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REVIEW ARTICLE

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A systematic review of the survival and complication rates of zirconia-ceramic and metal-ceramic single crowns

Bjarni E Pjetursson[1,2] | **Nicola A Valente**[2] | **Malin Strasding**[2] | **Marcel Zwahlen**[3] | **Shiming Liu**[2,4] | **Irena Sailer**[2]

[1]Department of Reconstructive Dentistry, Faculty of Odontology, University of Iceland, Reykjavik, Iceland

[2]Division of Fixed Prosthodontics and Biomaterials, University Clinics for Dental Medicine, University of Geneva, Geneva, Switzerland

[3]Institute of Social and Preventive Medicine, University of Bern, Bern, Switzerland

[4]Department of Prosthodontics, Peking University School and Hospital of Stomatology, Beijing, China

Correspondence
Bjarni E. Pjetursson, Department of Reconstructive Dentistry, Faculty of Odontology, University of Iceland, Vatnsmyrarvegi 16, 101 Reykjavik, Iceland.
Emails: bep@hi.is and bjarni.pjetursson@unige.ch

Abstract

Objectives: The aim of the present systematic review was to analyze the survival and complication rates of zirconia-based and metal-ceramic implant-supported single crowns (SCs).

Materials and Methods: An electronic MEDLINE search complemented by manual searching was conducted to identify randomized controlled clinical trials, prospective cohort and retrospective case series on implant-supported SCs with a mean follow-up time of at least 3 years. Patients had to have been clinically examined at the follow-up visit. Assessment of the identified studies and data extraction was performed independently by two reviewers. Failure and complication rates were analyzed using robust *Poisson's* regression models to obtain summary estimates of 5-year proportions.

Results: The search provided 5,263 titles and 455 abstracts, full-text analysis was performed for 240 articles, resulting in 35 included studies on implant-supported crowns. Meta-analysis revealed an estimated 5-year survival rate of 98.3% (95% CI: 96.8–99.1) for metal-ceramic implant supported SCs ($n = 4,363$) compared to 97.6% (95% CI: 94.3–99.0) for zirconia implant supported SCs ($n = 912$). About 86.7% (95% CI: 80.7–91.0) of the metal-ceramic SCs ($n = 1,300$) experienced no biological/technical complications over the entire observation period. The corresponding rate for zirconia SCs ($n = 76$) was 83.8% (95% CI: 61.6–93.8). The biologic outcomes of the two types of crowns were similar; yet, zirconia SCs exhibited less aesthetic complications than metal-ceramics. The 5-year incidence of chipping of the veneering ceramic was similar between the material groups (2.9% metal-ceramic, 2.8% zirconia-ceramic). Significantly ($p = 0.001$), more zirconia-ceramic implant SCs failed due to material fractures (2.1% vs. 0.2% metal-ceramic implant SCs). No studies on newer types of monolithic zirconia SCs fulfilled the simple inclusion criteria of 3 years follow-up time and clinical examination of the present systematic review.

Conclusion: Zirconia-ceramic implant-supported SCs are a valid treatment alternative to metal-ceramic SCs, with similar incidence of biological complications and less aesthetic problems. The amount of ceramic chipping was similar between the material groups; yet, significantly more zirconia crowns failed due to material fractures.

KEYWORDS
biological, complications, fixed dental prostheses, implant crown, meta-analysis, metal-ceramics, success, survival, systematic review, technical, zirconia framework

1 | INTRODUCTION

The continuous pursuit for aesthetic perfection has led to a constant search for materials that could best serve this purpose, that is, the aesthetic improvement of tooth- and implant-supported reconstructions. The desire for materials that closest approached the appearance of natural dental tissues led to the development and use of zirconia ceramic as reconstructive material (Filser et al., 2001). Over the years, this material has been introduced into common everyday clinical practice, thanks in particular to the promising outcomes of many studies on the properties of zirconia (Guazzato, Albakry, Ringer, & Swain, 2004; Guazzato, Proos, Quach, & Swain, 2004; Guazzato, Quach, Albakry, & Swain, 2005; Studart, Filser, Kocher, & Gauckler, 2007a,2007b; Studart, Filser, Kocher, Luthy, & Gauckler, 2007). Today, it is also widely utilized in implant prosthodontics, in both the realization of single crowns (SCs) and fixed dental prostheses (FDPs).

Even though the data coming from the basic research on zirconia have reassured the clinicians that the mechanical characteristics of zirconia are promising and its clinical use is save (Pjetursson, Sailer, Makarov, Zwahlen, & Thoma, 2015; Sailer, Makarov, Thoma, Zwahlen, & Pjetursson, 2015), it is still uncertain whether or not the zirconia-ceramic reconstructions are a valid alternative to classic metal-ceramics today.

Two recent systematic reviews have investigated the outcomes of implant supported SCs and FDPs without focusing on the difference between all-ceramics and metal-ceramics but rather on the survival and frequency of complications in general (Jung, Zembic, Pjetursson, Zwahlen, & Thoma, 2012; Pjetursson, Thoma, Jung, Zwahlen, & Zembic, 2012).

The systematic review of Jung et al., 2012 reported a 5-year survival rate of implant-supported SCs of 96.3% (95% CI: 94.2–97.6). The 5-year rate of different technical complications reached 8.8% for screw loosening, 4.1% for loss of retention and 3.5% for fracture of the veneering material. The aesthetic complication rate was 7.1% over the 5-year observation period (Jung et al., 2012).

Zirconia implant abutments have been well-documented in the last decade, and their outcomes were shown to be equal to the ones of metal abutments (Sailer et al., 2009). Yet, until today it is not yet fully elucidated whether or not the prognosis of zirconia implant-supported reconstructions is similar to that of metal-ceramic implant reconstructions or not.

For this reason, the aim of the present systematic review was to analyze the outcomes, that is survival rates and technical, biologic and aesthetic complication rates of veneered zirconia and/or monolithic zirconia implant-supported SCs compared to the golden standard, the metal-ceramic implant reconstructions.

2 | MATERIALS AND METHODS

This review was registered at the National Institute for Health Research PROSPERO, International Prospective Register of Systematic Reviews (CRD42017079002).

2.1 | General search strategy

The focused question for this review was determined according to the well-established PICO strategy (Population, Intervention, Comparison, and Outcome) (Sackett 2000, Akobeng 2005).

1. Population: Partially edentulous patients,
2. Intervention: Implant-supported SCs with zirconia framework or monolithic zirconia as restoration material,
3. Comparison: Implant-supported SCs with metal-ceramic as restoration material,
4. Outcome: Survival and complication rates of the reconstructions.

2.2 | Focused question

The focused question of the present review was: “In partially edentulous patients with implant-supported single crowns (SCs) do veneered zirconia and/or monolithic zirconia SCs exhibit differences in prosthetic outcomes compared with metal-ceramic implant-supported SCs?”

2.3 | Literature search strategy

The literature search for this systematic review concentrated on the outcomes of single-unit and multiple-unit implant reconstructions, all relevant literature was included. In the final article selection phase, data were divided into implant-supported SCs, for the present systematic review and fixed dental prostheses (FDPs) for the review by Sailer et al. (2018). Both reviews were prepared in the context of the ITI Consensus Conference 2018.

An extensive search for clinical trials was conducted, through PubMed, until and including November 2016, without time limits. No language limits were applied. An additional manual search was executed to identify relevant articles among the reference lists of all included full-text articles and among the references of the above-mentioned systematic review on implant-supported SCs (Jung et al., 2012).

2.4 | Search terms

The terms of the research were as follows: (((((jaw, edentulous, partially, dental implants, Dental Prosthesis, Implant-Supported[mesh]) OR (partially edentulous) OR (partial edentulism) OR (fixed implant prosthesis))) AND/OR ((Implant-Supported Dental Prosthesis, Crown* AND/OR Bridge* AND/OR fixed partial denture* AND/OR fixed dental prosthesis, zirconium, zirconia, zirconium oxide[mesh]) OR (dental implants, dental prostheses[mesh]) OR (zirconia framework) OR (monolithic zirconia))) AND/OR ((Implant-Supported Dental Prosthesis, Crown*, Bridge*, fixed partial denture*, fixed dental prosthesis, metal*, metal ceramic* [mesh]) OR (dental implants, dental prostheses[mesh]) OR (metal framework))) AND/

OR (Outcome Assessment, Treatment Outcome, dental implants, dental prostheses[mesh] OR dental prostheses outcomes OR dental implant prosthetic outcomes OR dental implant prosthetic failure).

2.5 | Inclusion criteria

Clinical studies were considered for inclusion if all of the following inclusion criteria were met:

1. Human studies.
2. At least 10 patients treated.
3. A follow-up time of at least 3 years.
4. Detailed information on the restoration material utilized.
5. Restoration type clearly described and data from SC and FDP reported separately.
6. If multiple publication on the same patient cohort, only the publication with the longest follow-up time is included.
7. Zirconia-based all-ceramic crowns.
8. Gold-alloy-based metal-ceramic crowns, other metals such as titanium, cobalt-chromium, etc. were excluded.
9. In studies mixing data on different restoration materials, data were only included if less than 10% of the reconstructions were of the second material.

2.6 | Exclusion criteria

Studies not meeting all inclusion criteria were excluded. Also reports based on questionnaires, interviews, and case reports were excluded from the present review.

2.7 | Selection of studies

Two authors (SL and NAV) independently screened the titles derived from the initial search in consideration for inclusion. Disagreements were resolved by discussion. After title screening, the abstracts obtained were screened for inclusion by SL, MS, and NAV. Whenever an abstract was not available electronically, it was extracted from the printed article. Based on the selection of abstracts, articles were then obtained in full text. Again, disagreements were resolved by discussion. Finally, the selection based on inclusion/exclusion criteria was made for the full-text articles by the authors SL, MS, and NAV. For this purpose, materials and methods, results, and discussions of these studies were screened. The selected articles were then double checked by the senior authors IS and BEP. Any issues regarding the selection that came up during the screening were discussed within the group to reach a consensus.

2.8 | Data extraction and method of analysis

Four reviewers (IS, MS, BEP, and NAV) independently extracted the data of the selected articles using data extraction tables. For standardization purposes, every author extracted the data of the same three articles in the beginning of the literature analysis, and the results were then compared within the group and any disagreements were discussed aiming at a consensus to standardize the subsequent analyses.

In some case, when a publication did not provide sufficient information but was judged worthy to be included, the authors were contacted by e-mail or telephone.

All extracted data were double checked, and any questions that came up during the screening and the data extraction were discussed within the group.

Information on the following parameters was extracted: author(s), year of publication, study design, number of patients, number of patients at the end of the study, number of crowns, dropouts, mean age of patients, age range, implant type, restoration type, framework material, brand name for framework material, whether the restoration was monolithic or not, material veneering ceramic, manufacturing procedure, brand name for manufacturing procedure, abutment material, type of fixation, number of crown in-situ at the end of the observation, location in the oral cavity, follow-up time (range, mean), published crown survival rate, location of lost crowns, number of complications (technical, biological), and aesthetic outcomes, reported number of crowns free of complications.

2.9 | Statistical analysis

In the present systematic review, like in previous work, *survival* was defined as the SCs remaining in situ with or without modification for the observation period.

In addition, failure and complication rates were calculated by dividing the number of events (failures or complications) in the numerator by the total SC exposure time in the denominator.

The numerator could usually be extracted directly from the publication. The total exposure time was calculated by taking the sum of:

1. Exposure time of SCs that could be followed for the whole observation time.
2. Exposure time up to a failure of the SCs that were lost due to failure during the observation time.
3. Exposure time up to the end of observation time for SCs in patients that were lost to follow-up due to reasons such as death, change of address, refusal to participate, non-response, chronic illnesses, missed appointments, and work commitments.

For each study, event rates for the SCs were calculated by dividing the total number of events by the total SC exposure time in years. For further analysis, the total number of events was considered to be Poisson's distributed for a given sum of FDP exposure years and Poisson's regression was used with a logarithmic link-function and total exposure time per study as an offset variable (Kirkwood & Sterne, 2003).

Robust standard errors were calculated to obtain 95% confidence intervals of the summary estimates of the event rates (White, 1980, 1982).

To assess heterogeneity of the study specific event rates, the Spearman goodness-of-fit statistics and associated p-value were calculated. The five year survival proportions were calculated via the relationship between event rate and survival function S, $S(T) = \exp(-T^{*}\text{event rate})$, by assuming constant event rates (Kirkwood & Sterne, 2003). The 95% confidence intervals for the survival proportions were calculated using the 95% confidence limits of the event rates. Multivariable Poisson's regression was used to investigate formally whether event rates varied by material utilized, location in the oral cavity, and study design. For the present systematic review, the literature review and evidence synthesis was conducted following the PRISMA guidelines from 2009 with the exception of a formal quality assessment of the included studies as all the included studies were case series and cohorts for which no appropriate tools have been developed and the main issue is completeness of follow-up. All analyses were performed using Stata®, version 12.1 (Stata Corp., College Station, TX, USA).

3 | RESULTS

3.1 | Included studies

A total of 36 studies were included in the present systematic review (Figure 1). Thirty of the 36 studies reported on implant-supported metal or metal-ceramic SCs, eight reported on zirconia-based implant-supported SCs, and two included material consisting of both metal-ceramic and zirconia-ceramic implant-supported SCs. The included zirconia-based SCs all consisted of zirconia core with veneering ceramic and no monolithic zirconia crowns. Two of the included studies were randomized controlled clinical trials (RCTs) comparing flapless implant placement and immediate loading with conventional placement (Cannizzaro, Leone, Consolo, Ferri, & Esposito, 2008) and comparing early implant placement with delayed placement (Schropp & Isidor, 2008a,2008b) 20 studies were prospective cohort studies and the remaining 14 studies were retrospective in design (Table 1).

The studies reporting on implant-supported metal-ceramic SCs were published between 1998 and 2017 with a median publication year of 2012. The studies on zirconia-ceramic implant-supported SCs were on average younger, all published 2013 or later.

The studies included patients between 15 and 81 years old. The proportion of patients who could not be followed for the entire study period was available for majority of the studies and ranged from 0% to 52%. However, only three of the included studies had a drop-out proportion of more than 25% (Table 1).

The 30 included studies, analyzing the outcome of metal-ceramic implant-supported SCs, included a total of 4,542 crowns, from which 83% were cement-retained and only 17% screw-retained. The 8 included studies reporting on zirconia-based implant-supported SCs included a total of 912 crowns, from which 51% were cement-retained and 49% screw-retained (Table 2).

The studies were conducted both in an institutional environment, such as university or specialized implant clinics and in private practice setting.

3.2 | Survival

SC survival was defined as the SCs remaining in situ, with or without modification, for the entire observation period. Twenty-eight studies provided data on survival of metal-ceramic implant-supported SCs and eight studies provided data on survival of zirconia-based implant-supported SCs (Table 3). The first group consisted of 4,363 metal-ceramic SCs, with a mean follow-up of 5.7 years and the second group with a total of 912 zirconia-ceramic SCs and a mean follow-up time of 5.1 years (Table 3).

Meta-analysis revealed that of the originally 4,363 metal-ceramic implant-supported SCs inserted, 87 were lost. The annual failure rate was estimated at 0.35% (95% CI: 0.19–0.66) (Figure 2), translating into a 5-year survival rate for metal-ceramic implant-supported SCs of 98.3% (95% CI: 96.8–99.1) (Table 3). From the 912 zirconia implant-supported SCs, 23 were known to be lost. For this group, the annual failure rate was estimated at 0.49% (95% CI: 0.21–1.18) (Figure 3), translating into a 5-year survival rate for zirconia implant-supported SCs of 97.6% (95% CI: 94.3–99.0) (Table 3). The difference in survival rates between metal-ceramic and zirconia-ceramic SCs did not reach statistical significance ($p = 0.514$).

Moreover, the survival rate of implant-supported SCs was analyzed regarding the location in the dental arch. The 5-year survival rates for both metal-ceramic and zirconia-ceramic SCs were slightly higher in the posterior compared with the anterior area. For metal-ceramic implant-supported SCs, the difference was 97.3% vs. 99.0% and for zirconia-ceramic implant-supported SCs, and the difference was 97.9% vs. 98.6%. The difference, however, did not reach statistical significance ($p = 0.201$ and $p = 0.511$) (Table 4).

The reported survival rate was also analyzed according to study design. The 22 RCTs and prospective studies and the 14 retrospective studies were analyzed separately. For the prospective studies, with 1,873 implant-supported SCs, the estimated 5-year survival was 97.5% (95% CI: 95.3–98.7) and for the retrospective studies, based on 3,402 implant-supported SCs, the estimated 5-year survival was 98.4% (95% CI: 96.8–99.2). The difference between the two groups did not reach statistical significance ($p = 0.373$).

3.3 | Success

Success was defined as an implant-supported SC being free of all complications over the entire observation period.

Nine studies, including 1,300 metal-ceramic implant-supported SCs and two studies with 76 zirconia implant-supported SCs, reported on the total number of implant-supported SCs with experiencing biological or technical complications during the observation period. The estimated 5-year complication rate for metal-ceramic SCs was 13.3% (95% CI: 9.0–19.3) and for zirconia SCs 16.2% (95% CI: 6.2–38.4). The difference between the material groups did not reach statistical significance ($p = 0.622$) (Table 4). Hence, 86.7% of the metal-ceramic implant-supported SCs and 83.8% of the zirconia implant-supported SCs were free of all complications over the entire observation period.

3.4 | Biological complications

Peri-implant mucosal lesions were reported in various ways by the different authors. The 5-year rate of peri-implantitis or soft tissue complications was estimated to by 5.1% for metal-ceramic implant-supported SCs and 5.3% for zirconia implant-supported SCs. Moreover, 3.3% of the implants supporting metal-ceramic SCs and 4.3% of the implants supporting zirconia-based SCs experienced significant bone loss, defined as marginal bone levels more the 2 mm below what can be expected as normal bone remodeling. The difference between the two material groups did, however, not reach statistical significance ($p = 0.946$ and 0.481) (Table 5).

3.5 | Aesthetic complications

From seven studies including 627 metal-ceramic implant-supported SCs, 1.7% of the reconstructions were redone due to aesthetic reasons over the 5-year observation period. Four of the included studies on zirconia implant-supported crowns reported on this issue, and none of the zirconia based crowns had to be redone due to aesthetic reasons. The difference between the material groups reached in this respect statistical significance ($p < 0.001$).

3.6 | Technical complications

Fracture of abutments, abutment screws, or occlusal screws were rare complications with only 0.2% of the metal-ceramic and 0.4% of the zirconia implant-supported SCs experiencing abutment fractures and 0.05% of the metal-ceramic and 0.1% of the zirconia SCs having abutment or occlusal fractures during a 5-year observation period. Abutment or occlusal screw loosening was, however, significantly ($p = 0.015$) more frequent by metal-ceramic implant-supported SCs compared with the zirconia implant-supported SC with a 5-year complication rate of 3.6% and 1.0%, respectively (Table 5).

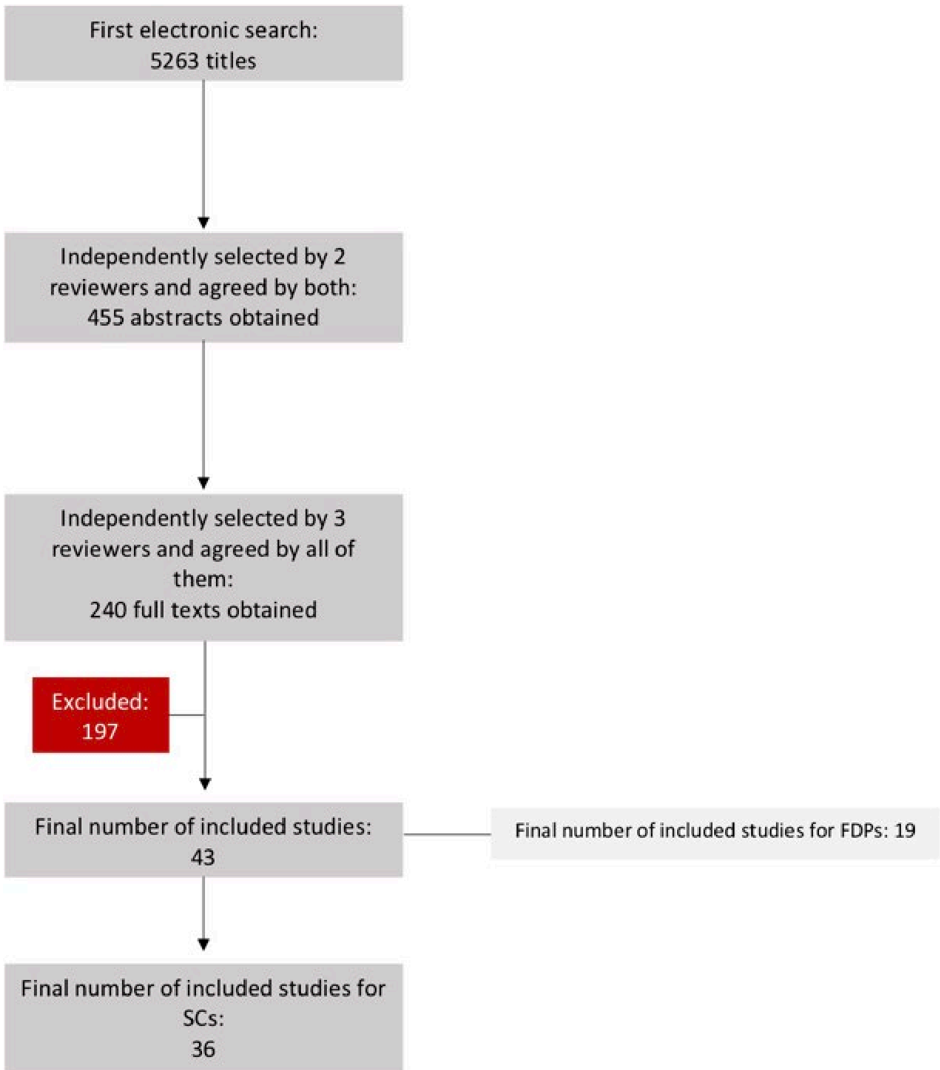

FIGURE 1 Search strategy

TABLE 1 Study and patient characteristics of the reviewed studies

Author (year)	Study design	Planned no. of patients	No. of patients at the end	Drop-out (%)	Mean age (years)	Age range (years)	Setting	Implant system
(a) Metal-ceramic single crowns								
Tey, Phillips and Tan (2017)	Retrospective	781	194	n.r.	57	24–80	Specialist practice	Straumann, Nobel Biocare, Biomet 3i
Mangano et al. (2017)	Retrospective	103	103	0	41.1	24–65	Multicentric private practice	n.r.
Vigolo, Gracis, Carboncini and Mutinelli (2016)	Retrospective	1,159	934	19	49.6	n.r.	Private practices	Various brands with internal and external connections
Donati, Ekestubbe, Lindhe and Wennstrom (2016)	Prospective	40	31	23	40.9	20–71	University	Astra
Walton (2015)	Retrospective	174	174	0	42.3	15–79	Private practice	Nobel Biocare
Mangano, Iaculli, Piattelli and Mangano (2015)	Retrospective	49	49	0	54.5	22–70	Private practice	Mac System
Pozzi, Tallarico and Moy (2014)	Prospective	34	34	0	52.2	39–59	University	Nobel Biocare, Groovy, Speedy
Francetti, Azzola, Corbella, Taschieri and Del Fabbro (2014)	Prospective	22	19	14	n.r.	n.r.	Private clinic	Nobel Replace
Mangano, Shibli, et al. (2014)	Prospective	194	189	3	49.1	24–74	Private practice	Leone Implant System
Mangano, Macchi, et al. (2014)	Prospective	642	606	6	n.r.	20–82	Private practice	Leone Implant System
Wittneben et al. (2014)	Retrospective	358	303	15	n.r.	n.r.	University	Straumann
Vanlioglu, Ozkan and Kulak-Ozkan (2013)	Retrospective	95	95	0	41.2	n.r.	University	Straumann
Lops, Bressan, Chiapasco, Rossi and Romeo (2013)	Prospective	85	81	5	54	36–67	University	Astra
Lai et al. (2013)	Retrospective	168	168	0	45.9	23–72	Hospital	Straumann SLA implants
Perelli, Abundo, Corrente and Saccone (2012)	Prospective	87	87	0	n.r.	n.r.	Private Practice	n.r.
Gotfredsen (2012)	Prospective	20	20	0	33	18–59	University	Astra Tech ST
Schmidlin et al. (2010)	Retrospective	64	41	51	47	24–66	University	n.r.
Cannizzaro et al. (2008)	RCT	40	40	0	n.r.	n.r.	Private practice	Tapered swiss plus (zimmer dental)
Jemt (2008)	Retrospective	38	27	29	25.4	n.r.	Specialist clinic	Brånemark
Schropp and Isidor (2008a,2008b)	Randomized study	45	34	24	48	20–74	University	Osseotite implant (Biomet 3i)

(Continues)

TABLE 1 (Continued)

Author (year)	Study design	Planned no. of patients	No. of patients at the end	Drop-out (%)	Mean age (years)	Age range (years)	Setting	Implant system
(a) Metal-ceramic single crowns								
Ozkan, Ozcan, Akoglu, Ucankale and Kulak-Ozkan (2007)	Prospective	63	63	0	46.9	18–63	University	Straumann, Camlog, Frialit
Turkyilmaz (2006)	Prospective	19	19	0	39	20–55	University	Nobel Mk III
Romeo et al. (2006)	RCT	188	161	14	55.8	21–74	University	Straumann
Dhanrajani and Al-Rafee (2005)	Prospective	101	101	0	35.4	17–69	Private practice	Nobel, 3i, Calcitek, Steri-Oss
Covani, Crespi, Cornelini and Barone (2004)	Prospective	95	n.r.	n.r.	n.r.	20–68	University	Sweden and Martina
Norton (2001)	Retrospective	23	11	52	49	23–77	Private practice	Astra
Bambini, Lo Muzio and Procaccini (2001)	Retrospective	59	59	0	57	38–65	Private practice	Calcitek
Mericske-Stern, Grutter, Rosch and Mericske (2001)	Prospective	72	70	3	50	19–82	University, private practice	Straumann
Polizzi, Fabbro, Furri, Herrmann and Squarzoni (1999)	Prospective	21	21	0	30	13–58	Private center	Nobel Biocare, Brånemark
Scheller et al. (1998)	Prospective	82	66	20	35	14–73	Multicenter	Nobel
		4,921	≈ 3,895					
(b) Zirconia ceramic single crowns								
Vigolo et al. (2016)	Retrospective	1,159	934	19	49.6	n.r.	Private practices	Various brands with internal and external connections
Guncu, Cakan, Aktas, Guncu and Canay (2016)	Prospective	24	24	0	44.1	30-64	University, private practice	Astra
Branzen, Eliasson, Arnrup and Bazargani (2015)	Retrospective	46	36	22	20.5	16–37	University	Nobel Biocare- Brånemark
Worni, Kolgeci, Rentsch-Kollar, Katsoulis and Mericske-Stern (2015)	Retrospective	95	90	5	59.1	n.r.	University	Nobel Biocare
Kolgeci et al. (2014)	Prospective	137	127	7	62.5	n.r.	Private practice	Nobel Replace
Nothdurft, Nonhoff and Pospiech (2014)	Prospective	24	23	4	n.r.	n.r.	University	Xive, Dentsply
Lops et al. (2013)	Prospective	85	81	6	54	36–67	University	Astra
Hosseini, Worsaae, Schiodt and Gotfredsen (2013)	Prospective	59	59	0	27.9	18–50	University	Astra
		1,629	1,374					

Note. n.r.: not reported; RCT: randomized controlled clinical trial.

TABLE 2 Information on materials and procedures of single crowns

Author (year)	Material framework	Monolithic (yes/no)	Veneering material	No. of cemented crowns	No. of screw-retained crowns	No. of crowns anterior	No. of crowns posterior	Total no. of crowns	No. of crowns at the end of observation
Tey et al. (2017)	Metal-ceramic	No	n.r.	263	3	38	228	103	103
Mangano et al. (2017)	Metal-ceramic	No	n.r.	103	0	103	0	45	35
Vigolo et al. (2016)	Metal-ceramic	No	n.r.	1,174	253	169	1,210	1,428	1,428
Donati et al. (2016)	Metal-ceramic	No	n.r.	45	0	21	24	220	220
Walton (2015)	Metal-ceramic	No	n.r.	13	207	139	81	15	15
Mangano et al. (2015)	Metal-ceramic	No	n.r.	n.r.	n.r.	n.r.	n.r.	88	88
Pozzi et al. (2014)	Metal-ceramic	No	n.r.	88	0	0	88	15	14
Francetti et al. (2014)	Metal-ceramic	No	Ceramic	15	0	3	14	215	215
Mangano, Shibli, et al. (2014)	Metal-ceramic	No	Feldspathic porcelain	215	0	0	215	482	478
Mangano, Macchi, et al. (2014)	Metal-ceramic	No	n.r.	478	0	n.r.	n.r.	268	261
Wittneben et al. (2014)	Metal-ceramic	No	Feldspathic porcelain	n.r.	n.r.	n.r.	n.r.	125	125
Vanlioglu et al. (2013)	Metal-ceramic	No	Feldspathic porcelain	125	0	n.r.	n.r.	47	44
Lops et al. (2013)	Metal-ceramic	No	n.r.	47	0	n.r.	44	229	218
Lai et al. (2013)	Metal-ceramic	No	Ceramic	229	0	0	229	63	nr
Perelli et al. (2012)	Metal-ceramic	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	20	20
Gotfredsen (2012)	Metal	No	Ceramic	20	0	n.r.	n.r.	39	39
Schmidlin et al. (2010)	Metal	No	Ceramic	35	4	n.r.	n.r.	108	108
Cannizzaro et al. (2008)	Metal	No	n.r.	108	0	35	73	47	47
Jemt (2008)	Metal	No	Ceramic (n.r.)	0	47	47	0	42	34
Schropp and Isidor (2008a,2008b)	Metal	No	n.r.	40	2	24	21	50	50
Ozkan et al. (2007)	Metal-ceramic	No	Feldspathic porcelain	n.r.	n.r.	0	50	34	33
Turkyilmaz (2006)	Metal-ceramic	No	Ceramco	36	0	14	20	73	72
Romeo et al. (2006)	Metal-ceramic	No	n.r.	58	15	n.r.	n.r.	147	138
Dhanrajani and Al-Rafee (2005)	Metal-ceramic	No	n.r.	n.r.	n.r.	74	73	163	158
Covani et al. (2004)	metal-ceramic	No	n.r.	n.r.	n.r.	n.r.	n.r.	23	12
Norton (2001)	Metal-ceramic	No	Feldspathic porcelain	14	0	12	2	32	32
Bambini et al. (2001)	Metal-ceramic	No	Feldspathic porcelain	0	32	n.r.	n.r.	109	109
Mericske-Stern et al. (2001)	Metal-ceramic	No	Feldspathic porcelain	7	102	n.r.	n.r.	30	30
Polizzi et al. (1999)	Metal-ceramic	No	Feldspathic porcelain	30	0	30	0	16	16

(Continues)

TABLE 2 (Continued)

Author (year)	Material framework	Monolithic (yes/no)	Veneering material	No. of cemented crowns	No. of screw-retained crowns	No. of crowns anterior	No. of crowns posterior	Total no. of crowns	No. of crowns at the end of observation
Scheller et al. (1998)	Metal-ceramic	n.r.	n.r.	16	0	n.r.	n.r.	n.r.	n.r.
Vigolo et al. (2016)	Zirconia-ceramic	No	n.r.	283	257	84	457	541	541
Guncu et al. (2016)	Zirconia-ceramic	No	Feldspathic porcelain	24	0	0	24	24	24
Branzen et al. (2015)	Zirconia-ceramic	n.r.	n.r.	n.r.	n.r.	28	0	28	28
Worni et al. (2015)	Zirconia-ceramic	No	Feldspathic porcelain	0	70	n.r.	n.r.	70	65
Kolgeci et al. (2014)	Zirconia-ceramic	No	Nobel Rondo, Cerabien, Creation	12	108	n.r.	n.r.	120	120
Nothdurft et al. (2014)	Zirconia-ceramic	No	System specific veneering ceramic	39	0	0	39	39	37
Lops et al. (2013)	Zirconia-ceramic	No	n.r.	38	0	0	37	38	37
Hosseini et al. (2013)	Zirconia-ceramic	No	IPS Empress, IPS e.maxceram	61	0	41	11	52	n.r.

Note. n.r.: not reported.

The incidence of ceramic fractures or chippings was reported in majority of the studies. The incidence was similar between the material groups, with 2.9% of the metal-ceramic and 2.8% of the zirconia implant-supported SCs experiencing this complication over the 5-year observation period. Significantly more zirconia implant-supported SCs than metal-ceramic implant-supported SCs, however, failed due to material fractures, with a failure rate of 2.1% compared with 0.2% for metal-ceramic ($p = 0.001$) (Table 5).

Eighteen studies, with 2,211 cemented metal-ceramic implant-supported SCs reported an estimated 5-year complication rate of 2.0% for loss of retention compared with no loss of retention reported for the 115 cemented zirconia implant-supported SCs included in the analysis. The difference between the material groups reaches statistical significance in this aspect ($p < 0.001$).

4 | DISCUSSION

The present meta-analysis showed excellent estimated 5-year survival rates for both zirconia and metal-ceramic implant-supported single crowns with no significant differences between the two material types. Both types of crowns performed equally from a biologic point of view, but the zirconia crowns performed better from an aesthetic point of view.

With respect to technical complications, the incidence of ceramic chipping was similar between the material groups. The zirconia crowns, however, had more frequently to be redone due to fracture of the core or the veneering ceramic than metal-ceramic crowns.

Zirconia-ceramic crowns are well-established as all-ceramic alternative to metal-ceramics on both implants and teeth in clinical practice today. At both indications, the zirconia crowns showed very good 5-year survival rates (Sailer, Makarov, Thoma, Zwahlen, & Pjetursson, 2016; Sailer et al., 2015). Supported by teeth zirconia SCs reached an estimated 5-year survival rate of 91.2% (82.8%–95.6%), (Sailer et al., 2015, 2016) and supported by implants in the present systematic review the zirconia implant-supported SCs even reached a higher estimated 5-year survival rate of 97.6% (94.3%–99%). No statistically significant differences were found between zirconia-based and metal-ceramic crowns in both reviews (Sailer et al., 2015, 2016).

Hence, from this perspective, zirconia is a feasible all-ceramic restorative option for single implants in anterior and posterior regions. It has to be considered that survival rates do not take into consideration that problems might have occurred at the reconstructions over time.

One frequently reported problem of zirconia-ceramic reconstructions in the literature is chipping of the veneering ceramic (Heintze & Rousson, 2010). In the initial applications of zirconia as framework material, this complication was due to the fact that prototype veneering ceramics were used (Sailer et al., 2007).

Later, low fusing veneering ceramics specifically adapted to the biomechanical properties of zirconia were introduced and the technical procedure of veneering the zirconia framework was modified (Aboushelib, Kleverlaan, & Feilzer, 2006). The problem of chipping of the zirconia veneering ceramic still persisted in the more recent

TABLE 3 Annual failure rates and survival of single crowns (SCs) divided according to material utilized

Study (year of publication)	Total no. of SCs	Mean follow-up time (years)	No. of failures	Total exposure time (years)	Estimated annual failure rate[a] (per 100 SC years)	Estimated survival after 5 years[a] (in %)
Metal ceramic						
Tey et al. (2017)	266	5.2	5	1,383	0.36	98.2
Mangano et al. (2017)	103	3	2	309	0.65	96.8
Vigolo et al. (2016)	1,428	5.7	6	8,180	0.07	99.6
Donati et al. (2016)	45	11	1	483	0.21	99.0
Walton (2015)	220	5	3	1,110	0.27	98.7
Mangano et al. (2015)	15	14.3	0	214	0	100
Pozzi et al. (2014)	88	3	0	264	0	100
Francetti et al. (2014)	15	6.8	1	102	0.98	95.2
Mangano, Shibli, et al. (2014)	215	5.6	1	1,204	0.08	99.6
Mangano, Macchi, et al. (2014)	482	5	1	2,410	0.04	99.8
Wittneben et al. (2014)	268	10.8	13	2,806	0.46	97.7
Vanlioglu et al. (2013)	125	5	2	625	0.32	98.4
Lops et al. (2013)	47	4.9	0	230	0	100
Lai et al. (2013)	229	7.2	11	1,653	0.67	96.7
Perelli et al. (2012)	63	4.8	6	300	2.00	90.5
Gotfredsen (2012)	20	10	2	200	1.00	95.1
Schmidlin et al. (2010)	39	6.2	2	243	0.82	96.0
Cannizzaro et al. (2008)	108	3	3	324	0.93	95.5
Jemt (2008)	47	12.3	11	576	1.91	90.9
Schropp and Isidor (2008a,2008b)	42	4.7	2	210	0.95	95.3
Ozkan et al. (2007)	50	3	1	150	0.67	96.7
Turkyilmaz (2006)	34	3	1	101	0.99	95.2
Romeo et al. (2006)	73	5.5	5	404	1.24	94.0
Covani et al. (2004)	163	3.9	3	636	0.47	97.7
Norton (2001)	23	5.3	0	74	0	100
Mericske-Stern et al. (2001)	109	4.3	3	469	0.64	96.9
Polizzi et al. (1999)	30	5.3	2	158	1.27	93.9
Scheller et al. (1998)	16	4.2	0	66	0	100
Total	4,363	5.7	87	24,884		
Summary estimate (95% CI)[a]					0.35 (0.19–0.66)	98.3 (96.8–99.1)

(Continues)

TABLE 3 (Continued)

Study (year of publication)	Total no. of SCs	Mean follow-up time (years)	No. of failures	Total exposure time (years)	Estimated annual failure rate[a] (per 100 SC years)	Estimated survival after 5 years[a] (in %)
Zirconia ceramic						
Vigolo et al. (2016)	541	6.1	8	3,276	0.24	98.8
Guncu et al. (2016)	24	3.9	2	94	2.13	89.9
Branzen et al. (2015)	28	6.8	0	190	0	100
Worni et al. (2015)	70	3.6	4	253	2.44	92.4
Kolgeci et al. (2014)	120	3.2	5	385	1.30	93.7
Nothdurft et al. (2014)	39	2.9	2	116	1.72	91.7
Lops et al. (2013)	38	4.9	0	185	0	100
Hosseini et al. (2013)	52	3.1	2	161	1.24	94.0
Total	912	5.1	23	4,660		
Summary estimate (95% CI)[a]					0.49 (0.21–1.18)	97.6 (94.3–99.0)

Note. [a]Based on robust Poisson's regression.

studies as predominant technical complication. Yet chipping of the veneering material is also the predominant technical complication at metal-ceramic implant reconstructions (Pjetursson et al., 2012).

Besides the material-specific factors, numerous clinical factors contribute to the risk of chipping of the veneered, that is, bi-layer materials at implant-supported reconstructions. It has been shown that the tactile sensitivity is 8.7 times lower at implants than at teeth (Hammerle et al., 1995). Furthermore, a combination of intraoral conditions like temperature and pH changes (Scherrer, Denry, Wiskott, & Belser, 2001) and material defects due to the veneering procedures could also increase the risk (Kelly, 1995).

A promising new alternative to the bi-layer reconstructions are monolithic reconstructions, for example, out of zirconia (Hamza & Sherif, 2017). A pronounced increase in application of the monolithic zirconia implant-supported reconstructions can already be noted. One of the aims of the present systematic review was to analyze the outcomes of monolithic zirconia reconstructions after an observation period of at least 3 years. Unfortunately, no clinical studies on monolithic zirconia reconstructions fulfilled the relatively simple inclusion criteria of the present systematic review. Clinical medium- to long-term studies have, hence, to be awaited before clinical recommendations can be made in this respect.

One main reason for the use of all-ceramics instead of metal-ceramics was and still is aesthetics. Indeed, the zirconia-ceramic SCs exhibited better aesthetic outcomes than the metal-ceramic crowns in the present systematic review.

Zirconia has been reported to have a low plaque accumulation rate, (Cionca, Hashim, & Mombelli, 2017; Roehling et al., 2017) and an excellent hard and soft tissue integration (Thoma et al., 2015) equivalent to the one of titanium. In the present review, no differences of the biologic outcomes of the zirconia and metal-ceramic implant-supported SCs were found. Low incidence of soft tissue complication and marginal bone loss was found for both types of reconstructions.

The main limitation of the present systematic review was that no RTCs were available addressing the present focused question, and that the overall conclusions were based on pooled data of different types of implants placed in different positions in the jaws (maxilla, mandible; anterior, posterior) and different genders. Furthermore, there was a lack of standardized approaches to report biological and technical complications in the available studies. Furthermore, the included studies often clustered data from patients with different observation periods instead of following patients for a well-defined time period. Finally, it may be questioned whether searching only one literature database, that is, Medline, involves a risk that important studies that fulfill the inclusion criteria of the present systematic review go un-noticed. In several systematic reviews published by our research team, the primary literature search was performed in Medline, followed by additional searches of different databases such as Embase and the Cochrane Library. However, the number of additional studies, included through these additional sources, was limited. Therefore, the search strategy of our group has changed to apply a very open and unrestricted title search, avoiding limitations and filters in order to be as inclusive as possible on the title level. Additionally, meticulous hand-searching of all reference lists of previous reviews and all included full-text papers of the present systematic review helped locating the included studies of the present and a parallel review addressing multi-unit implant supported fixed dental prostheses (Sailer et al., 2018; ITI CC SR).

5 | CONCLUSIONS

In conclusion, the zirconia-ceramics can be recommended as valid alternative to metal-ceramics for implant-supported SCs. Although bi-layered, veneered zirconia has been dominantly associated with the technical complication such as "chipping of the veneering ceramic" in the literature, this problem was also frequently found for metal-ceramic implant reconstructions. Newer types

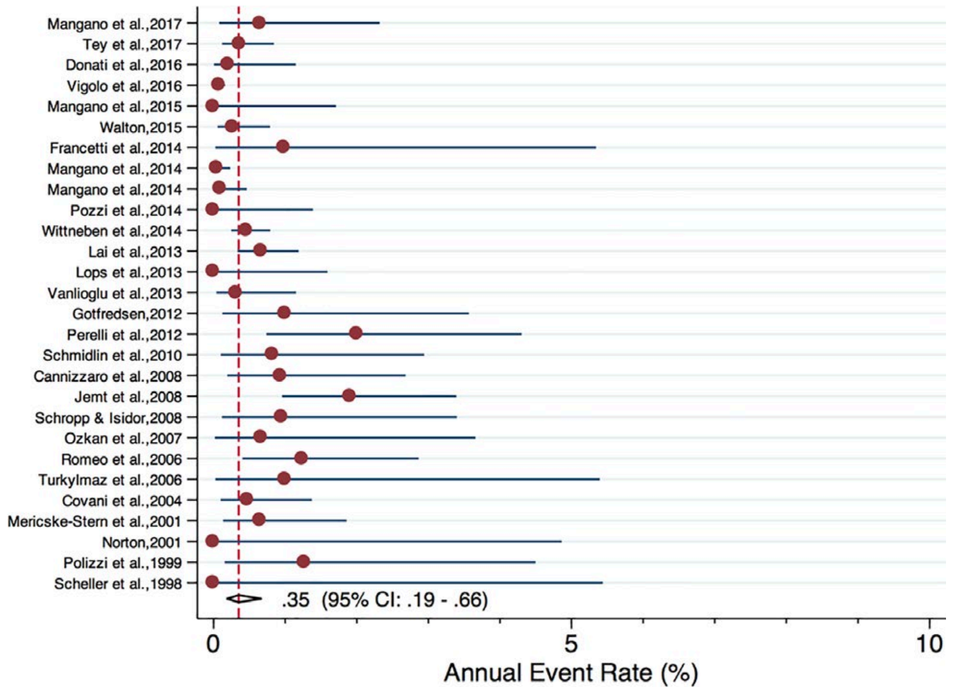

FIGURE 2 Annual failure rates (per 100 years) of implant-supported metal-ceramic single crowns.

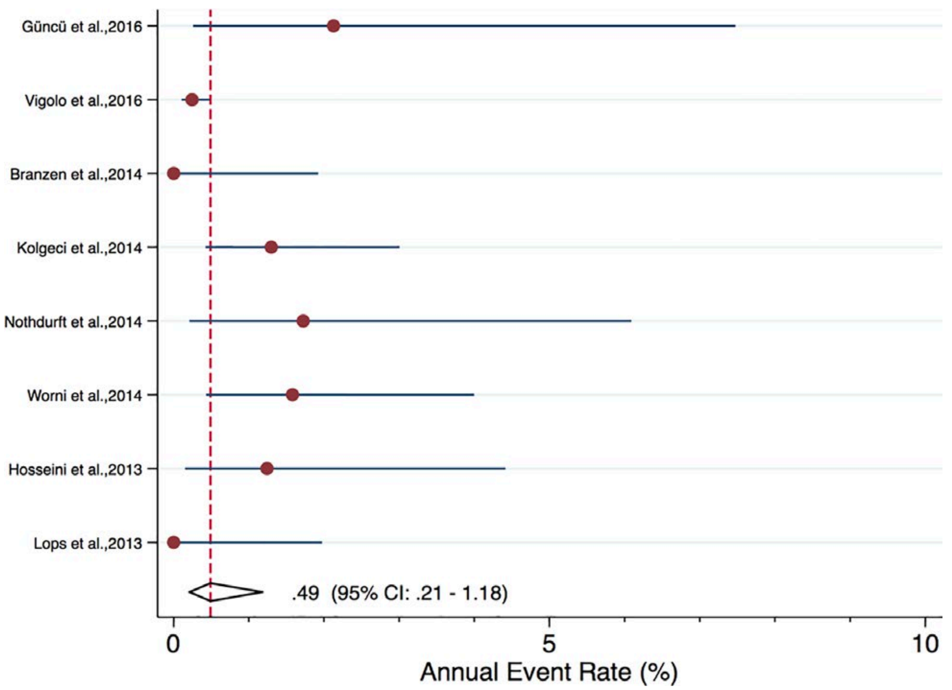

FIGURE 3 Annual failure rates (per 100 years) of implant-supported zirconia single crowns.

TABLE 4 Annual failure rates and estimated 5-year survival according to position in the mouth. Based on robust Poisson's regression

	Total number of single crowns (SCs)	Estimated annual failure rate (95% CI)	5-year summary estimate, % (95% CI)	Total number of SCs	Estimated annual failure rate (95% CI)	5-year summary estimate, % (95% CI)	*p*-Value*
	Anterior			Posterior			
Metal-ceramic	520	0.55* (0.14–2.06)	97.3* (90.2–99.3)	2,078	0.19* (0.07–0.53)	99.0* (97.4–99.6)	0.201
Zirconia-ceramic	112	0.43* (0.15–1.25)	97.9* (94.0–99.3)	557	0.28* (0.11–0.74)	98.6* (96.4–99.5)	0.511

*Based on robust Poisson's regression.

TABLE 5 Comparing annual failure and complication rates of metal-ceramic single crowns (SCs) and zirconia-ceramic SCs. Based on robust Poisson's regression

Complication	Number of SCs	Estimated annual complication rates (95% CI)	Cumulative 5 year complication rates, % (95% CI)	Number of SCs	Estimated annual complication rates (95% CI)	Cumulative 5 year complication rates, % (95% CI)	*p*-Value
	Metal-ceramic			Zirconia-ceramic			
Total number of SCs with complications	1,300	2.85* (1.89–4.29)	13.3* (9.0–19.3)	76	3.53* (1.29–9.69)	16.2* (6.2–38.4)	0.622
Soft tissue complications	2,118	1.05* (0.47–2.34)	5.1* (2.3–11.0)	234	1.09* (0.40–2.95)	5.3* (2.0–13.7)	0.946
Significant marginal bone loss	3,254	0.67* (0.32–1.41)	3.3* (1.6–6.8)	670	0.88* (0.69–1.13)	4.3* (3.4–5.5)	0.481
Aesthetic failures	627	0.34* (0.10–1.15)	1.7* (0.5–5.6)	224	0 (0–0.44)	0* (0–2.2)	<0.001
Abutment fracture	3,998	0.03* (0.01–0.09)	0.2* (0.06–0.5)	790	0.07* (0.04–0.12)	0.4* (0.2–0.6)	0.199
Abutment or occlusal screw fracture	3,788	0.01* (0.003–0.3)	0.05* (0.01–0.2)	814	0.02* (0.01–0.04)	0.1* (0.07–0.2)	0.204
Abutment or occlusal screw loosening	3,954	0.7* (0.34–1.56)	3.6* (1.7–7.5)	694	0.21* (0.10–0.43)	1.0* (0.5–2.1)	0.015
Ceramic fracture or chipping	4,090	0.58* (0.35–0.97)	2.9* (1.7–4.7)	694	0.57* (0.13–2.60)	2.8* (0.6–12.2)	0.986
Failure due to fracture of the restoration	2,592	0.04* (0.01–0.14)	0.2* (0.07–0.67)	371	0.43* (0.18–1.06)	2.1* (0.9–5.1)	0.001
Loss of retention of cemented SCs	2,211	0.40* (0.25–0.64)	2.0* (1.3–3.1)	115	0 (0–0.99)	0* (0–4.8)	<0.001

*Based on robust Poisson's regression.

of monolithic zirconia reconstructions seem interesting with this respect; yet, clinical studies reporting on medium-to long-term outcomes of monolithic zirconia restorations are still lacking. Hence, more research is needed until conclusions on their indications and limitations can be drawn.

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CONFLICT OF INTEREST

The authors have no specific conflict of interest related to the present systematic review.

ORCID

Bjarni E Pjetursson http://orcid.org/0000-0002-2063-5092

Nicola A Valente http://orcid.org/0000-0003-1403-5274

Irena Sailer http://orcid.org/0000-0002-4537-7624

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SUPPORTING INFORMATION

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