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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 restorations[3].

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 matrix[3]. 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 restorations[3].

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 systems[3]. 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 prostheses[4], 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 complication[7-9]. 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 literature[10]. 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 fracture[11].

To overcome the limitations of bilayer systems with a weak veneering layer, several systems such as resin matrix ceramics[12], lithium disilicate[13] and zirconia ceramics[14] are increasingly used in monolithic application. The advantages of monolithic vs bilayer

restorations are well described in the dental literature[13]. *In vitro* data evaluating the potential of monolithic resin matrix ceramic[15], lithium disilicate[16-18] and zirconia[19] 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 restorations[20]. 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

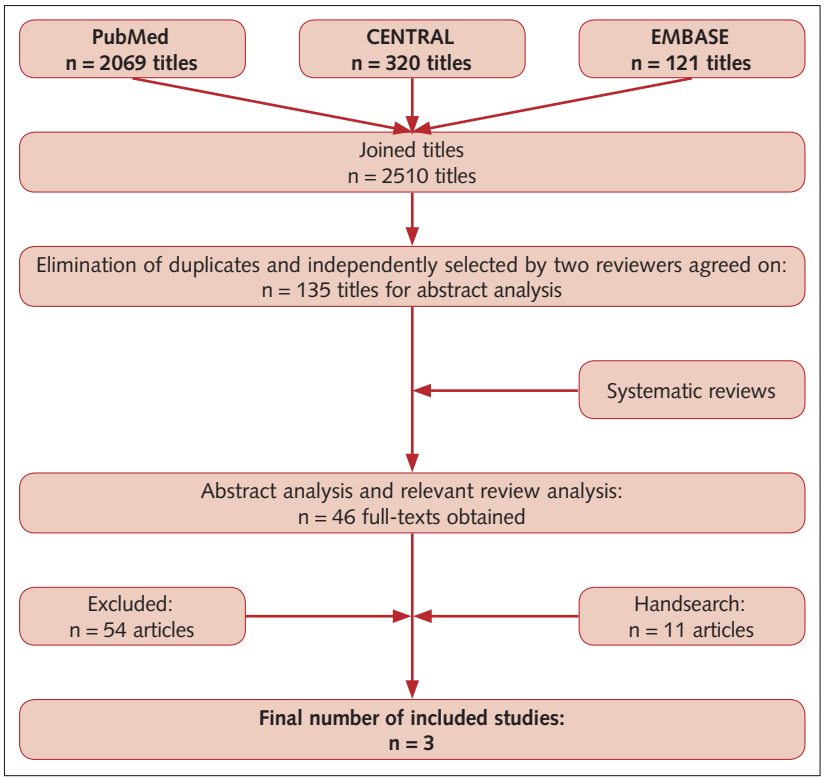

Fig 1 The search strategy.

- 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 publications[21-23] 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 included[21].

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 environment[22]. One study was retrospective and the patients were treated both at a university and in private practices[23]. The third study was a consecutive case series, set in a private practice[21].

The studies reported on different available implant systems: Titanium implants (Astra Tech Implant System, Dentsply Implants, Mannheim, Germany; Straumann, Freiburg, Germany; Nobel Biocare[23]; 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 retention[22], screw retention or a combination of screw and cement retention[21,23]. The material of the reconstructions was lithium disilicate (IPS e.max CAD[22] or IPS e.max Press[23],Ivoclar Vivadent) or zirconia ceramic[21] (Prettau, Zirkonzahn, 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 failed[23] and one crown restoration experienced a technical complication[22].

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 months[23]. 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 months[22].

Zirconia

One cemented implant-supported monolithic zirconia single-crown had to be remade due to a fracture of the zirconia abutment[21] 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 acceptable[22].

The success rate for lithium disilicate crowns bonded to titanium or zirconia was 97,78% after a mean observation period of 28.3 months[23].

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 al[23] 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. Moscovitch[21] 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 or material that leads to improved structural properties of the material. Thus, the risk of fracture and/or chipping events is significantly reduced[13]. 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 restorations[24]. 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 series[25] 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 restorations[25]. 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 frameworks[23] or zirconia implants[9].

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 fracture[23].

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 time[26]. 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 restorations[20]. However the evidence on monolithic zirconia implant-supported single and multi-unit restorations is presently low. In the study by Moscovitch[21] 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.

References

1. Jung RE, Zembic A, Pjetursson BE, Zwahlen M, Thoma DS. Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. Clin Oral Implants Res 2012;23:2–21.
2. Pjetursson BE, Thoma D, Jung R, Zwahlen M, Zembic A. A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years. Clin Oral Implants Res 2012;23:22–38.
3. Gracis S, Thompson VP, Ferencz JL, Silva NR, Bonfante EA. A new classification system for all-ceramic and ceramic-like restorative materials. Int J Prosthodont 2015;28:227–235.
4. Sailer I, Philipp A, Zembic A, Pjetursson BE, Hämmerle CH, Zwahlen M. A systematic review of the performance of ceramic and metal implant abutments supporting fixed implant reconstructions. Clin Oral Implants Res 2009;20:4–31.
5. Pozzi A, Sannino G, Barlattani A. Minimally invasive treatment of the atrophic posterior maxilla: a proof-of-concept prospective study with a follow-up of between 36 and 54 months. J Prosthet Dent 2012;108:286–297.
6. Lops D, Bressan E, Parpaiola A, Sbricoli L, Cecchinato D, Romeo E. Soft tissues stability of cad-cam and stock abutments in anterior regions: 2-year prospective multicentric cohort study. Clin Oral Implants Res 2015;26:1436–1442.
7. Nothdurft FP, Pospiech PR. Zirconium dioxide implant abutments for posterior single-tooth replacement: first results. J Periodontol. 2009;80:2065–2072.
8. Spies BC, Witkowski S, Butz F, Vach K, Kohal RJ. Bi-layered zirconia/fluor-apatite bridges supported by ceramic dental implants: a prospective case series after thirty months of observation. Clin Oral Implants Res 2016; 27:1265–1273.
9. Spies BC, Kohal RJ, Balmer M, Vach K, Jung RE. Evaluation of zirconia-based posterior single crowns supported by zirconia implants: preliminary results of a prospective multicenter study. Clin Oral Implants Res 2017;28:613–619.
10. Guess PC, Bonfante EA, Silva NR, Coelho PG, Thompson VP. Effect of core design and veneering technique on damage and reliability of Y-TZP-supported crowns. Dent Mater 2013;29:307–316.
11. Kinsel RP, Lin D. Retrospective analysis of porcelain failures of metal ceramic crowns and fixed partial dentures supported by 729 implants in 152 patients: patient-specific and implant-specific predictors of ceramic failure. J Prosthet Dent 2009;101:388–394.
12. Swain MV, Coldea A, Bilkhair A, Guess PC. Interpenetrating network ceramic-resin composite dental restorative materials. Dent Mater 2016;32:34–42.
13. Guess PC, Zavanelli RA, Silva NR, Bonfante EA, Coelho PG, Thompson VP. Monolithic CAD/CAM lithium disilicate versus veneered Y-TZP crowns: comparison of failure modes and reliability after fatigue. Int J Prosthodont 2010;23:434–442.
14. Lohbauer U, Reich S. Antagonist wear of monolithic zirconia crowns after 2 years. Clin Oral Investig 2017;21: 1165–1172.
15. Joda T, Huber S, Bürki A, Zysset P, Brägger U. Influence of Abutment Design on Stiffness, Strength, and Failure of Implant-Supported Monolithic Resin Nano Ceramic (RNC) Crowns. Clin Implant Dent Relat Res 2015;17:1200–1207.
16. Joda T, Bürki A, Bethge S, Brägger U, Zysset P. Stiffness, strength, and failure modes of implant-supported monolithic lithium disilicate crowns: influence of titanium and zirconia abutments. Int J Oral Maxillofac Implants 2015;30: 1272–1279.
17. Albrecht T, Kirsten A, Kappert HF, Fischer H. Fracture load of different crown systems on zirconia implant abutments. Dent Mater 2011;27:298–303.

18. Martínez-Rus F, Ferreiroa A, Özcan M, Bartolomé JF, Pradíes G. Fracture resistance of crowns cemented on titanium and zirconia implant abutments: a comparison of monolithic versus manually veneered all-ceramic systems. Int J Oral Maxillofac Implants 2012;27:1448–1455.
19. Rosentritt M, Rembs A, Behr M, Hahnel S, Preis V. In vitro performance of implant-supported monolithic zirconia crowns: Influence of patient-specific tooth-coloured abutments with titanium adhesive bases. J Dent 2015;43:839–845.
20. Abdulmajeed AA, Lim KG, Närhi TO, Cooper LF. Complete-arch implant-supported monolithic zirconia fixed dental prostheses: A systematic review. J Prosthet Dent 2016;115: 672–677.e671.
21. Moscovitch M. Consecutive case series of monolithic and minimally veneered zirconia restorations on teeth and implants: up to 68 months. Int J Periodontics Restorative Dent 2015;35:315–323.
22. Spies BC, Patzelt SB, Vach K, Kohal RJ. Monolithic lithium-disilicate single crowns supported by zirconia oral implants: three-year results of a prospective cohort study. Clin Oral Implants Res 2016;27:1160–1168.
23. Fabbri G, Zarone F, Dellificorelli G, Cannistraro G, De Lorenzi M, Mosca A, Sorentino R. Clinical evaluation of 860 anterior and posterior lithium disilicate restorations: retrospective study with a mean follow-up of 3 years and a maximum observational period of 6 years. Int J Periodontics Restorative Dent 2014;34:165–177.
24. Patel N. Integrating three-dimensional digital technologies for comprehensive implant dentistry. J Am Dent Assoc 2010;141 Suppl 2:20S–24S.
25. Joda T, Brägger U. Complete digital workflow for the production of implant-supported single-unit monolithic crowns. Clin Oral Implants Res 2014;25:1304-1306.
26. Wiedhahn K. From blue to white: new high-strength material for Cerec–IPS e.max CAD LT. Int J Comput Dent 2007;10: 79–91.
27. Cardelli P, Manobianco FP, Serafini N, Murmura G, Beuer F. Full-Arch, Implant-Supported Monolithic Zirconia Rehabilitations: Pilot Clinical Evaluation of Wear Against Natural or Composite Teeth. J Prosthodont 2016;25:629–633.

List of Reviews

Atieh MA, Payne AG, Duncan WJ, de Silva RK, Cullinan MP. Immediate placement or immediate restoration/loading of single implants for molar tooth replacement: a systematic review and meta-analysis. Int J Oral Maxillofac Implants 2010;25:401–415.

Atieh MA, Atieh AH, Payne AG, Duncan WJ. Immediate loading with single implant crowns: a systematic review and meta-analysis. Int J Prosthodont 2009;22:378–387.

Aglietta M, Siciliano VI, Zwahlen M, Aglietta M1, Siciliano VI, Zwahlen M, Brägger U, Pjetursson BE, Lang NP, Salvi GE. A systematic review of the survival and complication rates of implant supported fixed dental prostheses with cantilever extensions after an observation period of at least 5 years. Clin Oral Implants Res 2009;20:441–451.

den Hartog L, Slater JJ, Vissink A, Meijer HJ, Raghoebar GM. Treatment outcome of immediate, early and conventional single-tooth implants in the aesthetic zone: a systematic review to survival, bone level, soft-tissue, aesthetics and patient satisfaction. J Clin Periodontol 2008;35:1073–1086.

Jung RE, Zembic A, Pjetursson BE, Zwahlen M, Thoma DS. Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. Clin Oral Implants Res 2012;23:2–21.

Patzelt SB, Spies BC, Kohal RJ. CAD/CAM-fabricated implant-supported restorations: a systematic review. Clin Oral Implants Res 2015;26:77–85.

Pjetursson BE, Thoma D, Jung R, Zwahlen M, Zembic A. A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years. Clin Oral Implants Res 2012;23:22–38.

Tomasi C, Wennström JL, Berglundh T. Longevity of teeth and implants – a systematic review. J Oral Rehabil 2008;35:23–32.

List of excluded studies and reason for exclusion

Andersson B, Odman P, Lindvall AM, Brånemark PI. Cemented single crowns on osseointegrated implants after 5 years: results from a prospective study on CeraOne. Int J Prosthodont 1998;11:212–218. [Exclusion criteria: Layered]

Andersson B, Glauser R, Maglione M, Taylor A. Ceramic implant abutments for short-span FPDs: a prospective 5-year multicenter study. Int J Prosthodont 2003;16:640–646. [Exclusion criteria: no detailed information on prosthetics]

Anitua E, Murias-Freijo A, Flores J, Alkhraisat MH. Replacement of missing posterior tooth with off-center placed single implant: Long-term follow-up outcomes. J Prosthet Dent. 2015;114:27–33. [Exclusion criteria: Layered]

Anitua E, Saracho J, Begoña L, Alkhraisat MH. Long-Term Follow-Up of 2.5-mm Narrow-Diameter Implants Supporting a Fixed Prostheses. Clin Implant Dent Relat Res 2016;18: 769–777. [Exclusion criteria: no detailed information on prosthetics]

Attard NJ, Zarb GA. Implant prosthodontic management of partially edentulous patients missing posterior teeth: the Toronto experience. J Prosthet Dent 2003;89:352–359. [Exclusion criteria: no distinction between different materials]

Becker CM. Cantilever fixed prostheses utilising dental implants: a 10-year retrospective analysis. Quintessence Int 2004;35:437-441. [Exclusion criteria: Layered]

Becker W, Becker BE. Replacement of maxillary and mandibular molars with single endosseous implant restorations: a retrospective study. J Prosthet Dent 1995;74:51–55. [Exclusion criteria: no detailed information on prosthetics]

Belli R, Petschelt A, Hofner B, Hajtó J, Scherrer SS, Lohbauer U. Fracture Rates and Lifetime Estimations of CAD/CAM All-ceramic Restorations. J Dent Res 2016;95:67–73. [Exclusion criteria: no implant restorations]

Bonde MJ, Stokholm R, Isidor F, Schou S. Outcome of implant-supported single-tooth replacements performed by dental students. A 10-year clinical and radiographic retrospective study. Eur J Oral Implantol 2010;3:37–46. [Exclusion criteria: Layered]

Cicciù M, Beretta M, Risitano G, Maiorana C. Cemented-retained vs screw-retained implant restorations: an investigation on 1939 dental implants. Minerva Stomatol. 2008;57:167–179. [Exclusion criteria: no detailed information on prosthetics]

Cooper LF, Stanford C, Feine J, McGuire M. Prospective assessment of CAD/CAM zirconia abutment and lithium disilicate crown restorations: 2.4 year results. J Prosthet Dent. 2016;116:33–39. [Exclusion criteria: no distinction between different materials]

De Boever AL, Keersmaekers K, Vanmaele G, Kerschbaum T, Theuniers G, De Boever JA. Prosthetic complications in fixed endosseous implant-borne reconstructions after an observations period of at least 40 months. J Oral Rehabil 2006;33: 833–839. [Exclusion criteria: Layered]

Dhima M, Paulusova V, Carr AB, Rieck KL, Lohse C, Salinas TJ. Practice-based clinical evaluation of ceramic single crowns after at least five years. J Prosthet Dent 2014;111:124–130. [Exclusion criteria: small number of restorations]

Ekfeldt A, Fürst B, Carlsson GE. Zirconia abutments for single-tooth implant restorations: a retrospective and clinical follow-up study. Clin Oral Implants Res. 2011;22:1308–1314. [Exclusion criteria: no detailed information on prosthetics]

Eliasson A, Eriksson T, Johansson A, Wennerberg A. Fixed partial prostheses supported by 2 or 3 implants: a retrospective study up to 18 years. Int J Oral Maxillofac Implants 2006;21: 567–574. [Exclusion criteria: Layered]

Ferrara A, Galli C, Mauro G, Macaluso GM. Immediate provisional restoration of post-extraction implants for maxillary single-tooth replacement. Int J Periodontics Restorative Dent 2006;26:371–377. [Exclusion criteria: Layered]

Ferrari M, Tricarico MG, Cagidiaco MC, Vichi A, Gherlone EF, Zarone F, Sorrentino R. 3-Year Randomized Controlled Prospective Clinical Trial on Different CAD-CAM Implant Abutments. Clin Implant Dent Relat Res 2016. [Exclusion criteria: Layered]

Gallucci GO, Grütter L, Nedir R, Bischof M, Belser UC. Esthetic outcomes with porcelain-fused-to-ceramic and all-ceramic single-implant crowns: a randomized clinical trial. Clin Oral Implants Res 2011;22:62–69. [Exclusion criteria: Layered]

Gotfredsen K. A 5-year prospective study of single-tooth replacements supported by the Astra Tech implant: a pilot study. Clin Implant Dent Relat Res 2004;6:1–8. [Exclusion criteria: Layered]

Groten M, Huttig F. The performance of zirconium dioxide crowns: a clinical follow-up. Int J Prosthodont 2010;23: 429–431. [Exclusion criteria: no implant restorations]

Grunder U, Polizzi G, Goené R, Hatano N, Henry P, Jackson WJ, Kawamura K, Köhler S, Renouard F, Rosenberg R, Triplett G, Werbitt M, Lithner B. A 3-year prospective multicenter follow-up report on the immediate and delayed-immediate placement of implants. Int J Oral Maxillofac Implants 1999;14:210–216. [Exclusion criteria: no detailed information on prosthetics]

Hosseini M, Worsaae N, Schiødt M, Gotfredsen K. A 3-year prospective study of implant-supported, single-tooth restorations of all-ceramic and metal-ceramic materials in patients with tooth agenesis. Clin Oral Implants Res 2013;24: 1078–1087. [Exclusion criteria: Layered]

Kolgeci L, Mericske E, Worni A, Walker P, Katsoulis J, Mericske-Stern R. Technical complications and failures of zirconia-based prostheses supported by implants followed up to 7 years: a case series. Int J Prosthodont 2014;27:544–552. [Exclusion criteria: Layered]

Larsson C, Vult von Steyern P. Five-year follow-up of implant-supported Y-TZP and ZTA fixed dental prostheses. A randomized, prospective clinical trial comparing two different material systems. Int J Prosthodont 2010;23:555–561. [Exclusion criteria: Layered]

Lekholm U, Gunne J, Henry P, Higuchi K, Lindén U, Bergström C, van Steenberghe D. Survival of the Brånemark implant in partially edentulous jaws: a 10-year prospective multicenter study. Int J Oral Maxillofac Implants.1999;14:639–645. [Exclusion criteria: Layered]

Lops D, Mosca D, Casentini P, Ghisolfi M, Romeo E. Prognosis of zirconia ceramic fixed partial dentures: a 7-year prospective study. Int J Prosthodont 2012;25:21–23. [Exclusion criteria: no implant restorations]

Maló P, de Araújo Nobre M, Borges J, Almeida R. Retrievable metal ceramic implant-supported fixed prostheses with milled titanium frameworks and all-ceramic crowns: retrospective clinical study with up to 10 years of follow-up. J Prosthodont 2012;21:256–264. [Exclusion criteria: Layered]

Misch CE, Misch-Dietsh F, Silc J, Barboza E, Cianciola LJ, Kazor C. Posterior implant single-tooth replacement and status of adjacent teeth during a 10-year period: a retrospective report. J Periodontol 2008;79:2378–2382. [Exclusion criteria: Layered]

Naert I, Koutsikakis G, Duyck J, Quirynen M, Jacobs R, van Steenberghe D. Biologic outcome of single-implant restorations as tooth replacements: a long-term follow-up study. Clin Implant Dent Relat Res 2000;2:209–218. [Exclusion criteria: Layered]

Naert I, Koutsikakis G, Duyck J, Quirynen M, Jacobs R, van Steenberghe D. Biologic outcome of implant-supported restorations in the treatment of partial edentulism. part I: a longitudinal clinical evaluation. Clin Oral Implants Res 2002;13:381–389. [Exclusion criteria: Layered]

Nedir R, Bischof M, Szmukler-Moncler S, Belser UC, Samson J. Prosthetic complications with dental implants: from an up-to-8-year experience in private practice. Int J Oral Maxillofac Implants 2006;21:919–928. [Exclusion criteria: Layered]

Nejatidanesh F, Moradpoor H, Savabi O. Clinical outcomes of zirconia-based implant- and tooth-supported single crowns. Clin Oral Investig 2016;20:169–178. [Exclusion criteria: Layered]

Palmer RM, Palmer PJ, Smith BJ. A 5-year prospective study of Astra single tooth implants. Clin Oral Implants Res 2000;11: 179–182. [Exclusion criteria: Layered]

Pozzi A, Sannino G, Barlattani A. Minimally invasive treatment of the atrophic posterior maxilla: a proof-of-concept prospective study with a follow-up of between 36 and 54 months. J Prosthet Dent. 2012;108:286–297. [Exclusion criteria: Layered]

Priest G. Single-tooth implants and their role in preserving remaining teeth: a 10-year survival study. Int J Oral Maxillofac Implants 1999;14:181–188. [Exclusion criteria: Layered]

Romeo E, Chiapasco M, Ghisolfi M, Vogel G. Long-term clinical effectiveness of oral implants in the treatment of partial edentulism. Seven-year life table analysis of a prospective study with ITI dental implants system used for single-tooth restorations. Clin Oral Implants Res 2002;13:133–143. [Exclusion criteria: Layered]

Romeo E, Lops D, Margutti E, Ghisolfi M, Chiapasco M, Vogel G. Implant-supported fixed cantilever prostheses in partially edentulous arches. A seven-year prospective study. Clin Oral Implants Res 2003;14:303–311. [Exclusion criteria: Layered]

Sagirkaya E, Arikan S, Sadik B, Kara C, Karasoy D, Cehreli M. A randomized, prospective, open-ended clinical trial of zirconia fixed partial dentures on teeth and implants: interim results. Int J Prosthodont 2012;25:221–231. [Exclusion criteria: Layered]

Scheller H, Urgell JP, Kultje C, Klineberg I, Goldberg PV, Stevenson-Morre P, Alonso JM, Schaller M, Corria RM, Engquist B, Toreskog S, Kastenbaum F, Smith CR. A 5-year multicenter study on implant-supported single crown restorations. Int J Oral Maxillofac Implants 1998;13:212–218. [Exclusion criteria: Layered]

Sorrentino R, Galasso L, Tetè S, De Simone G, Zarone F. Clinical evaluation of 209 all-ceramic single crowns cemented on natural and implant-supported abutments with different luting agents: a 6-year retrospective study. Clin Implant Dent Relat Res 2012;14:184–197. [Exclusion criteria: Layered]

Sulaiman TA, Delgado AJ, Donovan TE. Survival rate of lithium disilicate restorations at 4 years: A retrospective study. J Prosthet Dent 2015;114:364–366. [Exclusion criteria: no implant restorations]

Tartaglia GM, Sidoti E, Sforza C. A 3-year follow-up study of all-ceramic single and multiple crowns performed in a private practice: a prospective case series. Clinics (Sao Paulo. 2011;66:2063–2070. [Exclusion criteria: Layered]

Testori T, Del Fabbro M, Feldman S, Vincenzi G, Sullivan D, Rossi R Jr, Anitua E, Bianchi F, Francetti L, Weinstein RL. A multicenter prospective evaluation of 2-months loaded Osseotite implants placed in the posterior jaws: 3-year follow-up results. Clin Oral Implants Res 2002;13:154–161. [Exclusion criteria: no detailed information on prosthetics]

Tey VH, Phillips R, Tan K. Five-year retrospective study on success, survival and incidence of complications of single crowns supported by dental implants. Clin Oral Implants Res 2016. [Exclusion criteria: Layered]

Vanlıoglu BA, Özkan Y, Evren B, Özkan YK. Experimental custom-made zirconia abutments for narrow implants in esthetically demanding regions: a 5-year follow-up. Int J Oral Maxillofac Implants 2012;27:1239–1242. [Exclusion criteria: Layered]

Vervaeke S, Collaert B, De Bruyn H. Immediate loading of implants in the maxilla: survival and bone loss after at least 2 years in function. Int J Oral Maxillofac Implants 2013;28:216–221. [Exclusion criteria: no detailed information on prosthetics]

Vigolo P, Mutinelli S. Evaluation of zirconium-oxide-based ceramic single-unit posterior fixed dental prostheses (FDPs) generated with two CAD/CAM systems compared to porcelain-fused-to-metal single-unit posterior FDPs: a 5-year clinical prospective study. J Prosthodont 2012;21:265–269. [Exclusion criteria: Layered]

Wennström JL, Ekestubbe A, Gröndahl K, Karlsson S, Lindhe J. Implant-supported single-tooth restorations: a 5-year prospective study. J Clin Periodontol 2005;32:567–574. [Exclusion criteria: Layered]

Wittneben JG, Buser D, Salvi GE, Bürgin W, Hicklin S, Brägger U. Complication and failure rates with implant-supported fixed dental prostheses and single crowns: a 10-year retrospective study. Clin Implant Dent Relat Res 2014;16:356–364. [Exclusion criteria: Layered]

Worni A, Kolgeci L, Rentsch-Kollar A, Katsoulis J, Mericske-Stern R. Zirconia-based screw-retained prostheses supported by Implants: A retrospective study on technical complications and failures. Clin Implant Dent Relat Res 2015;17:1073–1081. [Exclusion criteria: Layered]

Zarb JP, Zarb GA. Implant prosthodontic management of anterior partial edentulism: long-term follow-up of a prospective study. J Can Dent Assoc 2002;68:92–96. [Exclusion criteria: Layered]

Zarone F, Sorrentino R, Vaccaro F, Russo S, De Simone G. Retrospective clinical evaluation of 86 Procera AllCeram anterior single crowns on natural and implant-supported abutments. Clin Implant Dent Relat Res 2005;7:S95–103. [Exclusion criteria: Layered]

Zembic A, Bösch A, Jung RE, Hämmerle CH, Sailer I. Five-year results of a randomized controlled clinical trial comparing zirconia and titanium abutments supporting single-implant crowns in canine and posterior regions. Clin Oral Implants Res 2013;24:384–390. [Exclusion criteria: Layered]

Zembic A, Philipp AO, Hämmerle CH, Wohlwend A, Sailer I. Eleven-year follow-up of a prospective study of zirconia implant abutments supporting single all-ceramic crowns in anterior and premolar regions. Clin Implant Dent Relat Res 2015;17:e417–426. [Exclusion criteria: Layered]