clinical trials, this systematic review collected the data from prospective and retrospective cohort studies and case series. Inclusion and exclusion criteria were defined as followed:

- Human trials
- Language restriction to English and German
- Peer-reviewed dental journals
- Studies with a mean follow-up time of 2 years or more in function
- Case series with 10 or more patients

■ Exclusion criteria:

- *In vitro* studies
- Poster abstracts, interviews or protocols
- Studies reporting on interfering systemic or local factors

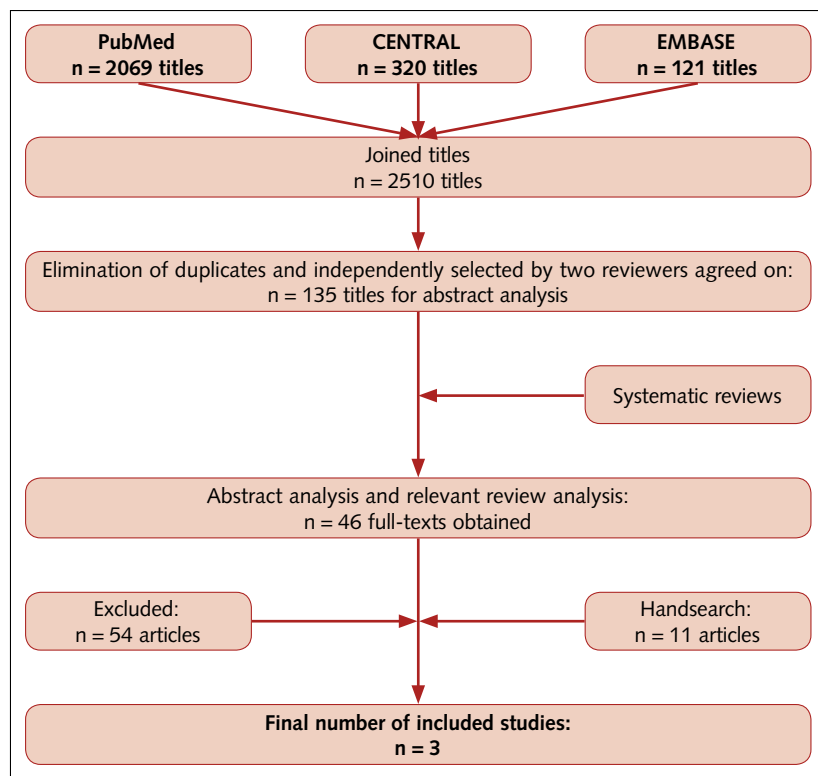


Fig 1 The search strategy.

- Studies with the same sample (most complete/most recent was considered)
- Studies not reporting in detail on the prosthodontic components
- Studies not meeting the inclusion criteria

■ Selection of studies:

Two authors (FS, SH) independently screened the titles from this extensive search, based on the inclusion and exclusion criteria. Any disagreement was dissolved by discussion with a third author (PG). Afterwards, abstracts of all relevant titles were captured and examined for relevant studies. Based on the selection of abstracts, articles were then obtained for full-text analysis.

Full-text analysis was again performed independently by two readers (FS, SH) by screening "Material and methods", "Results" and "Discussion", and then double-checked. Any disagreement was solved by discussion within the group of authors.

Data extraction

From the included studies the following information was extracted: study, year of publication, study design, setting, type of restoration (SC, FPD), implant system, implant material, retention system, reconstruction material, number of restorations, number of failures, follow-up range and mean follow-up and survival, as well as the success rate of prosthodontic treatment. Furthermore, if any included study reported insufficient data in the article, authors or co-authors were contacted.

Statistical analysis

Due to the limited number of included studies and the variability in the reporting, a statistical analysis or meta-analysis was not performed.

■ Results

■ Study characteristics

The electronic search yielded a total of 2510 titles from all databases. After elimination of duplicates, two reviewers assessed the titles and agreed on 135 abstracts for further analysis. Abstract evaluation and consideration of relevant reviews (see "List of reviews") resulted in 46 studies for full-text analysis. Manual searching provided 11 more studies. Altogether, 57 full-texts were obtained and after exclusion of 54 studies, a final number of three publications²¹⁻²³ met the inclusion criteria for data extraction.

The websites of clinicaltrials.gov, WHO and the DRKS provided five more relevant studies – however, none of the studies is completed. They were, therefore, not included in this systematic review.

■ Exclusion of studies

The reasons for excluding studies (n = 54, see reference list "List of excluded full-text articles and the reason for exclusion") after the full text was obtained were: use of layered restorations (40), no implant restorations (4), no detailed information on prosthetics (8), no distinction between monolithic

and layered restorations or different type of materials (1) and a too small number of restorations (1). In one study, some restorations were either facially veneered with a feldspathic porcelain, or pink feldspathic porcelain was used in the gingival areas. All three authors discussed this, and it was agreed that since all functional areas were in monolithic zirconia, the study could be included²¹.

■ Included studies

Finally, three studies met the inclusion criteria for the present analysis (Table 1). The studies were published between 2014 and 2016. One study revealed a prospective study design and was conducted in a university environment²². One study was retrospective and the patients were treated both at a university and in private practices²³. The third study was a consecutive case series, set in a private practice²¹.

The studies reported on different available implant systems: Titanium implants (Astra Tech Implant System, Dentsply Implants, Mannheim, Germany; Straumann, Freiburg, Germany; Nobel Biocare²³; Zimmer Biomet, Warsaw, USA)^{20,21} and zirconia implants (Ziraldent, Metoxit AG, Thayngen, Switzerland)²².

The implant-supported restorations were both single crowns (SC)^{22,23} and fixed dental prostheses (FPD)²¹. Connection to the implants was achieved either by using adhesive cement retention²², screw retention or a combination of screw and cement retention^{21,23}. The material of the reconstructions was lithium disilicate (IPS e.max CAD²² or IPS e.max Press²³, Ivoclar Vivadent) or zirconia ceramic²¹ (Prettau, Zirkozahn, Gais, Italy). The follow-up ranges of the studies are given in Table 1. No studies could be identified on resin matrix ceramics.

■ Prosthetic survival (SC, FPD)

The three studies included a total number of 258 restorative units. Of these, one crown restoration failed²³ and one crown restoration experienced a technical complication²².

Lithium Disilicate:

Fabbri and colleagues recorded a failed lithium disilicate crown in the position of a maxillary canine

Table 1 Information on SCs and FPDs of included studies, (NR: not reported).

Study	Year	Study design	Setting	Restoration (SC, FPD)	Implant system	Implant material	Retention system	Restoration material	Number of restorations	Number of failures	Follow-up range (months)	Mean follow-up (months)	Survival rate	Success rate
Spies et al	2016	Prospective	University	SC	Ziraldent (Metoxit)	Zirconia	Cement-retained	Lithium Disilicate (IPS e.max CAD)	24	0	25 to 34	31 ± 2,7	100%	95,70%
Moscovitch	2015	Case series	Private practice	SC, FPD	Astra Tech Implant System (Dentsply), Nobel Biocare, Straumann, Zimmer Biomet	Titanium	Screw-retained and combination screw/cement-retained	Zirconia (Prettau)	189	0	2 to 68	NR	100%	100%
Fabbri et al	2014	Retrospective	University and Private practice	SC	Nobel Biocare	Titanium	Screw-retained, cement-retained and combination screw/cement-retained	Lithium Disilicate, (IPS e.max Press)	45	1	12 to 61	28,3	97,78%	97,78%

that revealed a minor cohesive fracture and therefore reported a survival rate of lithium disilicate crowns adhesively bonded to titanium or zirconia frameworks of 97,78% after 28 months²³. However, the chipping did not impair function, the area was smoothed and the restoration could be left *in situ*²³. As no implant-supported crown had to be replaced, Spies et al reported a survival rate of 100% after a mean observation period of 31 months²².

Zirconia

One cemented implant-supported monolithic zirconia single-crown had to be remade due to a fracture of the zirconia abutment²¹ and was replaced with a screw-retained all-ceramic crown. As this was not a failure of the restorative material, the survival rate of both implant supported single crowns and fixed partial dentures was rated with 100%²¹.

■ Prosthetic success and technical complications

None of the studies observed any loss of retention or screw loosening of implant-supported restorations.

Lithium Disilicate

One prosthetic complication occurred in the study by Spies and colleagues on a maxillary first molar crown. The crown showed a major occlusal roughness and thus the success rate was reduced to 95.7% after 31 months. As this roughness could be polished, it was considered as clinically acceptable²².

The success rate for lithium disilicate crowns bonded to titanium or zirconia was 97,78% after a mean observation period of 28.3 months²³.

Zirconia

No prosthetic complications were reported for monolithic zirconia restorations on implants, leading to a success rate of 100%²¹.

■ Aesthetic outcomes

Two studies reported on aesthetic outcomes of their prosthodontic treatment. Outcome was either

measured visually by patients (VSA)²² or by both patients (satisfaction score) and clinicians (modified CDA criteria)²³.

Spies et al asked their patients before and after final prosthodontic treatment and at follow-ups to evaluate aesthetics and appearance, function (eating), sense ("feeling like natural teeth"), speech and self-esteem. The authors realised this by a Visual Analogue Scale (VSA) from 0 to 100%²². All questioned events improved after treatment and remained stable over time. Aesthetics increased from a treatment start of 64.1% up to 87.4 to 90.7% after therapy. Lithium disilicate crowns were further scored with modified USPHS criteria. Ceramic fracture, marginal discolouration and integrity were stable over the given follow-up period and therefore assessed with "Alpha", whereas occlusal roughness, contour and aesthetics were mostly evaluated with "Bravo" classification at the 3-year evaluation. However, "Bravo" was defined as clinically acceptable with minor deviations. None of the restorations showed a "Charlie" or "Delta" classification at any time during the study.

Patients in the study by Fabbri et al²³ could rate their self-satisfaction with nominal scores of "non-acceptable", "acceptable", "good" and "excellent". All restorations were rated either "good" or "excellent" by patients. The modified CDA (California Dental Association) criteria for Colour match, porcelain surface and marginal discolouration and integrity were also rated mostly with an A by clinicians at the 3-year follow-up. Moscovitch²¹ provided no information on these parameters.

■ Discussion

This systematic review focused on the outcomes of clinical studies reporting on implant-supported monolithic all-ceramic single- and multi-unit restorations. The number of published trials is limited due to the short time that monolithic restorations have been used in implant-supported restorations. Most of the published studies reported on small samples sizes or did not provide adequate information on the study details.

There is a general consensus in the dental literature that monolithic restorations show the lowest

number of mechanical complications. Monolithic restorative systems reveal no dissimilar interfaces, create a greater bulk of material that leads to improved structural properties of the material. Thus, the risk of fracture and/or chipping events is significantly reduced¹³. The combination of monolithic design and manufacture with CAD/CAM technology enables efficient handling and care delivery. Therefore, implant prosthodontics benefit from the CAD/CAM technology for the fabrication of full-contour restorations²⁴. Hence, the combination of monolithic materials connected to abutment substructures may represent a preferable treatment option, especially in the posterior region.

No valid clinical data could be identified on resin matrix ceramic implant-supported restorations. One proof-of-concept case series²⁵ showed that a fully digital workflow for the fabrication of implant supported crowns from a monolithic resin matrix ceramic (Lava Ultimate) is feasible. A reduction of the laboratory and treatment time resulted in a reasonable cost-benefit ratio and a high quality and precision of the restorations²⁵. However, the investigated resin matrix ceramic material has to be considered experimental, as no large-scale clinical investigations with long-term follow-up observations are currently available.

The combination of lithium disilicate restorations with zirconia substructures has been described as a reliable option to combine mechanical effectiveness with good aesthetics and promising long-term clinical outcomes for implant-supported prostheses^{5,9}.

The survival rate of cemented CAD/CAM fabricated monolithic lithium disilicate implant crowns was 100%²². No fractures or chippings were described. Debonding or any other technical complications were not noted in the given observation period after 3 years. Only one crown revealed a major occlusal roughness, resulting in a Kaplan Meier success rate of 95.7% after 31 months.

Good results in terms of aesthetics, function and loss of retention were observed for the combination of implant-supported lithium disilicate restorations with zirconia frameworks²³ or zirconia implants⁹.

The survival rate of monolithic implant-supported press fabricated lithium disilicate single crown restorations was 97,78% after a mean observation time of 28.3 months. Only one crown revealed a chip fracture²³.

CAD/CAM lithium disilicate implant crowns can also be fabricated chairside in 1 to 2 h, which leads to a significant reduction in the fabrication time²⁶. Hence a time- and cost-effective chairside workflow to produce reliable all-ceramic implant crowns has been established. However, no clinical studies on these hybrid abutment crowns have yet been published.

Several clinical studies have shown that monolithic or minimally veneered (no feldspathic veneer in function) zirconia would be a viable treatment option for implant-supported full-arch restorations²⁰. However the evidence on monolithic zirconia implant-supported single and multi-unit restorations is presently low. In the study by Moscovitch²¹ all monolithic zirconia restorations exhibited a 100% survival rate at 68 months. No fractures, cracks or chipping within the monolithic zirconia material were observed. Further complications relating to phonetics, masticatory function or screw loosening were not detailed in the identified study on monolithic zirconia outcomes.

This study indicated that there is a new paradigm shift in fixed implant prosthodontics that allows for the use of monolithic high-strength ceramics to enhance the overall aesthetics, biocompatibility, performance, efficiency and cost benefits.

As reported by several *in vitro* and clinical studies, zirconia induces minimal wear to opposing structures, and this property is maximised, when the occlusal surfaces are polished after definitive intraoral occlusal adjustments^{14,27}. Recently, more translucent zirconia materials were introduced to the dental market, with the aim of a broader application in anterior and premolar areas. While this improvement of the material is positive regarding the aesthetic result, it also leads to a weakening of the material. Hence its application is limited to small fixed dental prostheses.

Given that clinical reports are ranked low in the hierarchy of evidence-based research, the reported high success of monolithic lithium disilicate and zirconia restorations should be considered with cautious optimism.

This systematic review aimed, for the first time, to describe the short- and mid-term evidence regarding fixed dental monolithic prostheses in the rehabilitation of partially edentulous patients. The absence

of long-term clinical studies and related strong evidence supporting this treatment are the major limitations of this systematic review. Due to the limited number of published trials and the considerable heterogeneity among the included studies in terms of prosthodontics protocols, a meta-analysis was not feasible. The included studies that reveal a lower evidence level are subject to a certain risk of reporting bias, publication bias and attrition bias. Hence, clinicians should carefully consider the limitations of the included evidence when making decisions regarding this treatment.

In conclusion, this systematic review of the current literature evidenced high prostheses survival of implant-supported monolithic lithium disilicate and zirconia single- and multi-unit restorations in the short-term. Only a few mechanical complications, such as surface roughness and minor fractures, were described for lithium disilicate restorations. Given the level of evidence and the duration of the studies included, the use of monolithic lithium disilicate and zirconia prostheses for single and multi-unit implant supported prostheses requires additional comprehensive longer-term investigation.

■ Conclusions

According to the results of this review and within its limitations, the use of monolithic lithium disilicate and zirconia for implant-supported single crowns and fixed prosthodontics was effective and reliable in short-term studies.

The choice of this monolithic concept may represent a valid treatment for implant-supported single and multi-unit restorations, offering biological, technical and aesthetic advantages.

Further *in vivo* investigations are necessary to validate the clinical reliability of monolithic implant-supported restorations in the long-term, confirming the effectiveness of the proposed prosthetic approach.

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■ List of excluded studies and reason for exclusion

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Accuracy of digital implant impressions with intraoral scanners. A systematic review

Key words accuracy, CAD/CAM, dental implant, digital, impression, intraoral scanner, systematic review

Aim: The use of intraoral scanners (IOS) for making digital implant impressions is increasing. However, there is a lack of evidence on the accuracy of IOS compared with conventional techniques. Therefore, the aim of this systematic review was to collect evidence on the accuracy of digital implant impression techniques, as well as to identify the main factors influencing the accuracy outcomes.

Materials and methods: Two reviewers searched electronic databases in November, 2016. Controlled vocabulary, free-text terms, and defined inclusion and exclusion criteria were used. Publications in English language evaluating the accuracy outcomes of digital implant impressions were identified. Pooled data were analysed qualitatively and pertinent data extracted.

Results: In total, 16 studies fulfilled the inclusion criteria: one *in vivo* and 15 *in vitro* studies. The clinical study concluded that angular and distance errors were too large to be acceptable clinically. Less accurate findings were reported by several *in vitro* studies as well. However, all *in vitro* studies investigating the accuracy of newer generation IOS indicated equal or even better results compared with the conventional techniques. Data related to the influence of distance and angulation between implants, depth of placement, type of scanner, scanning strategy, characteristics of scanbody and reference scanner, operator experience, etc were analysed and summarised. Linear deviations (means) of IOS used in *in vitro* studies ranged from 6 to 337 μm . Recent studies indicated small angle deviations ($0.07\text{--}0.3^\circ$) with digital impressions. Some studies reported that digital implant impression accuracy was influenced by implant angulation, distance between the implants, implant placement depth and operator experience.

Conclusions: According to the results of this systematic review and based on mainly *in vitro* studies, digital implant impressions offer a valid alternative to conventional impressions for single- and multi-unit implant-supported restorations. Further *in vivo* studies are needed to substantiate the use of currently available IOS, identify factors potentially affecting accuracy and define clinical indications for specific type of IOS. Data on accuracy of digital records, as well as accuracy of printed or milled models for implant-supported restorations, are of high relevance and are still lacking.

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■ Introduction

Oral implants have improved the care of partially and completely edentulous patients for several decades. Although implant-supported dental prostheses have

proved to be a reliable long-term solution^{1,2}, many biological and technical challenges still remain^{3,4}. Digital technologies have revolutionised clinical prosthodontics, extending diagnostic, treatment and follow-up possibilities^{5,6}. They have improved

conventional prosthetic approaches and enabled completely new treatment workflows, as well as introducing the concept of the “virtual patient”⁷.

Accuracy is a key aspect in function and aesthetics of indirect restorations. The fit of implant-supported dental restorations has been discussed extensively in the literature⁸. In contrast to natural teeth, osseointegrated implants are not able to compensate for small inaccuracies of the prostheses, as they are virtually immobile⁹. Their sensory discrimination is more limited than for teeth¹⁰. The demand for accurately fitting implant-supported prostheses is further increased with the use of screw-retained restorations or when stiff and prone to cracking materials (e.g. materials (e.g. ceramics) are used to splint multiple implants with fixed partial dentures (FPD). Due to a build-up of errors in each clinical and laboratory step, a certain degree of inaccuracy is unavoidable. Many techniques have been proposed to evaluate the passive fit of restorations, however, none of them can be relied on solely⁸. Consequently, various methods to improve the fit of the multiple implant-supported restorations has been suggested^{11,12,13}. Non-passively fitting restorations could potentially be related to mechanical complications: loss of retention, screw loosening, fracture of framework or veneering material^{14,15}. However, consensus on the clinically acceptable level of misfit has not yet been reached. Several authors have proposed different recommendations for clinically acceptable misfit ranging from 10 µm to 150 µm¹⁶. It has even been suggested that for maintaining osseointegration of endosseous implants, passivity of fit of multi-unit restorations seems not to be as critical as previously thought¹⁷. Since the definition of the passive fit is still hypothetical and the level of clinically acceptable misfit has not been determined, clinicians should always strive to achieve the most accurate fit possible for implant-supported FPDs.

While modern CAM technologies technologies are capable of achieving a precise fit exceeding that of casting techniques, they still rely on the accuracy of impressions, definitive models and bite registrations¹⁸. Many previous studies reported on the accuracy of different conventional implant impression (CII) techniques, addressing the influence of number of implants, angulation, implant placement depth, type of implant-abutment connection, direct or indirect technique, and splinting of impression

copings^{19,20}. As a result, several systematic reviews have addressed the accuracy of conventional implant impression techniques²¹⁻²⁶. Recently published studies preferred direct to indirect impressions and splinted over non-splinted techniques, especially with increased number of implants^{21,27,28}. Implant angulation of 20 to 25 degrees negatively affected the multiple implant impression accuracy²⁴. Results reported for internal connection implants were less consistent, in contrast to reports on external connection implants²⁹. Even with procedural diligence, conventional impression techniques involve process-related risks, uncontrolled variables, expensive laboratory and chairside time, material expense, and patient discomfort³⁰.

Digital impressions were proposed as viable alternative to make impressions for tooth- and implant-supported restorations. The number of digital intraoral scanners (IOS) on the market is increasing, and new improved hardware and software versions are released continuously. IOS can capture the images as digital photographs or video. They eliminate tray selection, dispensing, setting and volumetric changes of impression materials, disinfection and transporting to dental laboratory, gypsum pouring and cast preparation for articulation²⁸.

As defined by ISO-5725-1:1994, accuracy of IOS consists of trueness and precision. Trueness describes the deviation of scans from the true dimensions of the object, while precision describes how much separate scans of the same object differ from each other.

IOS usage for teeth-supported restorations has more documentation than use with implant-supported prostheses. According to a recent systematic review, tooth-supported single-unit crowns fabricated using the digital impression technique presented statistically similar marginal discrepancies compared with those obtained with the conventional impression technique³¹. However, there is less evidence available on the accuracy of digital impressions for implant-supported restorations, especially FPDs²⁴. In fact, a systematic review, addressing the accuracy of different implant impression techniques concluded that insufficient data exists on digital impression techniques and that the further studies are needed²⁸. Recently, a number of articles addressing the accuracy of digital implant impressions (DII) have been published.

Table 1 Search strategy for MEDLINE/PubMed.

Search terms	Number of records returned
MeSH terms:	
“Dental Impression Technique”[Mesh] AND “Dental Implants”[Mesh]	657
“Dental Impression Technique”[Mesh] AND “Dimensional Measurement Accuracy”[Mesh]	59
“Dental Implants”[Mesh] AND “Printing, Three-Dimensional”[Mesh]	23
“Dental Implant-Abutment Design”[Mesh] AND “Dental Impression Technique”[Mesh]	136
“Dental Impression Materials”[Mesh] AND “Dental Implants”[Mesh]	398
Free-text:	
Implant AND intraoral scanner	37
Implant position AND digital	163
Implant AND impression	1007
Implant impression AND accuracy	233
Implant impression AND optical	44
Implant impression AND digital	104

Therefore, the aim of this review was to collect available evidence and evaluate accuracy outcomes of DII techniques. Additionally, different variables influencing accuracy of DII were identified when possible.

Materials and methods

This systematic review was conducted following PRISMA (Preferred Reporting for Systematic Reviews and Meta-Analyses) guidelines.

Focused question

What are the accuracy outcomes of digital implant impression techniques?

Inclusion and exclusion criteria

PICOS (patient, intervention, comparison, outcomes, study design) criteria were used for inclusion and exclusion of studies:

- Patients: partially or completely edentulous dental arch or replica with implants.
- Intervention: taking single-unit or multi-unit conventional and digital, or only digital implant impressions with commercially available IOS, using scanbodies.
- Comparison: accuracy of DII (or model produced from DII) compared to the reference model (or the model produced from CII).

- Outcomes: quantitative measurement of accuracy (linear, angular).
- Study design: *in vivo* and *in vitro* experimental studies.

Studies with clearly explained impression accuracy assessment methodology were included in the systematic review. Case reports, expert opinions, technical or clinical reports, incomplete publications, and review articles were excluded. However, potentially relevant information from these publications was also considered, though these publications were not included into the systematic review. Studies comparing outcomes of restorations fabricated from digital and conventional impressions were not included, as the restoration the fabrication process alone can considerably influence accuracy.

Search strategy and data collection

An electronic search was performed using selected databases: MEDLINE/PubMed, Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, AMED (Ovid). Only English language publications were Included. Published and early-view online articles were identified. The latest search was conducted on November 10, 2016. A detailed search strategy was prepared including free-text and MeSH (Medical Subject Headings) terms for each database search. Search strategy for MEDLINE/PubMed is presented in Table 1. Additionally, a hand search was performed reviewing references of potentially

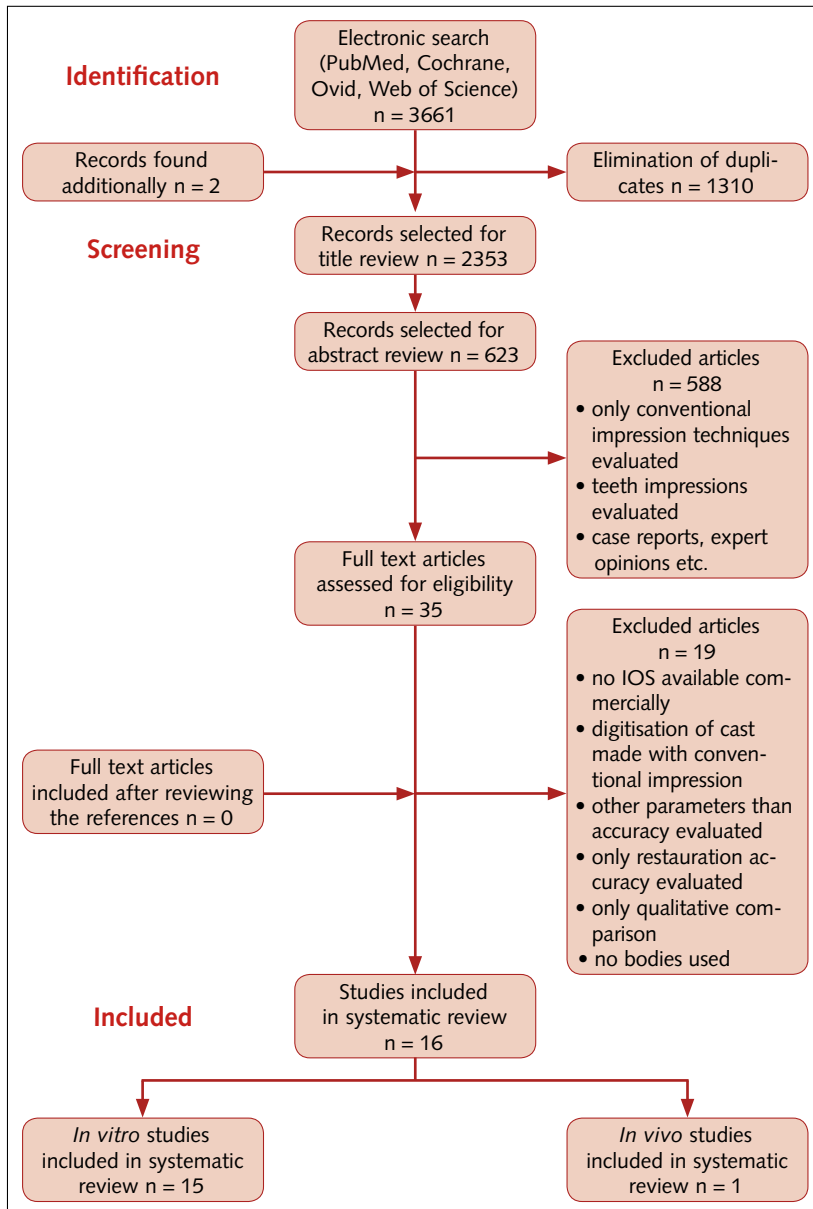


Fig 1 Study selection process.

pertinent papers, review papers as well as content of the following journals: Journal of Dental Research, Clinical Implant Dentistry and Related Research, Clinical Oral Implants Research, European Journal of Oral Implantology, Implant Dentistry, International Journal of Oral and Maxillofacial Surgery, Journal of Cranio-Maxillo-Facial Surgery, Journal of Oral Implantology, Journal of Dentistry, Clinical Oral Investigations, and Journal of Oral Rehabilitation.

Identified publications were imported into the reference manager program (Zotero, Fairfax, VA, USA) and duplicates were removed electronically. Titles of the publications were screened by two calibrated

reviewers (VR and AG). Abstracts of remaining publications were then screened. In cases when information provided in the abstract was insufficient, full-text articles were reviewed. Selected records were obtained for the full-text review. Based on inclusion and exclusion criteria, publications were selected for the systematic review. References of these publications were additionally searched for the other relevant publications. Following data, when possible, was extracted using the electronic spreadsheet: anatomic location, implant type, distance and angulation between implants, depth of placement, impression level, implant-abutment connection type, type of the scanner (powder/no powder), scanning strategy, characteristics of scanbody and reference scanner, operator experience, accuracy measurement methodology. Disagreements regarding record screening, title, abstract or full-text review, and data extraction were solved by discussion, leading to the consensus between all authors. In order to reduce the risk of bias, PRISMA guidelines were followed.

RESULTS

Included studies

The initial search resulted in 3661 records. After removing duplicates and adding records identified through other sources (one of them a PhD thesis published online), 2353 records were selected for title review. The subsequent selection at the title level yielded 623 titles. Screening of the abstracts revealed 35 publications. Of the 35 articles selected for the full-text review, 16 publications were finally included (Fig 1). Articles that were not included in this systematic review and the reasons for exclusion are shown in Table 2.

Characteristics of the included studies

Of the 16 included studies, one study was an *in vivo* study and 15 others were *in vitro* studies.

The majority of studies evaluated the accuracy of iTero IOS (n = 8), then True Definition (n = 5), Trios (n = 3), Lava COS (n = 3), Trios Color (n = 2), Cerec Bluecam (n = 2), ZFX Intrascan (n = 2), Cerec Omnicam (n = 1), 3D Progress (n = 1), CS3500

Table 2 Excluded studies and reasons for exclusion.

Studies	Reason for exclusion
Ortorp et al ⁶² 2005; Bergin et al ⁶³ 2013	No commercially available scanner. Limited clinical applications.
Eliasson et al ⁶⁴ 2012; Howell et al ⁶⁵ 2013	Conventional impressions from digitally coded healing abutments taken. No digital impression technique with intraoral scanner was used.
Lee et al ⁶⁶ 2013; Lee et al ⁶⁷ 2013; Wismeijer et al ⁶⁸ 2014; Calesini et al ⁶⁹ 2014; Joda et al ⁵³ 2015; Schepke et al ⁷⁰ 2015; Joda et al ⁵² 2015; Joda et al ⁷¹ 2016	Accuracy of digital implant impression techniques was not evaluated.
Aktas et al ⁷² 2014; Abdel-Azim et al ⁷³ 2014; Karl et al ⁷⁴ 2012	Accuracy of different impression techniques was not evaluated. Fit of the prosthesis produced from conventional and digital impressions was evaluated <i>in vitro</i> .
Gherlone et al ⁷⁵ 2015; Lee et al ⁷⁶ 2015; Gherlone et al ⁷⁷ 2016	Clinical study. No evaluation of digital implant impression accuracy.
Ajioka et al ³⁸ 2016	No scanbodies used for the experiment.

(n = 1) and Planmeca Planscan (n = 1). Eight studies indicated the version of the IOS software^{32–37,39,40}, while the other eight studies did not^{41–48}. Eight of the included studies evaluated accuracy of DII in the maxilla^{33–35,42–45,40} and the other eight related to the mandible^{32,36,37,41,46–48,39}. Six studies investigated situations with partially edentulous arch (from 1 to 3 implant-supported single- and multi-unit restorations)^{41,44–46,37,40}, and 10 looked at completely edentulous situations with two to six implants^{32–36,42,43,47,48,40}. Data obtained from DII was compared with data from the reference model in 12 studies^{33–35,41–44,48,40,36,47,39}, with data from conventional models in four studies^{36,47,39,32}. The majority of studies evaluated trueness of DII as a measure of accuracy. Precision was evaluated by five studies^{41,44,45,48,40}. Three studies compared the accuracy of milled models fabricated from DII with reference or conventional models^{44–46}. Distance (3D or in specific plane) and angle deviations were estimated in the included studies. Detailed characteristics and main findings of the included studies are listed in Tables 3 and 4.

Table 3 Characteristics and main findings of included *in vivo* study.

Article	No. of implants, positions	No. of patients, restorations	Implant angulation, average distance	Implant characteristics	Impression level	Scanned object, strategy	Type of intraoral scanner	Reference	Accuracy evaluation	Conclusion
Andriessen et al ³² 2014	2, regio #33 and #43	25, 25	No data	Standard SLA-active RN (Straumann, Basel, Switzerland), 4.1/12 mm; Internal connection	Implant level	RN Scanbody (Straumann); Hand-tightened; 5 scans (occlusal, 45 degrees buccal, 45 degrees lingual, mesioproximal, and distoproximal)	iTero (Cadent Inc); Software version 3.5.0; No powder	Master model, scanned with Lava Scan STscanner (3M ESPE, Seefeld, Germany)	Linear and angular. Measurement of the mid-centre line of the 2 scan abutments, showed a distance mean error of 226.0 mm compared with the reference scan. Distance error was smaller than 100 µm in 5 of the 21 scans. The mean absolute angulation error was 2.582 degrees. An angulation error <0.4 degrees was recorded in 3 of the 21 scans.	Digital impression accuracy is not adequate

Table 4 Characteristics and main findings of included *in vitro* studies.

Article	No. of implants. positions	Angulation	Placement depth (mm)	Implant manufacturer. connection	CII technique	DII technique: IOS; use of powder; scanning strategy	Number of impressions	Scanbody. torque value Ncm
Single-unit digital implant impressions								
Lee et al ⁴⁵ 2015	1. #25	No data	No data	Bone Level. Regular Crossfit. (Straumann); Internal connection	CT. IL	iTero (Align Technology. Israel). no data on version; NP; No data on strategy	30	Scanbody (Straumann); No data on torque value
Koch et al ⁴⁴ 2016	1. #25	No data	No data	Bone Level. Regular Crossfit (Straumann); Internal connection	Not used	iTero (Align Technology). no data on version; NP; No data on strategy	30	Scanbody (Straumann); No data on torque value
Multi-unit digital implant impressions								
Lin et al ⁴⁶ 2015	2. #35 and #37. distance of 10 mm		1 mm coronal	RN. Standard Plus (Straumann); Internal connection	OT. NSp. IL	iTero (Align Technology). no data on version; NP; No data on strategy	40	Two-piece scanbody (Straumann); 15 Ncm
		0° divergency						
		15° divergency						
		30° divergency						
		45° divergency						
Papaspyridakos et al ⁴⁷ 2015	5. interforaminal region	The medial 3implants - parallel; distal left - 10°. distal right - 15°.	No data	Bone Level Regular Crossfit (Straumann); Internal connection	OT 1)IL. Sp 2) IL. NSp 3) AL. Sp 4) AL. NSp	Trios (3Shape). No data on version; NP; No data on strategy	10	Scanbody (Straumann). No data on torque value
Vandeweghe et al ⁴⁸ 2016	6. #36. #34. #32. #42. #44. #46	Parallel	No data	IBT. Southern Implants (Irene. South Africa); External connection	Not used	Lava COS (3M ESPE). no data on version; P; No data on strategy	10	PEEK. (Proscan Zonhoven Belgium); 10 Ncm preload
						3M True Definition (3M ESPE). no data on version; P; No data on strategy		
						Cerec Omnicam (Sirona). no data on version; NP; No data on strategy		
						Trios (3Shape). no data on version; NP; No data on strategy		

VPS – polyvinylsiloxane; PE – polyether; CII – conventional implant impression; DII – digital implant impression; IOS – intraoral scanner; CMM – coordinate measuring machine; CT – closed tray; OT – open tray; IL – implant level; AL – abutment level; Sp – splinted; NSp – non-splinted; S – significant; NS – non-significant; BL – bone level; TL - tissue level; Absd - absolute angular distortion; P – powdered; NP – non-powdered.

Reference scanner	Accuracy evaluation. results	Conclusions					
Lava Scan ST (3M ESPE)	Comparison (linear): models produced from DII (milled model) and CII (gypsum model). compared to reference model Horizontal CII 34 ± 9 mm. DII 11 ± 13 mm (NS) Vertical CII -88 ± 44 mm. DII 93 ± 61 mm (S)	Vertical position of the implant in milled models was more coronal than in the plaster model. Cause of vertical position errors is commented to be processing errors of the analogue placement.					
Lava Scan ST (3M ESPE)	Comparison: mean volumetric deviations at 5 selected points between DII model (digitized milled model) at implant surface and reference model DII vs reference model -6 ± 40µm DII vs milled model from DII 19 ± 162µm DII model (milled) vs reference model 14 ± 170µm	Cumulative errors were found in the line of workflow. Software, scanner, and milling error (standard deviations, respectively: ±1, ±21, and ±98 µm) were shown to propagate throughout the digital workflow to the milled model (100 µm).					
Cagenix scanner (Cagenix Inc)	Differences between models produced from DII (digitised milled models) and CII (digitised impression models) (comparison of CII/DII models with reference model is not included in the table)	Models made from CII were more accurate than made from DII. Divergence between the two implants significantly affected the accuracy. In 0° and 15° groups, the digital pathway resulted in less accurate models compared with the conventionally created ones. DII produced more accurate definitive models when the two implants diverged more.					
	Linear differences		Angular differences				
	221 ± 35µm (S)		0.986 ± 0.218° (S)				
	260 ± 35 µm (S)		1.551 ± 0.218° (S)				
	159 ± 36 µm (S)		0.004 ± 0.218° (NS)				
	75 ± 36 µm (NS)	0.438 ± 0.218° (NS)					
IScan D103i (Imetric)	Comparison of 3D deviations (µm) of scanbodies on models produced from DII (digital model) and CII (digitised stone model) as compared to reference model (Interquartile range is shown in parenthesis).					The accuracy of DII was not different than the implant-level, splinted CII and more accurate than the implant-level, non-splinted impressions. The accuracy of implant impressions was not affected by the implant angulation up to 15°	
	Implant number	IL - Sp	IL - NSp	DII	AL - Sp		AL - NSp
	1	5.79 (5.69–5.94)	21.89 (21.84–21.98)	23.39 (23.27–23.47)	33.10 (32.93–33.24)		14.59 (14.52–14.76)
	3	9.16 (8.99–9.28)	13.00 (12.84–13.21)	15.27 (15.18–15.53)	14.31 (13.98–14.49)		1.27 (1.19–1.37)
	4	4.70 (4.54–4.81)	13.39 (12.97–13.46)	7.60 (7.54–7.67)	12.04 (11.86–12.13)		6.91 (6.69–6.96)
	5	12.52 (12.44–12.67)	131.75 (131.6–132.1)	29.02 (28.78–29.15)	8.86 (8.81–9.01)		9.63 (9.37–9.78)
104i scanner (Imetric)	Comparison: 3D deviations comparing DII (digital model) and reference model					Significant differences in accuracy between the different scanners were found. Lava COS scanner did not achieve the necessary level of accuracy to be used for large-span implant-supported reconstructions. Other scanners demonstrated an acceptable level of trueness and precision for this indication.	
	Trueness			Precision			
	112 ± 25 µm			66 ± 25 µm			
	35 ± 12 µm			30 ± 11 µm			
	61 ± 23 µm			59 ± 24 µm			
	28 ± 7 µm			33 ± 12 µm			
Non-significant difference between 3M True Definition and Trios for trueness and precision.							

Article	No. of implants. positions	Angulation	Placement depth (mm)	Implant manufacturer. connection	CII technique	DII technique: IOS; use of powder; scanning strategy	Number of impressions	Scanbody. torque value Ncm
Flügge et al ⁴¹ 2016	Model 1: 2. #36. #35 Model 2: 5. #36. #35. #33 and #45. #47	Non parallel	No data	Bone Level and Tissue Level (Straumann); Internal connection	Not used	iTero (Align Technology). no data on version; NP; No data on strategy Trios (3Shape). no data on version. NP; No data on strategy True Definition (3M ESPE). no data on version;P; No data on strategy	10	Bone Level and Tissue Level scanbody (Straumann) No data on torque value
Gimenez et al ⁴³ 2016	6. #17. #15. #12. #22. #25. #27	#17. #12. #22. #27 - 0° #15 - 30° distally. #25 - 30° mesially	#17. #27. #15. #25-0 mm #12 - 4 mm #22 - 2 mm	Certain 4. 1/11 mm. (Biomet 3i. Palm Beach Gardens. FL. USA); Internal connection	Not used	True Definition (3M ESPE); no data on version; P	4 operators. 5 DII each	PEEK (Createch Medical S.L.); No data on torque value
Gimenez et al ⁴² 2015	6. #17. #15. #12. #22. #25. #27	#17. #12. #22. #27 - 0° #15 - 30° distally. #25 - 30° mesially	#17. #27. #15. #25-0 mm #12 - 4 mm #22 - 2 mm	Certain 4. 1/11 mm. (Biomet 3i); Internal connection	Not used	Lava COS (3M ESPE); Version 0.3.0.2; P	4 operators. 5 DII each	PEEK (Createch Medical S.L.); No data on torque value
Gimenez et al ³⁵ 2015	6. #17. #15. #12. #22. #25. #27	#17. #12. #22. #27 - 0° #15 - 30° distally. #25 - 30° mesially	#17. #27. #15. #25-0 mm #12 - 4 mm #22 - 2 mm	Certain 4. 1/11 mm. (Biomet 3i); Internal connection	Not used	3D Progress (MHT); no data on version; NP ZFX Intrascan (ZFX); no data on version; NP	4 operators. 5 DII each	PEEK (Createch Medical S.L.); No data on torque value
Gimenez et al ^{AM34} 2015	6. #17. #15. #12. #22. #25. #27	#17. #12. #22. #27 - 0° #15 - 30° distally. #25 - 30° mesially	#17. #27. #15. #25-0 mm #12 - 4 mm #22 - 2 mm	Certain 4. 1/11 mm (Biomet 3i); Internal connection	Not used	CEREC AC Bluecam (Sirona); Version 4.0; P	4 operators. 5 DII each	PEEK (Createch Medical S.L.); No data on torque value

VPS – polyvinylsiloxane; PE – polyether; CII – conventional implant impression; DII – digital implant impression; IOS – intraoral scanner; CMM – coordinate measuring machine; CT – closed tray; OT – open tray; IL – implant level; AL – abutment level; Sp – splinted; NSp – non-splinted; S – significant; NS – non-significant; BL – bone level; TL – tissue level; Absd – absolute angular distortion; P – powdered; NP – non-powdered.

Reference scanner	Accuracy evaluation. results				Conclusions	
D250 (3Shape)	Measurement location	Comparison: DII (digital model) distances and angles between two neighboring scanbodies (only statistically significant (p<0.05) data)				A smaller variation of the distance measurements was observed for the intraoral scanners True Definition and Trios. and a higher variation was seen for the iTero. Scanning precision worsened with increasing distance and angulation between scanbodies. Differences of mean distances between scanbodies comparing to dental lab scanning system (D250. 3Shape) were less than 40 µm.
		Mean distance (mm) and standard deviation (µm)		Mean angle and standard deviation		
		iTero	True Definition	iTero	True Definition	
	#35 - #36	6.669 (28)	6.647 (4)	8.06° (0.18)	8.20° (0.04)	
	#35 - #36 (model 2)			8.19° (0.24)	8.12° (0.10)	
#35 - #45	40.608 (28)	40.566 (44)	17.47° (0.21)	17.33° (0.09)		
#36 - #47	50.479 (64)	50.405 (60)	23.09° (0.20)	23.28° (0.15)		
CMM Crista Apex (Mitu-toyo)	Comparison: DII (digital model) vs reference model				Accuracy is clinically acceptable. Scanbody visibility, observer experience, and scanning area affect accuracy.	
		Distance		Angulation		
	First quadrant	7.6 ± 17.6 µm (S)		0.21 ± 0.17° (S)		
	Second quadrant	-10.3 ± 39.2 µm (S)		0.28 ± 0.16° (S)		
CMM Crista Apex (Mitu-toyo)	Comparison: DII (digital model) vs reference model				Experienced operators delivered more accurate DII. Angulated implants and the deeply placed implants did not decrease the accuracy in digital impressions.	
	Group	Mean (SD)				
	Experienced	-30.8 ± 25.9 µm				
	Inexperienced	13.3 ± 51.2 µm				
	Angulated	-20.2 ± 21.9 µm				
	Parallel	-37.9 ± 26.2 µm				
	Deep implant	-34.3 ± 18.7 µm				
Gingival margin level	-28.5 ± 29.8 µm					
CMM Crista Apex (Mitu-toyo)	Comparison: DII (digital model) vs reference model				The 3D progress IOS performed significantly better in the first quadrant. ZFX Intrascan in the second quadrant. Tested scanners not suitable for multi-implant impressions.	
	Group	ZFX Intrascan	3D Progress			
	Experienced	-179 ± 601 µm	249 ± 702 µm			
	Inexperienced	-101 ± 705 µm	224 ± 930 µm			
	Angulated	-125 ± 596 µm	257 ± 776 µm			
	Parallel	-150 ± 693 µm	224 ± 854 µm			
	Deep implant (2 mm)	-150 ± 397 µm	87 ± 403 µm			
	Gingival margin level	-133 ± 782 µm	337 ± 997 µm			
CMM Crista Apex (Mitu-toyo)	Comparison: DII (digital model) vs reference model				Tested scanner is clinically acceptable. The experience of the operator affected the accuracy. Angulation and location of the camera affect scanner results. The error increased from the first to the last implant scanned.	
	Group	Mean (SD)				
	Experienced	-85.4 ± 98.9 µm				
	Inexperienced	-47.3 ± 75.7 µm				
	Angulated	-72.7 ± 81.7 µm				
	Parallel	-84.3 ± 99.9 µm				
	0 mm implant depth	-89.47 ± 105.59 µm				
	2 mm implant depth	-22.46 ± 30.92 µm				
	4 mm implant depth	-107.25 ± 68.65 µm				
	First quadrant	-17 ± 26.3 µm				
Second quadrant	-116 ± 103 µm					

Article	No. of implants. positions	Angulation	Placement depth (mm)	Implant manufacturer. connection	CII technique	DII technique: IOS; use of powder; scanning strategy	Number of impressions	Scanbody. torque value Ncm
Gimenez et al ³³ 2014	6. #17. #15. #12. #22. #25. #27	#17. #12. #22. #27 - 0° #15 - 30° distally. #25 - 30° mesially	#17. #27. #15. #25-0 mm #12 - 4 mm #22 - 2 mm	Certain 4. 1/11 mm (Biomet 3i); Internal connection	Not used	iTero (Align Technology); Version 4.5.0.1.5.1; NP	4 operators. 5 DII each	PEEK (Createch Medical S.L.); No data on torque value
van der Meer et al ³⁷ 2012	3. #36. #41. #46	-	Gingival level	No information	Not used	CEREC Bluecam. (Sirona); Version 3.85 P iTero. (Align Technology); Version 3.5.0 NP Lava COS (3M ESPE); Version 2.1 P	n = 10	PEEK (Createch Medical S.L.); No data on torque value
Mangano et al ⁴⁰ 2016	Model 1: 3. #21. #24. #26; Model 2: 6. #16. #14. #11. #21. #24. #26	No data	No data	BTK implants (Dueville. Vicenza. Italy)	Not used	Trios Color (3Shape); Version 2014 - 1. 1.3.3.1. NP CS 3500 (CarestreamHealth. Rochester. NY. US); Version 2016-4. 2.1.4.10. NP ZFX Intrascan (MHT); Version 0.9 RC33 2.8. NP Planmeca PlanScan (E4D Technologies. LLC. Richardson. TX. USA); Version 5 - 2015. NP	n = 5	PEEK; No data on torque value
Chew et al ³⁹ 2016	2. #44. #45	Parallel	No data	Tissue and Bone Level Standard Plus (Straumann)	OT	Trios Color (3Shape); Version 3.1.4 NP iTero (Align Technology); Version HD 2.9; NP True Definition (3M ESPE); no data on version. P	n = 5	Core Scanbody 2077 RC and 2088 WN (Core 3D centres); Handtightened

Reference scanner	Accuracy evaluation. results	Conclusions					
CMM Crista Apex (Mitu- toyo)	Comparison: DII (digital model) vs reference model	Angulated implants did not decrease digital impression accuracy. Impressions of implants placed at a depth of 0 mm?? were less accurate than deeper placed ones.					
	Implant depth		Mean error and standard deviation				
	0 mm		-23.1 ± 149.485 µm				
	2 mm		-16.2 ± 34.569 µm				
	4 mm		-27.9 ± 61.643 µm				
	First quadrant		-28 ± 153 µm				
	Second quadrant		-15 ± 30 µm				
Contact scanner Leitz (PMM 12106)	Comparison: DII (digital model) vs reference model	The Lava COS resulted in the smallest mean distance errors in full arch impressions. Lava COS had smallest angulation errors between cylinder 1–2 and the largest errors between cylinder 1–3. Although the absolute difference with the best mean value (iTero) was very small.					
	Absolute errors in distance between cylinders						
	CEREC Bluecam		iTero		Lava COS		
	1-2		1-3	1-2	1-3	1-2	1-3
	79.6 ± 77.1 µm		81.6 ± 52.5 µm	70.5 ± 56.3 µm	61.1 ± 53.9 µm	14.6 ± 12.7 µm	23.5 ± 14.2 µm
	Absolute errors in angle between cylinders						
	CEREC		iTero		Lava COS		
1-2	1-3	1-2	1-3	1-2	1-3		
0.6303 ± 0.5499°	0.4378 ± 0.3211°	0.3451 ± 0.3382°	0.4192 ± 0.1667°	0.2049 ± 0.0440°	0.4722 ± 0.1436°		
IScan D104I (Imetric3D GmbH)	Comparison: DII (digital model) vs reference model	No significant differences were found between partial and total edentulous models. CS 3500 intraoral scanner had the best result in terms of trueness and precision.					
	Scanner		Model 1	Model 2	Significance		
	Mean trueness						
	Trios Color		72.2 ± 19.5 µm	71.6 ± 26.7 µm	NS		
	CS 3500		47.8 ± 7.3 µm	63.2 ± 7.5 µm	S		
	ZFX Intrascan		117.0 ± 28.6 µm	103.0 ± 26.9 µm	S		
	Planscan		233.4 ± 62.6 µm	253.4 ± 13.6 µm	S		
	Mean precision						
	Trios Color		51.0 ± 18.5 µm	67.0 ± 32.2 µm	S		
	CS 3500		40.8 ± 6.4 µm	55.2 ± 10.4 µm	S		
ZFX Intrascan	126.2 ± 21.2 µm	112.4 ± 22.6 µm	S				
Planscan	219.8 ± 59.1 µm	204.2 ± 22.7 µm	S				
CMM (Model Global Silver Edition. Brown and Sharpe)	Comparison: DII (digital model) vs reference model	Between BL and TL groups BLCNV had the lowest global linear distortion, which was statistically significant. All TL groups were not significantly different. There were no significant differences in absolute angular distortions among all test groups.					
	Test group		Global linear distortion	Absolute angular distortion			
				Absdθ	Absdθ		
	BLCII		35 ± 6 µm	0.058 ± 0.031°	0.09 ± 0.082°		
	BLTrios Color		64 ± 10 µm	0.105 ± 0.058°	0.206 ± 0.044°		
	BLiTero		62 ± 18 µm	0.191 ± 0.124°	0.154 ± 0.113°		
	BLTrue Definition		63 ± 17 µm	0.315 ± 0.138°	0.226 ± 0.143°		
	TLCII		49 ± 10 µm	0.186 ± 0.161°	0.196 ± 0.147°		
	TLTrios Color		58 ± 11 µm	0.089 ± 0.039°	0.066 ± 0.033°		
	TLiTero		66 ± 34 µm	0.203 ± 0.094°	0.160 ± 0.121°		
TLTrue Definition	64 ± 16 µm	0.206 ± 0.115°	0.195 ± 0.140°				

Article	No. of implants. positions	Angulation	Placement depth (mm)	Implant manufacturer. connection	CII technique	DII technique: IOS; use of powder; scanning strategy	Number of impressions	Scanbody. torque value Ncm
Gintaute AM ³⁶ 2015	4. #34. #32. #42. #44	Parallel	No data	Osseotite 2 Certain Implants (Biomet 3i); Internal connection	OT. Sp. IL	True Definition Scanner (3M ESPE); Version 4.0.3.1. P		PEEK (Creattech Medical S.L.); No data on torque value
		2 anterior - parallel. 2 posterior - 40-45°						

VPS – polyvinylsiloxane; PE – polyether; CII – conventional implant impression; DII – digital implant impression; IOS – intraoral scanner; CMM – coordinate measuring machine; CT – closed tray; OT – open tray; IL – implant level; AL – abutment level; Sp – splinted; NSp – non-splinted; S – significant; NS – non-significant; BL – bone level; TL – tissue level; Absd – absolute angular distortion; P – powdered; NP – non-powdered.

The *In vivo* study evaluated accuracy of multi-unit DII (two implant-supported bar in the edentulous mandible) in 25 patients. The scanning procedure was done with iTero IOS, after detaching the bars, using a defined scanning strategy. Definitive casts, which had been used for the fabrication of bars, served as reference casts. Authors presumed that the maximum acceptable horizontal misfit and angulation errors, considering two implant-supported restoration, should not exceed 100 µm and 0.4° respectively³².

Of 15 included *in vitro* studies, two evaluated accuracy of single-unit and 13 evaluated the multi-unit DII. As for multi-unit DII, three studies used models with two implants^{46,49,39}, two had three implants^{50,40}, one was with 4 implants³⁶, two were with five implants^{47,49}, and seven used models with six implants^{33–35,42,43,48,40}. Five of the studies evaluating the accuracy of full-arch DII from six implants, used the identical model^{33–35,42,43}. Five studies evaluated the influence of operator experience and implant placement depth^{33–35,42,43}, nine evaluated implant angulation^{33–36,41–43,46,47}, eleven the distance between the implants^{33–37,41–43,39–40}, and one looked at the influence of scanning protocol⁴².

■ Main findings

The majority of included studies indicated the importance of error accumulation process throughout the

digital workflow. Lack of reference points, scanbody design, scanned surface characteristics, sensor size, scanning strategy, software and some other factors were considered to affect accuracy. The factors potentially influencing the DII accuracy are summarised in Figure 2.

A workflow to produce indirect restoration in the laboratory starts from the time of impression. Therefore, accuracy of the impression is one of the most important aspects. If inaccuracies build up this could lead to misfits and strains in the final restoration. As the threshold for a clinically acceptable misfit is not defined clearly, it is difficult to judge the accuracy of DII, reported in the included studies, as clinically acceptable or not. In the literature, misfit of the implant-supported restoration of 100 µm or less is often considered as clinically acceptable⁵¹. However, level of the acceptable misfit could relate to the extent of the implant-supported restoration¹⁴. Different IOS utilising various data acquisition principles were investigated in the included studies. A summary of separate accuracy measurements collected from included studies is presented in Figures 3 and 4.

In vivo study

According to the results of only one *in vivo* study included, due to a poor reference points caused by the mucosa of edentulous sites with little variation

Reference scanner	Accuracy evaluation. results		Conclusions	
CMM Crista Apex (Mitutoyo)	Comparison: DII (digital model) and CII (digitised VPS and PE models) vs reference model		Digital and conventional impression-making approaches (with polyether and VPS materials) are applicable for straight and tilted dental implants.	
		Distance deviation		Angulation deviation
	Model 1			
	DII	9.46 ± 16.04 μm (NS)		0.17 ± 0.14° (S DII vs PE); S DII vs VPS)
	VPS	12.74 ± 12.5 μm (NS)		0.07 ± 0.1°
	PE	12.22 ± 16.93 μm (NS)		0.08 ± 0.07°
	Model 2			
	DII	35.78 ± 24.22 μm (S DII vs VPS)		0.22 ± 0.19°. (NS DII vs VPS)
	VPS	4.87 ± 21.34 μm		0.04 ± 0.04°. (S)
PE	19.78 ± 21 μm	0.16 ± 0.1 6° (S)		

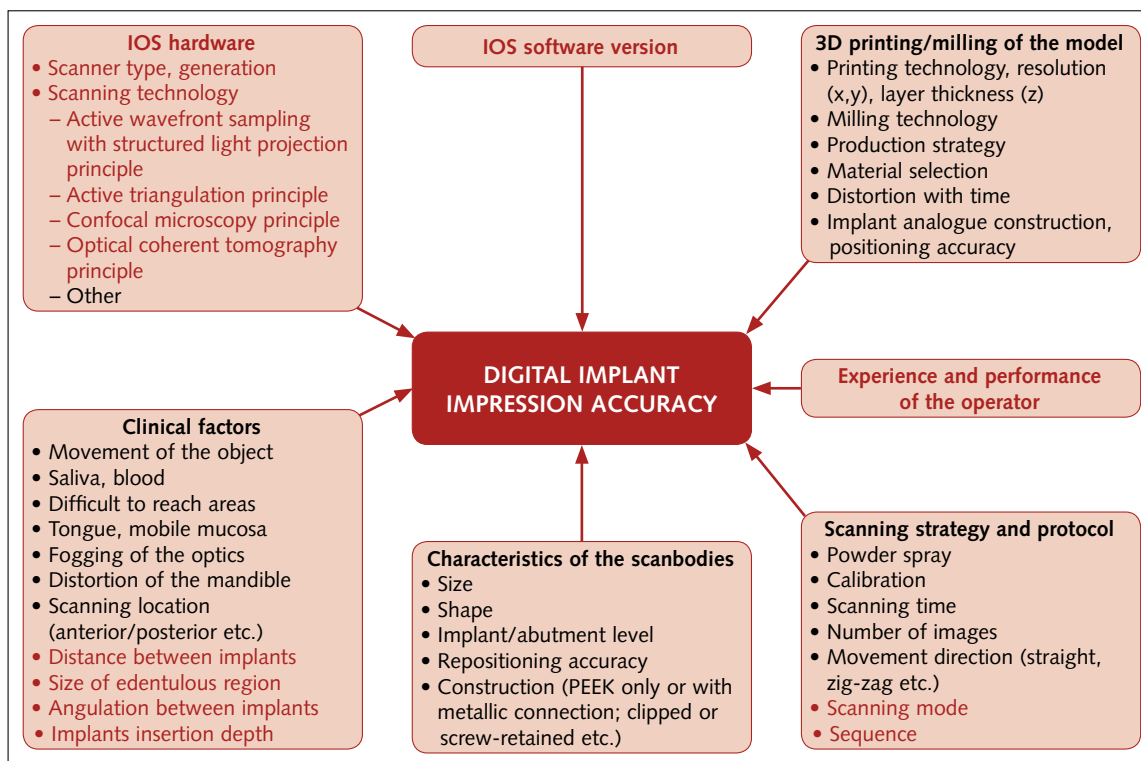


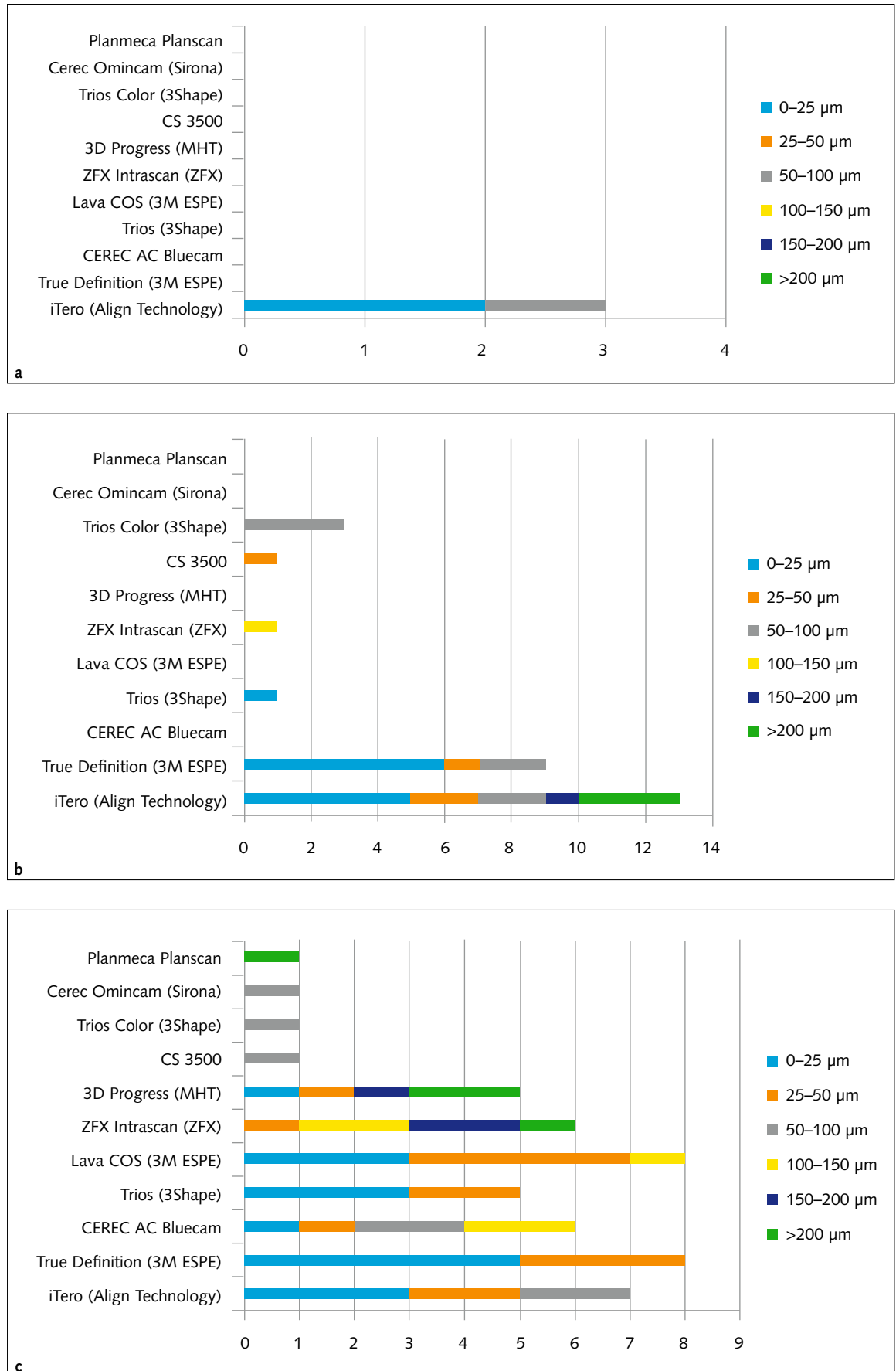
Fig 2 Main factors potentially affecting accuracy of digital implant impressions (DII). Items presented in red were investigated in the included studies.

in texture and height, digital impressions of four patients were impossible to perform³². Only in five cases were no optical irregularities of the IOS scans noticed. It was concluded that mean angular and distance errors were too large to be clinically acceptable.

In vitro studies

Two studies comparing models made from DII and CII for single-unit implant crowns reported different results. One study indicated significant change in the vertical position (93 μm) of the implant analogue in milled models⁴⁵, while in another the mean error was comparatively small, but with a larger

Fig 3 Digital implant impressions for: a) single-unit cases, b) FPD cases, c) fixed full-arch cases. Number of results reporting different linear absolute mean error intervals with certain IOS.



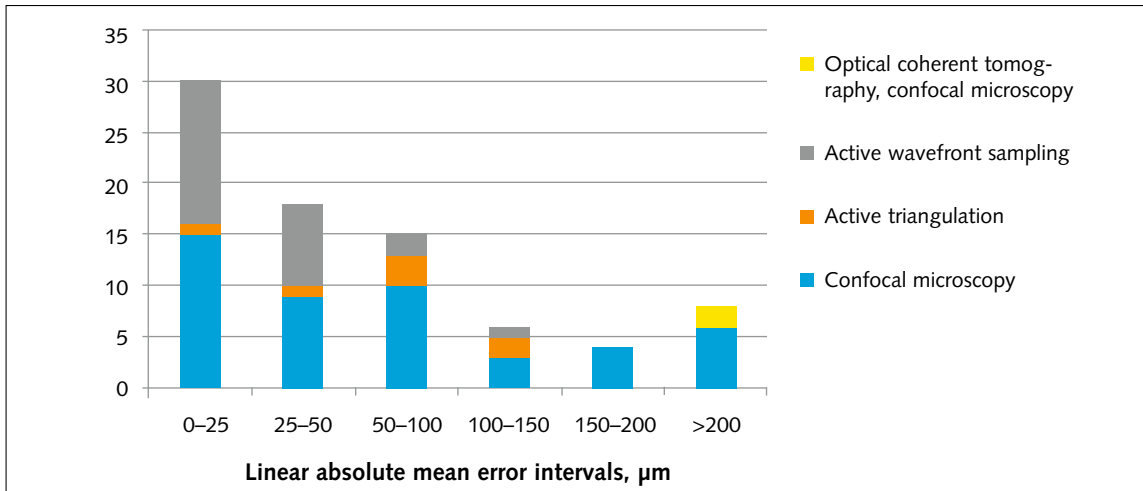


Fig 4 Number of results reporting linear absolute mean error intervals with different scanning technologies.

standard deviation: $14 \pm 170 \mu\text{m}^{45}$. These results could not be considered as clinically acceptable, however reported deviations are the net result of inaccuracies introduced during digital impression taking, milling of the model, and positioning of the implant analogue. One of these studies also compared deviations between DII and the reference model (isolated assessment of only DII accuracy), and the difference was considerably smaller – $-6 \pm 40 \mu\text{m}^{46}$. Analysis of the accumulated errors in the digital workflow showed that the largest source of inaccuracy was the milling process (contributed SD is $\pm 98 \mu\text{m}$) followed by the DII (contributed SD is $\pm 21 \mu\text{m}^{44}$). Therefore, other factors besides DII could be responsible for less consistent results reported in these studies.

Thirteen studies investigated the accuracy of DII for multi-unit implant-supported restorations. Mean errors of several IOS used in five of these studies was higher than $100 \mu\text{m}^{34,35,46,40,48}$.

The results diverged with older generation IOS used in the included studies (Lava COS, iTero, Cerec Bluecam, 3D Progress, ZfX Intrascan), as there were studies reporting deviations above^{34,35,46,48} and below^{33,37,42} $100 \mu\text{m}$.

Different results could be explained by methodological differences as well. One of the studies reporting adequate results used less clinically relevant full-arch models, with between distantly oriented scanbodies, dentate segments, avoiding simulation of edentulous areas³⁷. Remaining teeth in between the implants could help as reference areas, facilitating stitching of the images and, possibly, improving

the accuracy. In contrast, a study utilising the single-implant model reported higher mean errors with iTero IOS for single-unit implant situation, as measurements were done on the model milled from polyurethane material based on DII data. Thus, error accumulation during fabrication of the model was inevitable⁴⁶.

All studies analysing IOS of the newer generation (Trios, Color, True Definition, Cerec Omnicam, CS3500) reported deviations of less than $100 \mu\text{m}^{36,43,47,48,40}$. Interesting to note, was that all of these studies employed full-arch models with four to six implants. However, the accuracy of Planscan IOS was significantly less – $253,4 \pm 13,6 \mu\text{m}$ for the full-arch situation⁴⁰.

One study investigated only precision of DII with three different IOS⁴¹. It was concluded that the precision of IOS tested (iTero, Trios, True Definition) was significantly different, and decreased with increasing distances between the scanbodies.

Some of the included studies explored the influence of angulated implants on the accuracy of DII^{33–36,42,43,46,47}. Reference models in these studies had implants angulated from 10° ⁴⁷ to 45° ³⁶. The clinically acceptable threshold for the angle deviations generated during impression procedure is not defined in the literature. However, based on simple trigonometrical calculations (and assuming that the maximal lateral apex movement of $50 \mu\text{m}$ is acceptable), one study³² suggested that up to 0.4° angle deviation between implants could be acceptable, with total length of the implant of 14.8 mm . The majority of *in vitro* studies included in this systematic review

used shorter implants for the reference models. In the case of shorter implants, larger inter-implant angle deviation can possibly be accepted, as this angle can be defined by the formula: $2 \times \arctan(0,05/L)$ (implant length in mm). Two studies have reported higher deviations in angulation (up to 1.6°)^{37,46}, while recent studies using newer generation of IOS indicated much smaller angle deviations (0.07 to 0.3°)^{36,43,39}.

The depth of implant placement as a factor was also considered in the included studies. Supragingival⁴⁶, equigingival^{33–35,37,42,43} and 2 to 4 mm subgingival^{33–35,42,43} implant positions were used.

In summary, the included studies reported that DII accuracy was influenced by implant angulation⁴⁶, distance between the implants⁴³, implant placement depth^{33,43}, and scanning mode⁴². Most studies investigating impact of operator experience concluded that this aspect was of significant importance^{33,34,42,43}.

Studies comparing accuracy of newer generation IOS (True Definition, Trios) with conventional impressions for partial- and full-arch implant-supported dental restorations, indicated that the accuracy of DII did not significantly differ from CII and could serve as a viable alternative^{36,47,39}. Accuracy of implant-level, non-splinted CII was reported as being even less accurate compared with DII⁴⁷.

■ Discussion

To our knowledge, this is the first systematic review addressing DII accuracy. Results of this review are important, as intraoral implants and IOS are both used extensively in practitioners' clinical practice. IOS offers many new diagnostic and treatment workflows. Originally aimed at making the optical impression from the teeth, IOS has now become multifunctional instruments, which are able to measure the shade and work as intraoral cameras etc. Keeping the patient data unchanged for a long time, sharing it with treatment team members, following-up the patient condition objectively, integrating IOS data with data from CBCT, laboratory scanner, face scanner and photos, are among the few options IOS can offer today.

The number of publications related to the various uses of IOS is rapidly increasing. Patient- and

dentist-centred and efficiency outcomes are also being investigated^{52,53}. However, one of the main goals is to improve the accuracy of the digital workflow and to achieve aesthetic and functional restorations with minimal effort.

Digital workflow is still susceptible to errors, which can come from the digital impression and CAD/CAM software, as well as production (subtractive or additive) processes. Although manufacturing techniques have become very accurate, they still depend on the accuracy of the impression and master model. IOS are an integral part of the digital workflow; therefore accuracy is an essential requirement.

As the evidence on accuracy of DII is lacking, a thorough search was conducted in order to identify relevant publications. Strict criteria were applied for the studies, with accuracy measuring methodology described in detail. Despite the growing popularity of IOS devices, only one *in vivo* and 15 *in vitro* studies evaluating the accuracy of DII were identified.

While the *in vivo* study showed that accuracy of DII is not adequate for clinical applications, the majority of *in vitro* studies showed less than 100 μm deviations. This could also indicate significantly different conditions for *in vitro* and *in vivo* environments.

The only *in vivo* study used an older generation scanner. According to the *in vitro* results, newer versions of the scanners performed considerably better. Accuracy of these scanners was evaluated with partial- and full-arch models containing from two to six implants. A study comparing DII (obtained by True Definition and Trios) with a reference model containing six implants, reported values for trueness and precision ranging from 28 μm to 35 μm ⁴⁸. DII (True Definition) from four parallel mandibular implants did not statistically significantly differ from CII, however with distal implants tilted, statistically significant differences were detected³⁶. As absolute values of these differences were approximately 30 μm , it can be concluded these differences could be of limited clinical significance. Based on this, IOS seem to become a reliable alternative to conventional impressions for the selected indications. However, results of this review should be interpreted with caution, as there are several limiting factors. Only one *in vivo* study satisfied inclusion criteria³². iTero IOS was used for DII and stitching problems leading to the

deformed image of the scan abutment, as described by the authors. The information is lacking if the accuracy of definitive models was rechecked by again fitting the bar to the model, as the true reference is difficult to obtain in *in vivo* studies, and this remains one of the challenges for the clinical evaluations. Hypothetically, trueness of the DII data could be better, but still deviate from the potentially less accurate model fabricated from the conventional impression. Moreover, at the time of this systematic review, a new version of the scanner used in this *in vivo* study became available, claiming much faster and more accurate scanning in colour. As the older version of the scanner and software were used, the findings of the study are therefore less relevant today.

In vivo use of IOS could be compromised by many aspects: movements of the object, saliva, fogging of the optics, and other patient-, operator- and device-related limiting factors. Scanning location can be important, as distant regions could be difficult to reach in a real clinical situation. Length of the edentulous ridge, lack of attached gingiva, tongue and cheek mobility could also negatively affect the ability to stitch the images. Scanning strategy and mode were also proved important aspects^{42,55}. A recent study showed that intraoral scanning was less precise than model scanning⁵⁴.

Comparison of the results of the *in vitro* studies could also be limited by disparities in study design, the models and techniques used. IOS can utilise several different technologies: confocal microscopy, optical coherence tomography, active and passive stereovision/triangulation, phase-shift principles, accordion fringe interferometry, etc³⁶. Different IOS systems with different software versions compromise the comparisons further. Moreover, no studies have been published with other new IOS systems – DWIOS, Condor, CS3600, Aadva, Trios 3 and many others. In this regard, there is a big difference between DII and CII, as the principles of conventional impression taking do not change that dramatically with time, and features of the products from different companies are relatively less different compared with IOS.

Accuracy of DII can also be affected by other factors. Characteristics of the scanbodies could be another source of errors. Shorter and less visible scanbodies can negatively influence the accuracy⁵⁶.

It was recommended that longer scanbodies should be used with deep-placed implants⁴³. One of the studies included in the systematic review used longer scanbodies, which could also contribute to better-measured accuracy⁴⁷. Sharp angles of the scanbodies could negatively influence scan accuracy. One study was excluded from the review, as healing abutments instead of scanbodies were used, making the results of this study less relevant³⁸.

Spraying of the scanbodies with powder is still needed for some of the IOS to reduce the reflections and aid the stitching of the images. Powdering could potentially influence the accuracy of scanning through homogeneity and thickness of spray. It was reported that experienced clinicians achieved greater homogeneity and thinner coatings⁵⁷. Therefore it is recommended to use only light dusting on the surfaces to be scanned. As powder could be inhaled by the patient and clinician or swallowed by patient, more information is needed about the effect of it on human health⁵⁸.

Similarly, as with conventional impressions, type of the implant-abutment connection can influence the accuracy. External implant – abutment connection was reported to provide more consistent accuracy for CII²⁵. Only one of the included studies investigated DII accuracy with external connection implants⁴⁸.

A potential effect of embedment relaxation and manufacturing tolerances should be taken into consideration when selecting prosthetic components⁵⁹. Repositioning accuracy of scanbodies could have an effect on the accuracy of the DII. It was reported that the ability of repositioning of the scanbody is better on lab analogues than on original implants⁶⁰. However, other authors suggested that the precision of implant scanbody scanning was not significantly influenced by detachment and repositioning of the scanbody⁵⁶. Not all the studies standardised the use of the scanbodies (eg, tightening ranged from finger tightening to 15 Ncm) and this could act as an additional variable. Also, it could be hypothesised, that scanbodies with metallic base should have better repositioning accuracy as compared with fully plastic scanbodies.

Three studies evaluated accuracy of milled models obtained from DII^{44–46}. It appeared that milling and positioning of implant analogues resulted in bigger deviations as compared with reference model. None of these studies described milling parameters they have used to fabricate the models. Also, information

about implant analogues dedicated for milled models was lacking. No publication was identified, utilising 3D printing to fabricate the model from DII data. As models are necessary for layered restorations, occlusal adjustments etc., more research is needed to define milling and printing parameters in order to avoid inaccuracies and increase applications of IOS.

Despite good accuracy results reported by *in vitro* studies, digital workflow based on DII is still lacking some reliable conventional solutions – use of verification jigs to validate the master model, easy and reliable recording of the emergence profile, validated techniques to record static and dynamic occlusal relationships, etc. Recent studies also identify the significance of inaccuracies of occlusal contacts of stereolithographic models fabricated, based on data from IOS⁶¹.

Although scientific literature is struggling to keep up with the newest IOS developments, due to positive clinical experience, constantly increasing opportunities with digital workflow and marketing, its use in clinical practice is growing fast. Further IOS improvements need to be done in order to replace conventional techniques and increase the potential of digital workflow, especially in partially and fully edentulous patients.

■ Conclusions

1. Within the limitations of this systematic review (one *in vivo* and 15 *in vitro* studies identified), it can be concluded that digital implant impressions offer a valid alternative to conventional impressions for single- and multi-unit implant-supported restorations;
2. *In vivo* studies investigating the accuracy of newest available IOS are needed to further define their clinical indications;
3. Factors potentially affecting accuracy of digital implant impressions should be more extensively described and investigated in clinical studies;
4. Due to the constant changes in IOS hardware and software, reliable methodology, representing less forgiving *in vivo* situations should be defined to timely evaluate and compare trueness and precision of modern IOSs, and to provide clinical guidelines;
5. Digital implant impression techniques still have to be improved in order to fully substitute conventional ones;
6. Further studies are needed to investigate the accuracy of digital interocclusal records and master model production methods (milling, 3D printing) to ensure clinically acceptable results.

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Misfit of implant prostheses and its impact on clinical outcomes. Definition, assessment and a systematic review of the literature

Key words *clinical outcome, fixed dentures, implant prosthesis, interface, microgap, misfit, passive fit, precision, systematic review*

Background and aim: Compromised fit between the contact surfaces of screw-retained implant-supported fixed dentures (IFDs) is thought to create uncontrolled strains in the prosthetic components and peri-implant tissues, thus evoking biological and technical complications such as bone loss, screw loosening, component fractures and, at worst, loss of implants or prostheses. The aim of this systematic review was to evaluate the impact of marginal misfit on the clinical outcomes of IFDs, and to elucidate definition and assessment methods for passive fit.

Materials and methods: A systematic review of the literature was conducted with a PICO question: "For partially or complete edentulous subjects with screw-retained IFDs, does the marginal misfit at the implant-prosthesis interfaces have an impact on the clinical outcomes?". A literature search was performed electronically in PubMed (MEDLINE) with the help of Boolean operators to combine key words, and by hand search in relevant journals. English written *in vivo* studies published before August 31, 2016 that reported on both clinical outcome and related implant prosthesis misfit (gap, strains, torque) were selected using predetermined inclusion criteria.

Results: The initial search yielded 2626 records. After screening and a subsequent filtering process, five human and five animal studies were included in the descriptive analysis. The selected studies used different methods to assess misfit (linear distortion, vertical gap, strains, screw torque). While two human studies evaluated the biological response and technical complications prospectively over 6 and 12 months, the animal studies had an observation period < 12 weeks. Four human studies analysed retrospectively the 3 to 32 years' outcomes. Screw-related complications were observed, but biological sequelae could not be confirmed. Although the animal studies had different designs, bone adaptation and implant displacement was found in histological analyses. Due to the small number of studies and the heterogenic designs and misfit assessment methods, no meta-analysis of the data could be performed.

Conclusions: The current literature provides insufficient evidence as to the effect of misfit at the prosthesis-implant interface on clinical outcomes of screw-retained implant-supported fixed dentures. Marginal gaps and static strains due to screw tightening were not found to have negative effects on initial osseointegration or peri-implant bone stability over time. Based on two clinical studies, the risk for technical screw-related complications was slightly higher. While the degree of tolerable misfit remains a matter of debate, the present data do not imply that clinicians neglect good fit, but aim to achieve the least misfit possible.

Conflict of interest statement: *The authors declare no conflict of interest. The review was conducted as part of the 2016 Foundation of Oral Rehabilitation Consensus Conference on "Prosthetic Protocols in Implant-based Oral Rehabilitation".*



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■ Introduction

■ Background

Edentulous and partially edentate patients may benefit from additional treatment options offered by implant-supported removable and fixed dentures¹⁻⁵. Although the aesthetic aspects, especially in the anterior maxilla, have often become of highest importance in patients' perspective, a predictable outcome with healthy and stable biomechanical conditions is a prerequisite for a successful long-term result. While multiple clinical studies have reported on the survival and success rates of various implant systems⁶ and related reconstructions^{7,8}, it is generally difficult to estimate the impact of the specific factors that may have been associated, triggered by, or even causative to the adverse events. Compromised fit between the contact surfaces of screw-retained implant-supported fixed dentures (IFDs) is thought to create uncontrolled strains in the components and peri-implant tissues, thus evoking biological and technical complications such as bone loss, screw loosening, component fractures and, at worst, loss of the implants, the prosthesis, or both. The most frequent technical complications in full-arch reconstructions reported in a recent review article were screw fracture (yielding a 5-year complication rate of 10% and a 10-year rate of 21%) and chipping or fracture of the veneering material (33% at 5 years and 67% at 10 years)⁹. The role of passive fit or misfit of an implant reconstruction among the various factors has been controversially discussed in the past¹⁰⁻¹⁵. Opinion leaders have already stated in the early days of osseointegrated oral implants that marginal discrepancies of 10 μm ¹⁰ to 150 μm ¹¹ would be clinically acceptable in the long-term. From a biological point of view, the gap size should be smaller than any periodontally harmful bacteria (< 2 μm)¹⁶. However, all these suggestions are of theoretical or empirical origin, lacking clear evidence. Thus, the aim of this review was to systematically evaluate the impact of marginal misfit on the clinical outcome of IFDs, and to elucidate definitions and assessment methods for passive fit.

As different opinions exist about what a "clinically acceptable" fit of a prosthesis is, the term "passive fit" and further aspects within this context

needed to be clarified before the actual literature was screened for studies comparing the clinical outcome of passively vs non-passively fitting implant prosthesis. These are the different fabrication workflows including digital technologies, the definition of passive fit, the clinical and *in vitro* assessment methods, as well as the characteristics and requirements of a screw-retained implant prostheses.

■ Fabrication workflow

Before computer assisted design/computer assisted manufacturing (CAD/CAM) technology became commercially available, the lost wax technique for metal alloy frameworks was the gold standard. The accuracy of this conventional workflow depends mainly on physical material properties (impression, master model, casting) and human-related factors (timing, manual handling), thus, it is prone to an unpredictable degree of distortion^{17,18}. In comparison, the digital workflows are less influenced by manual errors and have fewer steps to follow, although also digital procedures (scanning, transfer) and milling may lead to minor imprecisions (Fig 1)¹⁹⁻²¹. The issue with casting, however, is its technique sensitivity and physical distortion, which can result in a poor prosthesis fit. The longer the span is, the greater the distortion and subsequently the misfit may occur. Therefore, short-span IFDs were preferred. The expert statements of an early International Symposium organised by the European Osseointegration Training Center in 1993 reflect the casting issues and the intensive thinking of 25 years ago²². In the early days of the computer numeric controlled (CNC) technology, a precise framework fabrication with the so-called "Procera-Method" was considered a promising alternative²³ to the traditional cast technique (and its different approaches to overcome the distortion problem by sectioning and passively reconnect the separate segments). The Procera technology was considered to be accurate but required a great deal of apparatus and effort, rendering it unfavourable at the time²³.

Meanwhile, CAD-software, CAM-machines, knowledge and experience have developed, and systems have become affordable and easier to use. In the past decade, the accessibility to CAD/CAM technology in dental offices and laboratories has

significantly increased. IFD frameworks and bars are milled out from one industrially produced homogeneous blank, providing highest material quality. As different studies^{18,24-32} have shown that the fabrication accuracy of short and long span CAD/CAM frameworks, bars or even full-contour reconstructions made from different materials (titanium, zirconium dioxide, cobalt chromium) are more accurate than the cast ones, this fabrication method is considered the standard method today.

■ Definition of “passive fit”

Various definitions of “passive fit” can be found in literature^{10-13,33,34}. Perfect passive fit is achieved when the opposing surfaces of the implants and the framework intaglio are in maximal spatial congruency, without strains in the components after tightening of all screws, provided the implant and framework surfaces are fabricated perfectly plain (Figs 2a to 2d). In consequence, non-passive fit may be; a) measured at this interface by linear^{25,30}, volumetric^{17,35}, and metrological³⁶ methods before screw tightening using the one-screw test; b) by

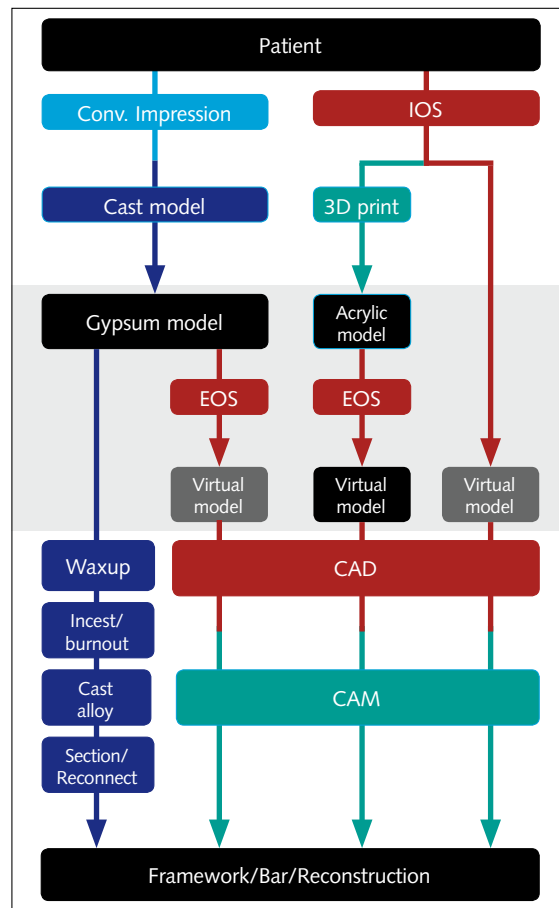
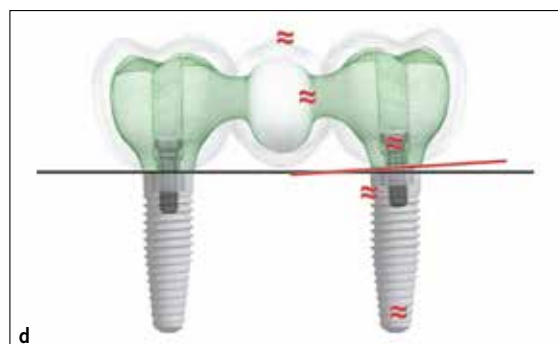
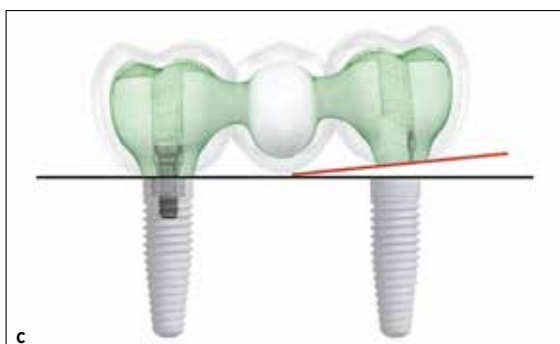
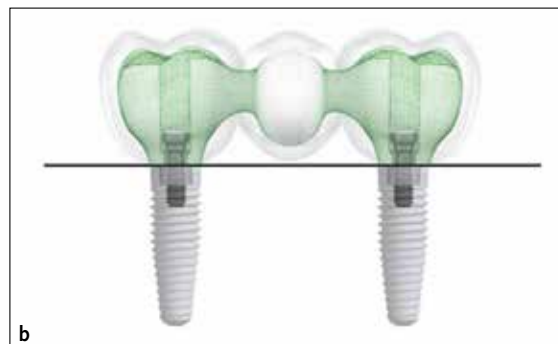
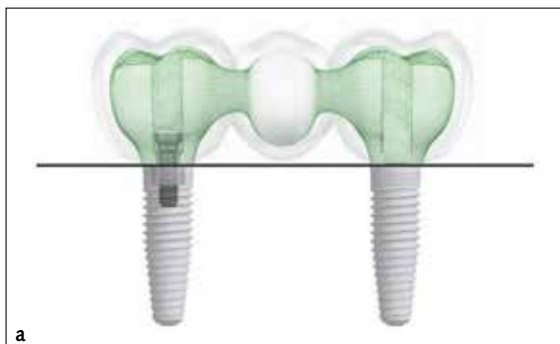


Fig 1 Conventional and digital workflows for the fabrication of the working model (grey box) and the final implant reconstruction. Each box corresponds to a working step (blue: manual, red: digital, green: CNC machine) with potential dimensional errors. (EOS: Extra-oral scanner (laboratory scanner); IOS: Intra-oral scanner).



Figs 2a to d Schematic illustration of a screw retained implant-supported fixed denture (IFD) and the two related implants. The perfectly fitting IFD shows passive fit in the one-screw test (a) and in the final position with all screws tightened (b). The ill-fitting IFD shows a certain gap at the interface in the one-screw test (c) and in the final position a non-passive fit with strains in the components (screw, framework, veneer, implant, bone) and a remaining micro-gap at the interface (d).

Table 1 Proposed fit and misfit classification according to reported assessment techniques.

Fit/misfit	Before screw tightening: ¹⁸ Gap size at the interface (vertical and horizontal)	During screw tightening or loosening: ¹⁴ Rotation (°) to final load (+ screw torque monitoring)	After screw tightening: ⁴⁰ Strains in the pontic	Fabrication feasibility and clinical acceptance
Perfect	0 µm	Small final rotation ° (Screw torque initial: low, final: steep increase)	0 µm/m	Theoretical
(Very good)	< 25 µm		< 25 µm/m	3-unit IFD
Good	< 50 µm	< 45° final rot.	< 50 µm/m	4-9-unit IFD
Fair	50–100 µm		50–100 µm/m	Complete IFD
Moderate	100–150 µm		100–150 µm/m	Not acceptable
Poor	> 150 µm	> 90° final rot.	> 150 µm/m	Not acceptable
(Very poor)	> 200 µm	Great final rotation ° (Screw torque initial to final: constantly high and increasing)	> 200 µm	Not acceptable

monitoring the screw torque during the tightening of each screw and the final rotation (degrees) to reach the recommended torque,¹⁴ and; c) by measuring the consequences after all screws are tightened and the prosthesis has reached its final position at the recommended screw torque, i.e. strains^{33,37,38} in the biological and prosthetic components (screw, framework, implant, peri-implant tissues). A linear relationship between vertical misfit and strain magnitude was observed without influence by the framework material at a certain misfit³⁹. The term “active fit” refers to this fit at the final position. In Table 1, a misfit classification is proposed against the background of today’s fabrication feasibility based on recent studies^{14,18,40}.

■ Clinical *in situ* assessment methods

The chairside possibilities to assess the fit of implant-retained prosthesis are limited. The prosthesis may be positioned on the implant replicas in the master model before intraoral *in situ* try-in of the implants. As discussed earlier, several steps in the workflow, either conventional or digital, may lead to a distorted model and thus to an insufficient representation of the intraoral situation (Fig 1). In Table 2, the most important clinical assessment methods and their limitations are summarised. Other additional methods (disclosing media, floss) can be useful when the implant-prosthesis interface is not positioned sub-, but epi- or supra-gingivally, and abutments are used to correct for the axis and

connection level^{12,34}. At a working distance of 25 cm, two points as close as 100 µm to each other can be distinguished as individual points by naked eye²⁴. With the help of 2x magnification lenses a sensitivity of 50 µm can be expected at the same distance. However, visual assessment is difficult or impossible for subgingivally positioned and conical type implants. For interfaces not accessible to direct vision, tactile discrimination methods with the help of an explorer may be useful to a certain degree. However, vertical gaps < 50 µm are difficult to determine using a worn (> 100 µm tip) or even a brand new explorer with a tip as small as 40 µm^{41,42}. The radiographic assessment allows visualising interfaces that are positioned deeply subgingival and impossible for direct vision and tactile exploration^{43,44}. Although a paralleling device helps the clinician to more accurately evaluate the implant-abutment interface⁴⁵, radiographic assessment with a tube angulation > 10 degrees becomes subjective for most implant types^{46,47}. Furthermore, conical implant connections may be more difficult to assess. During final prosthesis installation, one screw is tightened after the other with a system depending on maximal torque. Screw resistance can be subjectively assessed by hand tightening and, more objectively, with specific devices for torque-angle monitoring^{14,48,49}.

The specificity and sensitivity to determine fit/misfit with one method alone may not be sufficient, but it can be improved by combining different chairside techniques.

Table 2 Clinical in situ assessment methods on the fit of prosthesis requiring only basic chairside equipment. One-ST: one screw test, All-ST: all screw test.

Assessment method	Screw retention	Criteria	Limitations
Visual (Eye, binoculars)	None (One-ST) (All-ST)	Macroscopic gap visible	<ul style="list-style-type: none"> – Subgingival interface/mucosa interposition – Conical connection – Age > 40 years/visus – Experience – Light, angle, background – Quantitative discrimination
Tactile (Alternate finger pressure)	None (One-ST)	Lifting, Rocking, Motion Saliva movement	<ul style="list-style-type: none"> – Subgingival interface/mucosa interposition – Close implant position – Linear implant position – Conical connection – Experience – Inconsistent – Quantitative discrimination
Tactile (Explorer)	One-ST All-ST	Tactile discrimination	<ul style="list-style-type: none"> – Subgingival interface/mucosa interposition – Conical connection – Clinician's discriminatory ability – Explorer worn tip > 100 µm – Experience – Inconsistent – Quantitative discrimination
Radiographical (Periapical)	One-ST All-ST	Macroscopic gap visible	<ul style="list-style-type: none"> – Non-perpendicular alignment/angulation – Overlapping components – Radiolucent components – Knowledge on system – Experience – Analogue: size and contrast – Digital: filter effects
Screw retention	Serial screwing	Resistance while screwing up to final torque: none/steep vs consistent/flat	<ul style="list-style-type: none"> – Subgingival interface/mucosa interposition or pressure – Conical connection – Clinician's discriminatory ability – Ranking of serial screwing – Experience – Inconsistent – Quantitative discrimination

■ Laboratory *in vitro* assessment methods

Model-based assessment of prosthesis fit can be performed either with direct methods (light microscope, scanning electron microscope, strain measurements, screw-torque analysis) or with a virtual approach using accurate extraoral scanners and specific software for superimposition. Virtual analyses (linear distance, volumetric gap, metrological visualisation) are usually based on a best-fit algorithm. However, model-based methods may only assess the second part of the workflow (Fig 1). If digitised patient data from an intraoral scanner are used, then the entire workflow may be included. The same goes for the photogrammetric 3D approach, as reported by Jemt⁵⁰.

■ Screw-retained implant-supported fixed dentures (IFDs)

Teeth have a physiological mobility of 100 to 150 µm within the periodontal ligament that may reduce stress patterns from an inaccurate framework fit. Additionally, cement-retained (dental or implant-borne) reconstructions require an internal gap of approximately 25 to 50 µm for the cement material, which also eliminates strains in the components. In contrast, screw-retained implant reconstructions will neither benefit from a cement layer, nor from a peri-implant ligament buffer. Thus, a maximal (theoretically perfect) passive fit of the opposing surfaces at the implant-reconstruction interface should be the aim. Static stress resulting from a poorly fitting reconstruction will be directly transmitted to the implant components and the peri-implant bone, and

will be exacerbated by any dynamic loading in clinical use¹³. The contact area in single implant restorations is circumferential and may have a flat horizontal or a conical surface, depending on the implant geometry. The maximal fit of the components (abutment) at a single implant site therefore depends on the possible fabrication accuracy at an industrial CAD/CAM centre. Adverse biological and technical events as an effect of the micro-gap and movement under dynamic loading condition have been investigated earlier. Crestal bone remodelling has been observed for either internal and external, or conical and butt-joint connections. There was a trend favouring the platform-switching concept⁵¹ and supracrestal positioning of the implant-abutment interface⁵² to prevent or minimise peri-implant marginal bone loss. In contrast, no evidence was identified in another systematic review about the effectiveness of these designs (scaloped implants, platform-switched implants and gingivally converging or concave implant abutments) in preventing marginal bone loss and soft tissue recession⁵³. Furthermore, the size of the micro-gap at single implant does not seem to influence the crestal bone resorption, unlike possible movements between implant and abutment⁵⁴. The results of a recently published systematic review show that abutment screw loosening is a rare event in single-implant restorations regardless of the geometry of implant-abutment connection, provided that proper anti-rotational features and torque are employed⁵⁵. Further *in vitro* studies investigate bacterial leakage and colonisation of the interior implant space; mostly with single implant crowns that do not fully resist occlusal load⁵⁶.

Zirconia frameworks milled in the pre-sintered stage have to anticipate subsequent final sintering shrinkage. This step may include a certain inaccuracy, depending on the span length¹⁸. Most implant systems offer a hybrid solution for zirconia reconstructions by inserting an additional (often, but not always, cemented) titanium base facing the implant platform. This base may be considered as a very flat standard abutment introducing a new cement interface that has been polished in the laboratory. Although, this base is usually fixed on the master cast and not intraorally, it may reduce strains. Another aspect that needs to be mentioned

in mandibular full-arch implant prosthesis is the mandibular deformation of up to 420 µm in the posterior area and force transmission of up to 16 N as a result of jaw movement from the rest position⁵⁷. Therefore, 3D implant relation is not stable during mandibular jaw movement and strains will inevitably occur.

■ **Materials and methods**

This systematic literature review was conducted in accordance with the guidelines of Preferred Reporting for Systematic Reviews and Meta-Analyses (PRISMA)⁵⁸.

■ **PICO question**

The PICO (patient, intervention, comparison, outcome) question was: "For partially or fully edentulous subjects with screw-retained IFDs, does the marginal misfit at the implant-prosthesis interfaces have an impact on the clinical outcomes?"

■ **Search method**

An electronic search was conducted independently by two reviewers (JK, TT) on the PubMed (MEDLINE) database for articles published in English language through to August 31, 2016. The following four groups of key words were combined using Boolean operators: (clinical outcome OR biological complication OR mechanical complication OR bone loss OR peri-implantitis OR screw loosening OR fracture OR failure) AND (framework OR prosthesis OR bridge OR bar OR component OR abutment) AND (fit OR fitting OR misfit OR gap OR precision OR accuracy) AND (implant OR implants). Additional relevant articles were searched manually in the following journals accessible online at the University of Bern: Clinical Implant Dentistry and Related Research, Clinical Oral Implants Research, European Journal of Oral Implantology, International Journal of Oral & Maxillofacial Implants, International Journal of Prosthodontics, and Quintessence International. The reference lists of the selected articles were assessed for possible further eligible studies.

Table 3 Clinical outcome classification for the biological and technical complications.

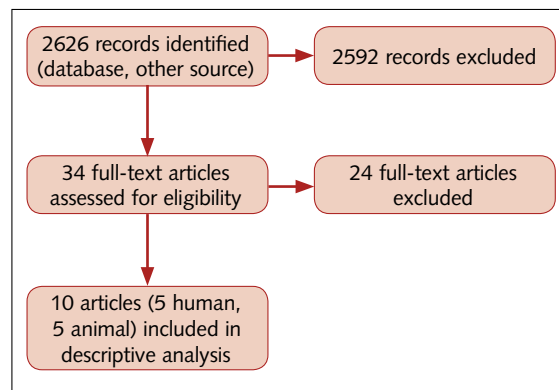
Type	Complication degree	Biological complication	Technical complication	Treatment options
I	Catastrophic, non-repairable	- Peri-implantitis with extensive bone resorption - Loss of osseointegration (aseptic) - Recurrent fistulae, etc.	- Fracture of implant body - Fracture of reconstruction - Major chipping	- Removal of implant and reconstruction - New treatment/retreatment
II	Major, repairable	Peri-implantitis with moderate bone resorption	- Fracture of occlusal screw - Minor chipping or fracture of framework not at the interface	- Repair, corrective intervention, additional material required
III	Minor, repairable	Mucositis/minor peri-implant inflammation without bone loss	- Screw loosening - Moving reconstruction	Hygiene and maintenance instruction, adaptation

■ Inclusion criteria

Clinical studies with a prospective and retrospective design were included if they provided information on the clinical outcome and the related prosthesis fit together. Additionally, animal studies with the same information were also analysed. In detail, studies were included if the following information was reported:

- *In vivo* study (human or animal)
- Screw-retained implant-supported prosthesis (minimum two implants)
- Misfit assessment at delivery (baseline) and/or at follow-up appointments (gap size at interface, strains in reconstruction, screw torque)
- Biological changes and technical complications assessment (Table 3)
- Data extraction

The previously mentioned reviewers screened the titles and the abstracts of the records found. If the inclusion criteria were fulfilled, the full text of the article was reviewed. One investigator extracted the data. A study was excluded if the misfit gap size was missing or the clinical outcomes (in terms of biological changes or technical complications) were not reported clearly. The following information was collected: Author and year of publication, study design, human or animal study, number of subjects, prosthesis and implants, location of prosthesis, implant system and platform type, use of abutment, torque for screw tightening, misfit at baseline and/or follow-up, observation period, biological changes and implant survival, technical complications, and misfit surrogate assessment.

**Fig 3** Flow chart showing the systematic selection process.

■ Statistical analysis

Due to the small number of studies, the different misfit assessment methods and heterogenic study designs, a meta-analysis could not be performed. Thus, descriptive statistics were reported.

■ Results

■ Search results

A total of 2626 records were identified through electronic databases and other sources. Based on their titles and abstracts, 2592 records had to be removed as they were not relevant to the topic. Out of 34 full-text articles assessed for eligibility, 24 articles were excluded because they did not meet the inclusion criteria. Most of the excluded studies were *in vitro* or single implant studies, or they did not clearly assess the misfit at the implant-prosthesis interface. Finally, a total of 10 studies (five human^{14,40,59-61} and five animal⁶²⁻⁶⁶) were included in the descriptive analysis

Table 4a Characteristics of the included human studies evaluating biological and mechanical outcomes of implant prosthesis with different levels of misfit. IOD: implant-overdenture, IFD: implant-supported fixed denture, FW: framework.

Author, year	Design	Subjects	Implants and platform	Prostheses
Karl & Taylor, 2016 ⁴⁰	Prospective	18 patients 10 maxillae, 10 mandibles	40 Straumann SP 10/4.1 mm Flat + Synocta	20 IFDs 3-units High nobel alloy Test group: misfit (> 100 µm/m) Static and functional load
				20 IFDs 3-units High nobel alloy Control group: fit (< 100 µm/m)
Jokstad & Shokati, 2015 ⁶¹	Retrospective	30 patients Edentulous mandibles	153 Branemark Diff. length/diam. Flat external hex + Abutment	30 IFDs full-arch Acrylic + metal alloy 4-6 implants/prosthesis Abutment 35 Ncm, occl screw 15 Ncm
Hjalmarsson & Smedberg, 2005 ¹⁴	Retrospective	46 patients 30 maxillae 20 mandibles	57 Astra 78 Astra + Cresco 76 Branemark 65 Branemark + Cresco	10+14+14+12 IFDs full-arch Titanium or gold FW, acrylic teeth & veneer
Jemt & Book, 1996 ⁶⁰	Prospective group	7 patients 7 maxillae	44 Nobel Biocare Diff. length/diam. Flat external hex + Abutment	7 IFDs full-arch Prospective 1 year: 10-15 Ncm
	Retrospective group	7 patients 7 maxillae	38 Nobel Biocare Diff. length/diam. Flat external hex + Abutment	7 IODs (0-1 year)/ 7 IFDs (1-5 years) Retrospective 5 years: 10-15 Ncm
Kallus & Bessing, 1994 ⁵⁹	Retrospective	50 patients 16 maxillae 34 mandibles	278 Branemark Diff. length/diam. Flat external hex + Abutment	50 IFDs full-arch Acrylic + metal alloy 4-6 implants / prosthesis Abutment max. manual force, occl screw max. manual force,

(Fig 3). The Cohen's kappa coefficient for the final selection was 0.92, indicating excellent agreement between the reviewers.

■ Design and observation period

In total, 194 and 65 prostheses with different levels of misfit were fabricated in human and animal studies, respectively. While two human studies evaluated the biological response and technical complications prospectively over 6⁴⁰ and 12 months⁶⁰, the animal studies had a short-term observation period of up to 12 weeks. Four human studies^{14,59-61} analysed retrospectively the clinical outcome over a period of 3 to 32 years (Tables 4 and 5).

■ Misfit assessment

Different assessment methods were applied in the 10 included studies, depending on the technology available at the time.

Human studies

One study used an approximate estimation (0 = no visual discrepancy, 1 = slight discrepancy < 0.5 mm, 2 = moderate discrepancy 0.5 to 1 mm, 3 = pronounced discrepancy > 1 mm), without a measuring instrument for direct visual assessment of the vertical gap⁵⁹. One clinical study calculated the linear horizontal distortion between the implants (3D photography, digital calculation)⁶⁰. One study monitored the screw retention stability and the torque profiles¹⁴.

Table 4b Characteristics of the included animal studies evaluating biological and mechanical outcomes of implant prosthesis with different levels of misfit. IFD: implant-supported fixed denture, FW: framework, SC: single crown.

Author and year	Design	Subjects	Implants and platform	Prostheses
Duyck et al 2005 ⁶⁶	Prospective	5 rabbits 10 tibiae (left and right)	10 (+20) Branemark 10/3.75 mm Flat external hex	5 FW Co-Cr ie 3 blocked SCs; test group: immediate load of medial implant static load from screw tightening no functional load 35 Ncm
				5 FW Co-Cr i.e. 3 blocked SCs; Control group: regular load of medial implant after osseointegration 35 Ncm
Jemt et al 2000 ⁶⁵	Prospective	12 rabbits 24 tibiae (left and right)	15 (+57) Branemark 7/3 mm flat external hex + abutment 4 mm	15 test FW + 9 control FW Titanium i.e. 3 blocked SCs; Test groups: Static load from screw tightening LT: 15-18 Ncm (10) HT: 25-26 Ncm (5) no functional load
Jemt & Lekholm, 1998 ⁶⁴	Prospective	4 rabbits 4 tibiae	4 (+8) Branemark 7/3 mm Flat external hex + abutment 4 mm	4 bars i.e. 2-units (Laser-welded abutments)
Michaels et al 1997 ⁶³	Prospective	8 + 1 rabbit 16 tibiae	32 + 4 Steri-Oss 8/3.8 mm one-piece/cylindric (?)	8 bars misfit 8 bars fit i.. 2-units (solder technique) Hand tightened screws
Carr et al 1996 ⁶²	Prospective	6 baboons 6 mandibles (bilat.)	12 + 10 Steri-Oss 10/3.8 mm Flat external hex + abutment	6 IFDs misfit 5 IFDs fit Cast alloy, soldered Hand-tightened screws

The most recent studies published in 2015 and 2016 used latest scanner technology⁶¹ and strain gauge measurements⁴⁰ to assess the misfit.

Animal studies

Similarly, different assessment methods were applied, such as linear distance measurement between the implants (horizontal distortion)^{62,63}, surface topographical analysis⁶⁴, screw torque⁶⁵ and vertical gap size measurements⁶⁶.

■ Biological changes

Generally, no complications were reported concerning the soft tissues. Plaque accumulation

was not correlated to misfit values^{14,59}. Neither vertical (> 1 mm)⁵⁹ nor horizontal marginal gaps ($\leq 275 \mu\text{m}$)⁶⁰, nor static strains ($\leq 533 \mu\text{m/m}$)⁴⁰ due to screw tightening were found to have a negative effect on initial osseointegration or peri-implant bone stability over time in humans. Data from animal studies support a trend of bone remodelling and not resorption. No significant correlation between level of misfit and crestal bone loss was found.

■ Technical complications

In the retrospective study with the longest observation period (mean 19 years, range 12 to 32 years) including 30 full-arch IFDs, the prostheses with a

Table 5a Descriptive data of the included human studies evaluating biological and mechanical outcomes of implant prosthesis with different levels of misfit. CSR: cumulative survival rate, IFD: implant-supported fixed denture, FW: framework.

Author and year	Misfit before load	Misfit after load	Follow-up time	Misfit assessment method	Biological outcome	Technical outcome
Karl & Taylor, 2016 ⁴⁰	In situ strains at pontic 100–533 µm/m 9 IFDs (test group)	5/9 IFDs strain reduction (% in regres. curve)	6 months	STRAINS In vitro: Model based strain gauge analysis mesial and distal of implant In vivo: strain development in IFD pontic	CSR implant 100 %	No screw loosening; In vivo: reduction of strain developments over time in 5 of 9 IFDs In vitro: no changes in strains = no wear at interface
Jokstad & Shokati 2015 ⁶¹	In situ strains at pontic 1–100 µm/m 10 IFDs (control group)	7/10 IFDs strain reduction (% in regres. curve)	6 months	STRAINS "	CSR implant 100 %	No screw loosening CSR IFDs 100 % In vivo: reduction of strain developments over time in 7 of 10 IFDs In vitro: no changes in strains = no wear at interface
Jemt & Book 1996 ⁶⁰	-	150 (95–232) µm	19 (12–32) years	3 D GAP Virtual superimposition: digitized intaglio surface of IFD (D800 3shape) vs. digitized implant positions intraorally (iTero)	CSR implant 96.7 % 5 implants lost in 4 patients Bone loss: 2.2 (SD 0.7, range 0.6 - 5.8) mm No correlation with misfit (r2 = 0.04, p = 0.29)	Loosening or fracture of abutment or occlusal screw in 47 % (14/30 IFDs) CSR IFDs 73.3 % (8 IFDs redone) Prosthesis with history of screw related adverse events had sign. higher misfit values (169 µm vs 134 µm, p = 0.005)
Hjalmarsson & Smedberg 2005 ¹⁴	-	Screw stability A: 18–30° A+C: 35–50° B: 20–50° B+C: 24–38°	3 years	TORQUE Stability of retention screw, monitoring of torque profile (Osseocare torque controller) Higher ° = misfit	No sign. difference between 4 groups regarding mobile IFD, FW/screw/veneer fracture, screw loosening A: 1 implant loss	No sign. difference between 4 groups regarding mobile IFD, FW/screw/veneer fracture, screw loosening
Kallus & Bessing 1994 ⁵⁹	-	111 (59) µm (mean centre point 3D) 275 µm max.	1 year	HORIZONTAL GAP 3 D photography (abutments, intraoral) and IFD (extraoral), digital superimposition and measurements (centre point and angular distortion); Difference of linear distance between centre point of FW	CSR implant 100 % Bone loss 0.5 mm: no sign. Correlation between bone loss and misfit	5/6 IFDs with extreme loose screw had moderate or pronounced gaps Screw loosening: correlation to fit and to operator; retightening after 5 years recommended Int. hexagon screws more stable than slot screws
	-	91 (51) µm (mean centre point 3D) 275 µm max.	5 years	HORIZONTAL GAP "	CSR implant 100 % Bone loss 0.2 mm: no sign. Correlation between bone loss and misfit	
	-	Fit: 0 mm: 24, < 0.5 mm: 14, 0.5–1 mm: 8, > 1 mm: 4	5.5 years	VERTICAL GAP Visual inspection/estimation of vertical gap size (0 = no visual discrepancy, 1 = slight d. < 0.5 mm, 2 = moderate d. 0.5–1 mm, 3 = pronounced d. > 1 mm) Modif. CAD classification for screw-tightness rating: R = no loosening, S = slight l./T = obvious l., T = extreme l.	CSR 99.6 % (1 implant loss) Bone loss: no correlation to fit Plaque accumulation: no correlation to fit	

Table 5b Descriptive data of the included animal studies evaluating biological and mechanical outcomes of implant prosthesis with different levels of misfit. BIC: bone-implant-contact, CSR: cumulative survival rate, IFD: implant-supported fixed denture, FW: framework.

Author and year	Misfit before load	Misfit after load	Follow-up time	Misfit assessment method	Biological outcome	Technical outcome
Duyck et al 2005 ⁶⁶	583 (358–836) μm	170 (8–320) μm	12 weeks	VERTICAL Model based examination of vert. gap, direct light microscope and digitized virtual measurement	Crater depth, surface, and BIC (histomorphometry): No sign. diff. between test and control implants CSR implant 100 %	No screw loosening CSR FW 100 % Sign. Decrease in gap size Sign. diff. between test and control implants
	495 (406–528) μm	299 (74–467) μm No sign. decrease of gap size	12 weeks	VERTICAL	CSR implant 100 %	No screw loosening CSR FW 100 %
Jemt et al 2000 ⁶⁵	Tightening torque in screw of intermediate implant with 1 mm gap LT: 17 Ncm HT: 26 Ncm	Loosening torque in screw of intermediate implant with 1 mm gap LT: 9 Ncm HT: 13 Ncm	2–3 weeks	TORQUE Screw tightening/loosening torque (static preload) for intermediate test screw Bone-metal-contact at threads (Bottom, upper, top, lower) histometry	CSR implant 100 % Sign. correlation between BMC % and preload induced BMC % at tip of thread: sign more in HT than LT or control	No screw loosening No abutment loosening
Jemt & Lekholm, 1998 ⁶⁴	Tightening torque in screw of intermediate implant with 1 mm gap was 15 Ncm		0 (before vs. after screw tightening)	TORQUE 3D photography, stereoscopic measurement, surface topography analysis ($\pm 100 \mu\text{m}$ variation)	100% of implants osseointegrated. Bone deformation with implant displacement toward FW: 123 (60 - 200) μm Complex, inconsistent, and individual deformation pattern Calculated load on implant: 246 (238 - 252) N	FW deformation with rotation toward implant: 177 (100 - 300) μm Complex, inconsistent, and individual deformation pattern
Michaels et al 1997 ⁶³	Misfit: 466 \pm 209 μm Fit: 62 \pm 35 μm	-	12 weeks	HORIZONTAL Travelling microscope Difference of linear distance between centre point of FW	CSR implant 100% Clinically no signs of inflammation or infection Vertical histological section % length and % area of osseointegration: not sign. diff. between fit vs. misfit group	-
Carr et al 1996 ⁶²	Misfit: 345 \pm 203 (183–738) μm Fit: 62 \pm 35 (2–130) μm		4 weeks	HORIZONTAL Travelling microscope Difference of linear distance between centre point of IFD	CSR implant 100% Clinically no signs of inflammation or infection Horizontal histological section % integration and % area of osseointegration: not significant difference between fit vs misfit group No diff. between compression vs. tension areas	-

history of screw-related adverse events had significantly higher misfit values (169 μm vs 134 μm , $P = 0.005$)⁶¹. The other clinical studies reported no complications^{40,60} or no differences in the frequency of adverse mechanical effects¹⁴. Slot screw types of the Brånemark implant system were more prone to screw loosening than int. hexagon screws⁵⁹.

A tolerable degree of misfit could not be determined for either gaps or strains.

■ Discussion

The present literature review aimed to extract new information on the clinical outcome of implant reconstructions in relation to the prosthesis misfit. The PICO question was “For partially or fully edentulous subjects with screw retained IFDs, does the marginal misfit at the implant-prosthesis interfaces have an impact on the clinical outcomes?” The results show that limited clinical evidence is available that supports the claimed fear for adverse biological and technical events as a direct and specific consequence of misfitting screw-retained IFDs.

In the preparation of this review, only five clinical human studies^{14,40,59-61} were found. Among these, one study⁴⁰ was a prospective clinical trial with an experimental IFD including 18 patients and a 6-month observation time; one study⁶⁰ had a group of seven patients who were prospectively followed for 1 year, while the others were retrospective studies including a total of 133 patients over 3 to 32 years^{14,59-61}. During the selection phase, another pilot study was excluded as only one single case and the methodology for strain measurements was reported⁶⁷. For ethical reasons it is not possible to conduct clinical studies with intentionally poorly fitting implant reconstructions to investigate biological changes and technical problems in the long-term. This is, on the other hand, acceptable with animals, provided animal welfare regulations are respected during the study. Five animal studies⁶²⁻⁶⁶ could be identified that fulfilled the inclusion criteria, and were therefore added in the present review to increase the power of the analysis.

A retrospective study by Jokstad and Shokati (2015)⁶¹ had the longest observation period (mean 19 years, range 12 to 32 years). Thirty patients with

an implant-supported fixed complete denture in the mandible were examined and data reported on both clinical outcomes and related misfit values, using sophisticated 3D metrological software for the misfit measurements. Apart from a slightly higher risk of screw-related adverse events, the effect of misfit up to 230 μm between the superstructures and their supporting implants appears to be minor on the long-term clinical outcomes.

While five implants were lost in four patients, no correlation of misfit values and marginal bone loss as a primary biological clinical outcome variable was found. There is no information available on the initial misfit at the time of loading, thus a potential implant displacement cannot be evaluated. It may be discussed if the torque of 15 Ncm applied through the occlusal screw on the abutment may induce implant displacement by micro-fractures of the surrounding bone or remodeling and orthodontic movement over time, as it is hypothesized elsewhere⁶⁶. It is noteworthy that the misfit values at the clinical follow-up ranged between 95 and 232 μm . On the other hand, 14 of the 30 participants (47%) had experienced at least one incidence of screw loosening or fracture of prosthetic or abutment screw(s) over the long follow-up period. The occurrence of technical complications among the frameworks fabricated with different metal alloys did not alter. The abutment screws (tightened with 35 Ncm) and the occlusal gold screws (tightened with 15 Ncm) to retain the implant-supported fixed complete dentures on four to six implants both absorbed the strains induced by the misfit. However, in this specific implant system the risk for screw loosening was increased with a shorter occlusal screw tightened with only 15 Ncm. The authors hypothesized that tightening a non-passive superstructure on the transmucosal abutments imposed an uneven distribution of tensile stresses on the shank and threads of the prosthetic screws resulting in screw loosening or fracture. According to the classification in Table 3, these would all be manageable events.

In the recently published prospective clinical study by Karl & Taylor (2016)⁴⁰ the authors reported some bone adaptation around implants that were statically and functionally loaded with poorly and accurately fitting IFDs in terms of reduced strain values in the pontic of the three-unit restorations. The test group included 10 non-passively fitting

IFDs, i.e. initial strain development at the pontic of the restoration $\geq 100 \mu\text{m}/\text{m}$. In the control group, nine passively fitting IFDs with strain values below $100 \mu\text{m}/\text{m}$ up to a perfect passive fit of theoretically $0 \mu\text{m}/\text{m}$ were allocated. In contrast to another clinical animal study⁶⁶, the IFDs were loaded not only statically (screw tightening), but also dynamically by functional loading (contacts in occlusion, articulation, and chewing), which may be well controlled only in humans. The results after 6 months of observation showed no negative effects on the primary biological and technical outcomes. Implant length, age, gender, and bone quality had no effect on the strain values. The osseous adaptation (remodelling and implant displacement) were not documented directly, but concluded by a surrogate measurement, i.e. reduction of the strain values in the IFD. Additionally, wear phenomena at the interface, or distortions of the restoration were excluded as no changes in the *in vitro* strains on the model could be observed. The clinical implication of this study remains unclear as the observation time was short (6 months), the number of patients enrolled with 19 (9 + 10) prostheses was rather small, and the strain developments did not correlate with the initial static load. However, the results support the conclusion that even IFDs with a greater level of misfit stress do not cause overload or peri-implant bone resorption, but lead to bone adaptation (without bony micro-fractures) and subsequently less misfit within the first couple of weeks. In a rabbit model, Duyck et al (2001)⁶⁸ observed that excessive dynamic loads cause crater-like bone defects lateral to osseointegrated implants. The effect of cyclic occlusal dynamic load is difficult to quantify, but is hypothesised to have more influence on the bone than static load from prosthesis misfit. The conclusions of the clinical study by Jemt and Book in 1996⁶⁰ are in accordance with the two previously mentioned studies^{40,61}. No statistical correlation was observed between the change of marginal bone levels and the different parameters of prosthesis misfit. The authors included 14 patients with four to six implant supporting a full-arch IFD. Two groups, each with seven patients, were enrolled in a prospective 1-year trial and a retrospective 5-year investigation. The misfit measurements were based on a 3D photography method and performed

only at the follow-up appointment. Thus, no comparison with the initial misfit at the delivery can be done, nor may possible implant displacement be measured. The authors compared the misfit between the two groups measuring no differences and concluded that no bone adaptation could therefore have taken place between 1 and 5 years. This comparison and the conclusion are based on the assumption that the two groups with only seven patients apiece would have the same biological reaction, and that the IFDs were fabricated initially with the same precision. Thus, their interpretation is to be considered with caution, as it is not based on evidence. The results indicate that a certain biological tolerance for misfit may be present. The degree of misfit reported in the study was estimated clinically acceptable with regard to observed marginal bone loss. The digitally measured misfit values of $100 \mu\text{m}$ and more at different implants of the full-arch IFDs indicate that the occlusal screws were under static (prosthesis misfit) and functional (occlusion) load, but resistant to mechanical fatigue over the whole period of observation, i.e. 1 and 5 years. A clinical study published in 1994 by Kallus and Bessing⁵⁹ investigated retrospectively the frequency of gold screw loosening of complete IFDs after 5 years of loading and found a weak correlation to the framework misfit (and the operator). However, it has to be mentioned that the frameworks and the abutments were tightened manually with maximum finger force, which may at best reach torque levels of 10 to 15 Ncm. In this context, loosening of the occlusal screws or the abutments is likely to occur even with perfectly fitting IFDs after functional loading of more than 5 years. It may be speculated that screw loosening would occur if the tightening was performed with a torque at 35 Ncm. Furthermore, clinical ratings of the screw-tightness and the gap size at the interface between abutment and IFD were not accurate enough and may have varied significantly between the three investigators. Although the interfaces must have been directly visible, a visual inspection was performed without measuring device, estimating the gap size in four categories (0 = no visual discrepancy, 1 = slight discrepancy $< 0.5 \text{ mm}$, 2 = moderate discrepancy 0.5 to 1 mm , 3 = pronounced discrepancy $> 1 \text{ mm}$). However, 500 to $1000 \mu\text{m}$ of

gap size (slight to moderate discrepancy according to the rating system) is far beyond the threshold of 100 μm considered to be clinically acceptable in literature so far, and also way beyond the fabrication feasibility of today's CAD/CAM systems (Table 1). Thus, the results and conclusions of this study may rather be considered of historical significance.

In an animal study Duyck et al (2005)⁶⁶ investigated the effect of prosthesis misfit and static tensile load from screw tightening on the osseointegration of immediately loaded implants. Five test implants were immediately loaded with a screw retained ill-fitting Co-Cr framework. The measured gape sizes at baseline ranged between 358 to 836 μm (mean 583 μm) and were found to be significantly decreased after 12 weeks. One limitation of the study is the method of measurement that was applied to document the change of gap size. The implant position was transferred at each stage to a model on which the vertical gap was measured with a light microscope. However, we do not know if the implant migrated slowly over the 12 weeks towards the framework platform or if rather the position change immediately while screw tightening at loading. No clinical or radiographic assessment was performed. The authors themselves estimate that the movement occurred most probably during fixation of the prosthesis inducing micro-fractures of the bone between and around the implant threads. This hypothesis was further supported by the fact that no screw loosening was observed neither in the test group (immediate load) nor in the control group (osseointegrated implant), although the implant displacement was not statistically significant in the latter group. However, the fact that even an already osseointegrated implant may be pulled towards the platform only by regular tightening of the occlusal screw with 35 Ncm, means that micro-fractures of the peri-implant bone will be produced and, at the same time, strains in the implant components will decrease. Thus, the surrounding bone would absorb the initial misfit while the screws are tightened to a clinically perfect final fit. In consequence, the risk for technical complication would thus be minimal. However, using more rigid implant systems the implant itself would be exposed to higher preload stress with increased risk for fracture or peri-implant effects⁶⁵. Wolff's law was described as structural bone adaptation to mechanical usage⁶⁹.

Strains transmitted to the implant surface would thus provoke adaptive changes of the trabecular architecture of the peri-implant bone over time to resist load. However, compressive and tensile areas around the threads were described⁶⁵. Furthermore, the process of immediate or slow implant displacement due to micro-fracture or orthodontic movement could occur before any structural bone adaptation. This issue is also discussed in the clinical study by Jøstad and Shokati⁶¹, where a torque of 15 Ncm was applied for tightening the occlusal screw on the abutment. It remains unclear whether an implant displacement by micro-fractures of the surrounding bone or remodelling and orthodontic movement over time was induced with only a 15 Ncm torque, or if the strains were absorbed from the prosthetic components. Jemt et al (2000)⁶⁵ applied almost the same levels of preload torque in a study on rabbits. The study design included two test groups with low (15 to 18 Ncm) and high torque (25 Ncm) applied to tighten the screw of an intermediate implant connected to an ill-fitting titanium framework with a 1 mm (!) vertical gap at the interface. The authors focused on the effect of different preload levels than on the gap size itself, which was chosen to be extremely high (1 mm) without possibility to close the gap by screw tightening. However, the gap size was not measured after initial tightening or at the end of the observation time. Thus, only the screw loosening torque was documented and was found to have decreased by approximately 50% in both groups. Histologically, less bone-to-metal contact was observed at the tip of the thread of the unloaded implant and the implant with lower preload forces than at the tip of implants loaded with higher static forces. Against clinical expectations, there was a significant correlation between increasing degrees of preload stress and increased bone-to-metal contact at the tip of the threads of the loaded implants. Thus, a positive bone remodelling response was observed around the implant without difference in the thread areas (bottom, lower part) anticipated to be exposed to pressure or tensile forces. In a previous pilot study by the same group published in 1998⁶⁴, a complex deformation pattern of the framework and the peri-implant bone was described in four rabbit tibiae. The same study design was used with three implants and an artificially induced gap of

1 mm at the intermediate implant and a controlled screw tightening with 15 Ncm. The flexure of the framework may be explained by the fact that the three abutments were laser-welded, resulting in a bar type framework. The thin bar design and the superficial laser connections may have allowed for a bending distortion while screw tightening with 15 Ncm. However, based on only four specimens, the authors stated that the deformation pattern was inconsistent and individual. While increasing levels of vertical misfit (10, 50 and 100 μm) in a single implant study by Hermann et al (2001)⁵⁴ did not lead to more crestal bone loss, possible movements between the abutment and the implant were found to lead to more bone loss. The implant with a previously laser-welded and thus immobilised abutment-implant connection showed significantly less bone resorption. However, the abutment screws were tightened only manually, which is significantly less torque compared to tightening occlusal screws for final fit (system depending up to 35 Ncm). By contrast, multiple-unit prostheses are splinted together and thus the possibility of repetitive distortion or motion at the interface due to functional loading is very small, if not impossible, with rigid framework materials, such as titanium or zirconia. The question remains unanswered as to whether immobilising IFDs by splinting would also yield a low bacterial colonisation under dynamic load like single implants with a rigid conical connection type⁷⁰.

One of the first animal studies to investigate the effect of prosthetic superstructure on the bone interface of osseointegrated implants was performed by Michaels et al in 1997⁶³. Eight rabbits each received a well and a poorly fitting soldered bar-type superstructure on two implants. The ill-fitting bars were fabricated with a linear distortion of 466 (mean) \pm 209 (SD) μm . Interestingly, the horizontal measurements of the fitting group ranged from 20 to 116 μm (62 \pm 35 μm). Today, these gap sizes would be considered to be moderately fitting at best. As the occlusal screws were tightened by hand (most probably with 10 to 15 Ncm max), and as there were no vertical gap size nor pontic strain measurements performed after screw tightening or after the observation time of 12 weeks, no information is available if and in which moment a gape size reduction occurred due to possible implant displacement. The

author did not histometrically find a significant difference in percentage length and area of osseointegration between the fit and misfit group. This study reported very high horizontal misfit values (up to 747 μm) without effect on the peri-implant bone based on histologic findings. However, there was no functional loading and only a short observation period of 12 weeks.

Similarly, the same limitations are present in the first animal study found in this review by Carr et al (1996)⁶². Over 4 weeks the study investigated histologically the bone response of unloaded implants with different levels of (horizontal) misfit in six primates (baboons). The misfit group included IFDs with a linear distortion of 183 to 738 μm (mean 345, SD 203 μm) compared to the fit group ranging from 2 to 130 μm (mean 38, SD 52 μm). Within the limitations of this study (low statistical power due to small sample size, no direct gap size or strain measurements at loading and follow-up, use of abutments, manual screw tightening) and contrary to clinical expectation, the data suggest a bone response trend in favour of the misfit group. However, the use of abutments may have biased the results. The static strains from screw tightening with the given misfitting IFDs may have been completely absorbed in the second interface and by the abutments eliminating tensile or compressive forces on the implant level.

Overall, no threshold for a clinically acceptable gap or strains could be determined. Biological and technical tolerance to non-passive fit with or without a remaining gap at the interface seems to be high. It may be discussed if a clinically acceptable misfit could be different from patient to patient depending on general and behavioural factors, similar to the risk for caries or periodontal disease. If misfit was a triggering factor, patients with a poor oral hygiene and genetic predisposition to pathologic periodontal bone resorption might be more susceptible to peri-implant bone loss from ill-fitting reconstructions. In such at risk patients with low misfit tolerance, the threshold for a clinically acceptable misfit would be very small. On the other hand, there seems to be patient resistant to pathologic processes, even in the absence of good oral hygiene. For this type of patient, a comparatively poor component fit would still be clinically acceptable. In this context, the age-related capacity to react on a disturbing factor and

to keep the bacterial balance in the oral cavity and at the interface should also be taken in consideration. Generally, it is hypothesised that older patients have a less intense and slower healing reaction. However, it is not clear whether a weak reaction to the misfit-stimulus would imply a greater misfit tolerance. On the contrary, young and healthy subjects with a stronger and faster local inflammatory defence on the misfit-stimulus could keep biological degradation under control, which would imply a high misfit tolerance in the same way. The interpretation is controversial and remains a matter of debate.

Although this systematic review included most PRISMA guidelines, there are some limitations. The small number of *in vivo* studies and the heterogenic design with different assessment methods did not allow us to clearly compare the misfit values. Therefore, a meta-analysis was not possible and only a descriptive statistical analysis was performed. The follow-up duration for most studies was in the short to medium range (0.5 to 5.5 years), except for one retrospective study⁶¹, which was from 12 to 32 years. The level of evidence of the included studies was rather poor according to the evidence pyramid^{71,72} because only one⁴⁰ out of five human studies^{14, 40, 59-61} was a randomised controlled clinical trial, and five were animal studies⁶²⁻⁶⁶. The reporting quality of the prospective human study⁴⁰ was good as the misfit assessment and the outcomes were clearly documented, which was not generally the case in the retrospective studies. The risk of bias was low in the prospective studies as the implant surgery, the prosthesis fabrication and the assessments were performed by only one trained investigator. On the contrary, the retrospective studies have to be considered as having a high risk for bias as multiple surgeons and investigators were involved^{14,59-61}, and for usage of subjective assessment methods in the visual gap estimation⁵⁹.

■ Conclusions

The current literature provides insufficient evidence about the effect of misfit at the prosthesis-implant interface on clinical outcomes of screw retained implant-supported fixed dentures. Marginal gaps and static strains due to screw tightening were not found to have negative effects on initial osseointegration or

peri-implant bone stability over time. Based on two clinical studies, the risk for technical screw-related complications was slightly higher. While the degree of tolerable misfit remains a matter of debate, the present data do not imply that clinicians should neglect good fit, but aim to achieve the least degree of misfit possible.

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Performance of CAD/CAM monolithic ceramic Implant-supported restorations bonded to titanium inserts: A systematic review



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Key words CAD/CAM fabricated implant restorations, hybrid abutments, hybrid abutment crowns, implant hybrid restorations, resin bonding to titanium, TiBase, titanium implant insert, two piece CAD/CAM abutments

Aims: This review assessed the available evidence on the performance of CAD/CAM monolithic implant-supported restorations bonded to titanium (Ti) inserts and bases, which has become a popular concept.

Materials and Methods: An electronic and manual search of PubMed databases was conducted to identify studies published in English between 2000 and 2016 on the performance of monolithic ceramic implant restorations with Ti inserts.

Results: The initial search revealed 505 titles. Full-text screening was carried out for 70 studies, yielding 25 articles that met the inclusion criteria. No clinical studies could be identified regarding the performance of monolithic ceramic restorations bonded to Ti inserts. Laboratory studies on selected aspects and studies on similar prosthetic designs indicate that Ti inserts improve the overall fracture strength of ceramic abutments and crowns, protect the implant connection from wear, and offer a better marginal fit when compared with all-ceramic abutments.

Conclusions: While laboratory studies and evaluations of similar designs indicated promising outcomes, clinical studies that evaluate the performance of CAD/CAM monolithic implant-supported restorations bonded to Ti inserts and bases are needed.

Introduction

Traditionally, titanium abutments have been used to support single-implant dental restorations, showing high strength and biocompatibility with surrounding soft tissues. Aesthetic results, however, are often compromised due to the grey colour of the abutment material and, consequently, the soft tissues¹. With the introduction of zirconia in dentistry, implant manufacturers and CAD/CAM systems started to offer custom-made zirconia abutments¹.

However, the significant differences in physical properties between zirconia abutments and the titanium implants, especially hardness and modulus of elasticity, have caused detrimental effects at the

abutment-implant interface². Zirconia abutments that directly engaged with the implant via internal connections, Morse conical connections, and narrow diameter external connections demonstrated a high number of fractures³. Titanium abutments revealed a significantly better fit than all titanium-implant-zirconia-abutment configurations, with mean gaps that were approximately three to seven times larger than those found with titanium abutment systems⁴.

Such findings led to the development of hybrid abutments that connect a titanium insert to the ceramic mesostructure, which is typically held together by a resin cement⁵. These abutments can offer improved aesthetics and biological response without negatively affecting stability of the implant-abutment

Fig 1 Clinical question in "PICO" format.

Patient population/problem	Patients requiring implant-supported restorations.
Intervention	CAD/CAM monolithic implant-supported restoration bonded to titanium implant inserts.
Comparison	CAD/CAM monolithic implant-supported restoration bonded to titanium implant inserts versus traditional screw-retained implant-supported restorations.
Outcome	Improve and/or maintain optimal function and achieve the maximal aesthetic outcome.

interface. Zirconia hybrid abutments are typically used for cement-retained restorations. However, limited restorative space and reduced axial thickness of the zirconia abutment and the crown may lead to fractures of any of the two prosthetic components (abutment and/or crown). Other limitations of cement-retained implant restorations include complicated retrievability, cement gap, biologic complications through excess cement, prosthetic complexity, and higher cost⁶. Therefore, several implant manufacturers have developed monolithic, or hybrid implant, restorations, which are typically connected to the implant with titanium inserts and retained either mechanically or bonded into the restoration.

Recent advances in digital technologies and ceramic materials facilitate the simplified and economical fabrication of monolithic screw-retained implant restorations, even with chairside CAD/CAM systems. Pre-crystallized silicate ceramic, hybrid ceramic, and polymer CAD/CAM blocks have been favoured for those systems to fabricate implant restorations in a time-efficient manner, especially when compared with pre-sintered zirconia abutments and components, which require a more elaborate sintering and finishing process⁷.

One of the most prominent chairside CAD/CAM systems is Cerec (Sirona Dental Systems; Bensheim, Germany), which offers a titanium connector featuring both an element that connects to the implant and a connection that is resin bonded into a ceramic or polymer block (TiBase, Sirona Dental Systems). The TiBase system is available for a number of implant systems and not linked to any specific implant manufacturer⁸. The combination of a titanium insert and a ceramic block with a perforation that

provides an intimate fit between both components has made monolithic implant-supported restorations popular among chairside CAD/CAM users. The monolithic nature of the restoration is supposed to prevent ceramic fractures and chipping. In addition, cementing the components extraorally should reduce the possibility of excess cement and cement-induced peri-implantitis⁹.

While these developments and concepts appear to be quite promising, clinical evidence is needed to validate their performance. Several papers have been published on similar concepts and aspects related to hybrid abutments, monolithic implant crowns as well as implant connectors and inserts¹⁻³⁰. The objective of this review was to identify scientific studies that specifically assess the performance of CAD/CAM monolithic implant-supported ceramic restorations bonded to titanium inserts and, if possible, to formulate clinical guidelines based on those results.

■ Materials and methods

■ Search strategy and study selection

A PubMed search for articles published in scientific dental journals in English from 2000 to July 2016 was conducted. The Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement³¹ was used in this study (Fig 1). The clinical question in "PICO" format³² (P = patient problem/population, I = Intervention, C = Comparison, O = Outcome) in our study was: In patients requiring implant-supported single-unit restorations, do CAD/CAM monolithic implant-supported restoration bonded to titanium implant inserts, comparing CAD/CAM monolithic implant-supported restorations bonded to titanium implant inserts vs traditional implant-supported restorations, improve and/or maintain optimal function and achieve the maximum aesthetic outcome?

The following search terms were used: "TiBase", "implant hybrid restorations", "resin bonding to titanium", "CAD/CAM fabricated implant restorations", "hybrid abutments", "hybrid abutment crowns", "two piece CAD/CAM abutments" and "titanium implant insert".

We also reviewed the bibliographies and related searches of all selected full-text articles. A hand search of the literature was also conducted.

Inclusion criteria

- All study types related to the topic;
- Articles in English;
- Publication dates from 2000 to July 2016.

Exclusion criteria

- Studies related to implant placement;
- CAD/CAM tooth-supported restorations;
- Full-mouth implant-supported restorations;
- Articles related to zirconia implants;
- Articles that did not contain detailed information about the topic of study;
- Case reports.

■ Selection of studies

From an initial 505 studies, 70 studies were selected for full-text analyses. Following detailed analysis by two independent reviewers, a final number of 25 articles met the inclusion criteria (Fig 2).

■ Excluded studies

Of the 70 full-text articles, 45 were excluded from the final analysis.

Reasons for exclusion:

- Research question and purpose of the study focused on parameters other than implant-supported monolithic restorations, hybrid abutments, or bonding to titanium abutments or inserts.
- Methods did not apply CAD/CAM for fabrication of the restorations.

■ Data extraction

Characteristics of selected studies are listed in Tables 1 to 3. The 25 studies included were classified into three groups based on their key topic:

- Zirconia hybrid abutments;
- Bonding to titanium;

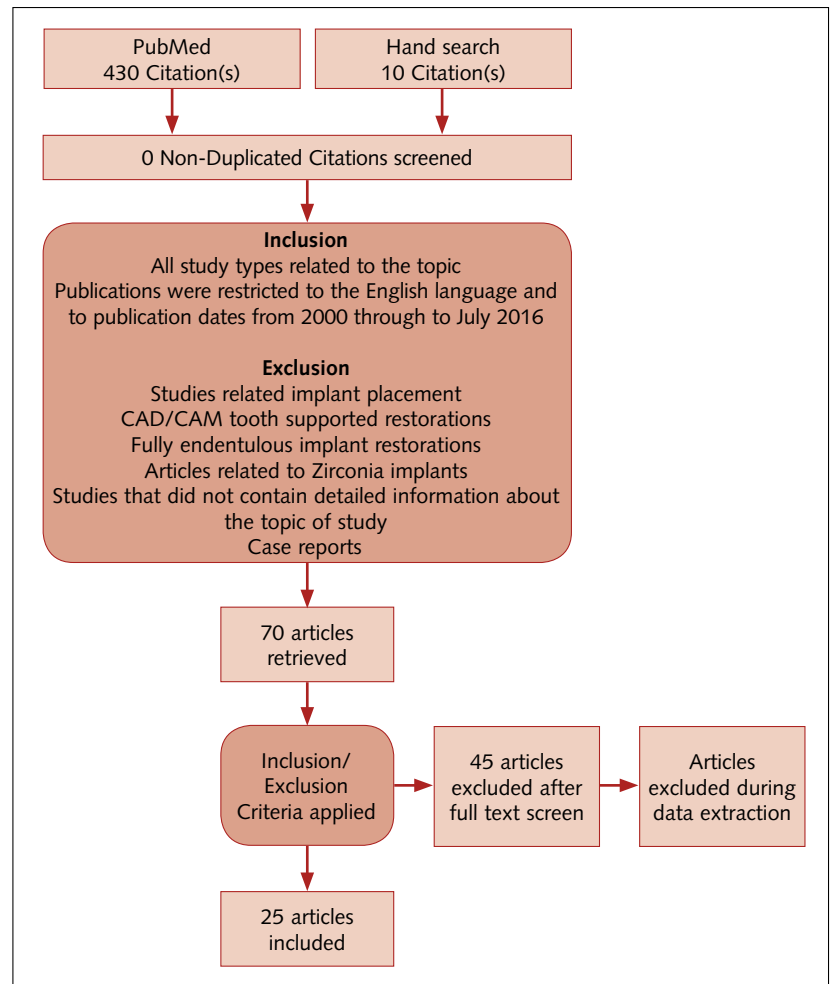


Fig 2 Search strategy.

- Monolithic CAD/CAM implant restorations (cement-retained).

Due to the lack of clinical data and heterogeneity of the in-vitro studies, meta-analyses were not possible.

■ Results

None of the selected studies reported on the clinical performance of CAD/CAM monolithic implant-supported restorations bonded to titanium inserts or bases. However, 25 studies met the broader inclusion criteria, evaluating key aspects of this protocol and similar restoration designs.

A total of 15 articles (Table 1) reported on the performance of zirconia hybrid abutments^{2-5,12-19}, indicating that titanium inserts bonded to zirconia abutments improve the overall fracture strength,

Table 1 Study characteristics of studies related to hybrid abutments.

Author	Year of publication	Study type	CAD-CAM, system	Materials
Chun et al	2015	In vitro study	Not specified	Ti abutments Dual Abutment Hex (Dentium) Zr abutments ZirAce internal (Acucera) Zr abutments ZirAce external (Acucera) Ti inserts Z socket (Dentium)
Gehrke	2015	In vitro study	Cercon (Dentsply)	SZ abutments (CERCON, DENTSPLY) CAD-CAM Zr abutments (Compartis, DeguDent) CAD-CAM Ti-base Zr abutments (Xive, Dentsply)
Joo et al	2015	In vitro study	Zenotec T1 (Wieland Dental)	Prop abutment and Anyridge Implant System (Megagen)
Cavusoglu et al	2014	In vitro study	Cerec InLab (Sirona)	Straumann RC anatomic IPS Emax abutments Straumann RC anatomic Ti abutments
Delben et al	2014	In vitro study	Procera (Nobel Biocare)	Y-TZP-Procera Aesthetic (Nobel Biocare) Y-TZP+Ti Insert ZiReal Post (Biomet 3i) Y-TZP-Cercon balance (Ankylos-Friadent) IPS e.max Ceram
Foong et al	2013	In vitro study	Etikon (Straumann)	Ti Design and Zir Design (Astratec Dental AB) base metal crowns Coron (Straumann)
Kim et al	2013	In vitro study	Aadva (GC Advance Technologies) Procera (Nobel Biocare) Lava (3MESPE)	Zr Abutment (GC Advance Technologies Inc.) Zr Abutment (Nobel Biocare) Zr Abutment (LAVA, 3M ESPE)
Stimmelmayer et al	2013	In vitro study	3Shape Dental Manager (CadBlue)	Sub-Tec CAD-CAM Ti Core (BEGO Implant Systems)
Baldassarri et al	2012	In vitro study	Procera (Nobel Biocare) Atlantis (Astratech Dental) Encode (Biomet3i)	Zr abutment- Ti insert Procera (Nobel Biocare) Full Zr abutments and full Ti abutments Encode (Biomet3i) Full Zr abutments (Atlantis)
Stimmelmayer et al.	2012	in vitro study	not specified	Prototypes Camlog Biotechnologies Zr crown Lava (3M ESPE)
Nguyen et al	2009	In vitro study	Procera (Nobel Biocare)	Procera Zr abutments (Nobel Biocare) ZiReal Post (Biomet 3i) Certain ZiReal Post (Biomet 3i)
Sailer et al	2009	In vitro study	Cerec InLab (Sirona)	CARES abutments (Straumann) Procera abutments (Nobel Biocare) Zirabut Synocta (Straumann)
Abbo et al	2008	In vitro study	Procera (Nobel Biocare)	Ti abutments Zr copings Procera (Nobel Biocare)
Alfarsi et al	2008	In vitro study	Cerec (Sirona)	Neo Ti preparable abutments Neo system implant (Neoss)
Canullo	2007	Clinical study	ZirkonZahn	ProUnic abutment (Impladent)

protect the implant connection from wear, and offer a better marginal fit when compared with full-zirconia abutments. One article revealed favourable clinical outcomes of customised zirconia abutments for single-implant restorations¹⁸.

Three articles reported on bonding to titanium abutments (Table 2)²²⁻²⁴. Superior bond strengths to titanium abutments or inserts can be achieved by pre-treating the bonding surfaces with air-particle abrasion with aluminium oxide, acid etching, and application of a special primer. A resin-based luting agent should be used²³.

Six articles reported on monolithic CAD/CAM restorations (Table 3)^{6,20,27-30}. Monolithic lithium disilicate crowns had significantly greater success than veneered lithium disilicate and zirconia ceramic systems, where chipping of the veneering porcelain was the most common failure²⁰.

■ Discussion

This review examined the current literature on the performance of CAD/CAM monolithic implant-supported

Table 2 Study characteristics of studies related to bonding to titanium abutments.

Author	Year of publication	Study type	CAD-CAM, system	Materials
Maltzahn et al	2015	In vitro study	CADSPEED GmbH	Ti bases (Medentika) CAD/CAM Zr copings (CADSPEED) Panavia F 2.0 (Kuraray Noritake Dental Inc.) RelyX Unicem and Rocotec System (3MESPE)
Egoshi et al	2013	In vitro study	not specified	Estenia C&B primer and resin composite (Kuraray Noritake Dental)
Mehl et al	2012	In vitro study	Autodesk Inventor (Autodesk) BEGO Medifactory System (BEGO)	Ti universal abutments (Camlog Biotechnologies) Ketac-Cem, Durelon (3M ESPE) Multilink Implant (Ivoclar Vivadent)
Abbo et al	2008	In vitro study	Procera (Nobel Biocare)	Ti abutments Zr copings Procera (Nobel Biocare)

Table 3 Study characteristics of studies related to monolithic CAD/CAM implant restorations.

Author	Year of publication	Study type	CAD-CAM, system	Materials
Lassle et al	2015	In vitro study	Procera (Nobel Biocare)	Snappy abutments 5.5 Conical connection (Nobel Biocare) IPS e.max crowns
Aktas et al	2014	In vitro study	Cerec (Sirona)	Solid and synOcta abutments (Straumann) inCoris ZI and Alumina silicate glass ceramic blocks (Sirona)
Cavusoglu et al	2014	In vitro study	Cerec InLab (Sirona)	Straumann RC anatomic IPS e.max abutments Straumann RC anatomic Ti abutments
Joda et al	2014	In vitro study	Cerec (Sirona)	synOcta prefabricated Ti CAD/CAM Ti CARES prefabricated Variobase Ti abutments (Straumann) Lava Ultimate (3M ESPE)
Martinez-Rus et al	2012	In vitro study	Cerec InLab (Sirona)	CARES ceramic abutments and CARES Ti abutments (Straumann) IPS e.max CAD,PRESS ZirCAD
Wolf et al	2008	In vitro study	Cerec (Sirona)	GingiHue Ti abutment ZiReal Zr abutment (Biomet 3i)

restorations bonded to titanium inserts. The search period was defined from 2000 to July 2016. There were no studies that met the inclusion criteria published before 2004. None of the studies assessed the exact protocol of titanium inserts bonded into CAD/CAM monolithic crowns, neither *in vivo* nor in the laboratory. The 25 studies that met the broader inclusion criteria evaluated various restoration designs of hybrid abutments, bonding to titanium, and monolithic CAD/CAM cement-retained restorations. Except for one, all of them were *in vitro* studies.

■ Monolithic hybrid abutment crown

Kurbad⁷ and Rauscher⁹ described the use of CAD/CAM lithium disilicate blocks (IPS e.max CAD, Ivoclar Vivadent), which are specifically designed for

screw-retained implant-supported restorations. They also used CAD/CAM zirconia blocks (InCoris Meso, Sirona) to fabricate two-piece hybrid abutments. All of their restorations were completed with a TiBase connector (Sirona), which engages into the ceramic block's perforation and features an anti-rotational component. Beuer and colleagues explained the digital One-Abutment/One-Time Concept¹¹. A digital intraoral impression is made on the day of the implant placement with a scan body and a CAD program (Dental Designer, 3shape) to design the final restoration. After bone healing, at the time of second stage surgery, the final screw-retained CAD/CAM-fabricated crown is inserted. This allows the soft tissue to heal around the definitive restoration and, therefore, avoids soft-tissue trauma through the repeated removal and re-insertion of abutments or

healing screws. Monolithic screw-retained implant-supported restorations depend on an ideal implant position because of the access screw hole. If an angulated implant needs to be restored, a hybrid abutment designed with a shoulder that follows the soft tissue contours and a cement-retained crown should be considered. The shoulder position is crucial for excess cement removal. The prefabricated fitting surfaces of the TiBases (Sirona) and new implant solution blocks (Vita Zahn-Fabrik, Bad Sackingen, Germany, and Ivoclar Vivadent), the mechanical anti-rotational component, and the parallelism and height of the walls (4.0 mm) seem to provide a safe design for monolithic restoration design¹⁹.

A variety of materials are described in the literature, ranging from polymer-based blocks for temporary restorations (VITA CAD Temp, Vita Zahn-Fabrik and Telio CAD, Ivoclar Vivadent) to silicate ceramic (VITA SUPRINITY IS, Vita Zahn-Fabrik and IPS e.max CAD A, Ivoclar Vivadent) and hybrid ceramic block (VITA ENAMIC IS, Vita Zahn-Fabrik). A minimal marginal shoulder width of 0.4 mm, a circumferential wall thickness of 0.8 mm, and an occlusal thickness of 1.0 mm are recommended by the manufacturers.

■ Zirconia hybrid abutments

Delben et al³ compared external hexagon, internal hexagon, and Morse taper full-zirconia abutment connections. Although the Morse taper connection was more prone to early abutment fracture, probably due to the thin cross-section at the abutment neck, all three groups offer higher strength than mean functional load in the anterior region³.

According to Beuer et al, fracture strength of implant abutments increased with the implant diameter¹⁵. Zirconia implant abutments connected to titanium cores showed higher fracture strength than one-piece zirconia abutments. This hybrid abutment design was recommended as a safe option even for the posterior areas of the mouth¹⁵. Several other authors reported similar findings^{5,12,13,21}.

In respect to the wear at the titanium-titanium and titanium-zirconia implant-abutment interface, Stimmelmayer et al¹⁷ reported a higher wear of titanium implants under cyclic loading when connected to one-piece zirconia abutments than when they

were connected to titanium abutments. Cavusoglu et al² also concluded that the zirconia-abutment-titanium-implant interface is susceptible to wear of the abutment coupled with deformation of the implant neck greater than that associated with the conventional titanium-abutment-titanium-implant interface under dynamic loading. According to Baldassarri et al⁴, the implant-titanium abutment connection showed significantly better fit than all implant-zirconia abutment configurations. Mean gaps were approximately three to seven times larger than those in the titanium abutment systems. In addition, Canullo¹⁸ reported that the gap in the zirconia-core-metal-abutment system was comparable to gap values of the abutment-implant systems available on the market. Another study demonstrated that single implants restored with lithium disilicate crowns and zirconia abutments with titanium inserts could withstand maximum masticatory force in the incisor area when the axial walls of the abutment were at least 0.5 mm thick¹⁹.

■ Bonding to titanium abutments and inserts

The adhesive bonding of titanium inserts into the implant restorations is a key element of the protocol under review. The combination of air-particle abrasion, acid etching and MDP-primer application seems to improve titanium bonding²². It was also concluded that surface modifications influence the retention forces between titanium and zirconia components in two-piece implant abutments²³.

Mehl et al²⁴ studied the influence of abutment height and thermocycling on retrievability of cemented implant-supported crowns. They concluded that crowns cemented with glass ionomer cement were potentially retrievable with a clinically applicable removable device when the abutment height ranged from 2 to 4 mm. Polycarboxylate or composite resin cements should be used as non-retrievable permanent cementation options. When restorations are cemented on abutments with a height of 2 mm or less, composite resin cement should be used to minimise the risk of crown loosening. Abbo et al²⁵ reported that the resistance to tensile forces was significantly increased when the height of the abutment was increased by 1 mm.

■ Monolithic CAD/CAM restorations

A simplified approach to implant restorations with digital technologies was described by Brooks et al²⁶. The benefits of this protocol for fabrication of multiple single crowns in one clinic session include: reduced chair and production time, greater accuracy, reduced cost, improved impression of the gingiva, fewer adjustments, ideal margin location and simplified cementation. Similarly, an *in vitro* study by Alfarsi et al²⁷ concluded that chairside CAD/CAM fabrication of customised ceramic abutments and their associated ceramic crowns using pre-sintered feldspathic porcelain blocks was a viable treatment option. These outcomes were further supported by Stona et al²⁸, who investigated the fracture resistance of CAD/CAM ceramic crowns cemented on solid abutments. Cerec Vita Blocks Mark II (Vita Zahnfabrik), IPS Empress CAD, and IPS e.max CAD (both Ivoclar Vivadent) ceramic crowns cemented on solid abutments had sufficient resistance to withstand physiological chewing forces²⁸. In addition, Martinez-Rus et al²⁰ demonstrated that titanium abutments restored with monolithic lithium disilicate crowns presented the highest fracture resistance compared with manually veneered pressed lithium disilicate and zirconia copings. Some authors suggested the concept of cementing CAD/CAM lithium disilicate crowns to the abutments extraorally and delivering them as screw-retained implant restorations. The preparation of a screw access channel into the lithium disilicate crowns significantly reduced the axial load capacity when compared with intact crowns without occlusal access⁶. However, the actual diameter of the screw access channel did not make a statistically significant difference in terms of load-bearing capacity⁶.

Anti-rotational abutment features positively affected the marginal fit of single implant-retained crowns²⁹. Furthermore, digitizing techniques improved the fit of single-implant restorations²⁹.

Joda et al³⁰ presented a complete digital workflow for the fabrication of implant-supported single-unit monolithic crowns in the posterior jaw. However, the suggested application of a resin nanoceramic (Lava Ultimate Restorative, 3M ESPE, St Paul, Minneapolis, USA) as full-contour material has to be considered

experimental. Clinical investigations with long-term follow-up are necessary³⁰.

Novel material blocks for CAD/CAM restorations supported by a single implant and bonded titanium inserts offer aesthetic advantages over conventional metal abutments and simpler processing than zirconia hybrid abutments. Also, manufacturing costs are reduced with full-anatomic abutment crowns, in which the abutment and the crown are designed as one piece. The absence of a cement space at the abutment-crown interface may present a biologic advantage.

CAD/CAM monolithic implant-supported restorations that are bonded to Ti inserts have several benefits and can be fabricated chairside. However, there is currently no scientific evidence to support the clinical application of this specific design. Several studies, most of them laboratory based, are available on select aspects and similar prosthetic designs. The lack of clinical data from several trials and heterogeneity of the *in vitro* studies did not allow for further statistical analyses of the results. Controlled clinical trials and longitudinal studies are necessary before this type of restoration can be recommended for use in clinical practice without restrictions.

■ Conclusions

While laboratory studies and evaluations of similar designs indicate promising outcomes, there is a strong need for clinical studies that evaluate the performance of CAD/CAM monolithic implant-supported restorations bonded to Ti inserts and bases before this prosthetic design can be recommended for routine use in clinical practice without restrictions.

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