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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 multiple-unit fixed dental prostheses

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Abstract

Objectives: The aim of the present review was to compare the outcomes, that is, survival and complication rates of zirconia-ceramic and/or monolithic zirconia implant-supported fixed dental prostheses (FDPs) with metal-ceramic FDPs.

Materials and Methods: An electronic MEDLINE search complemented by manual searching was conducted to identify randomized controlled clinical trials, prospective cohort studies and retrospective case series on implant-supported FDPs with a mean follow-up of at least 3 years. Patients had to have been examined clinically 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* 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 19 studies on implant FDPs that met the inclusion criteria. The studies reported on 932 metal-ceramic and 175 zirconia-ceramic FDPs. Meta-analysis revealed an estimated 5-year survival rate of 98.7% (95% CI: 96.8%–99.5%) for metal-ceramic implant-supported FDPs, and of 93.0% (95% CI: 90.6%–94.8%) for zirconia-ceramic implant-supported FDPs ($p < 0.001$). Thirteen studies including 781 metal-ceramic implant-supported FDPs estimated a 5-year rate of ceramic fractures and chippings to be 11.6% compared with a significantly higher ($p < 0.001$) complication rate for zirconia implant-supported FDPs of 50%, reported in a small study with 13 zirconia implant-supported FDPs. Significantly ($p = 0.001$) more, that is, 4.1%, of the zirconia-ceramic implant-supported FDPs were lost due to ceramic fractures compared to only 0.2% of the metal-ceramic implant-supported FDPs. Detailed analysis of factors like number of units of the FDPs or location in the jaws was not possible due to heterogeneity of reporting. No studies on monolithic zirconia implant-supported FDPs fulfilled the inclusion criteria of the present review. Furthermore, no conclusive results were found for the aesthetic outcomes of both FDP-types.

Conclusion: For implant-supported FDPs, conventionally veneered zirconia should not be considered as material selection of first priority, as pronounced risk for

framework fractures and chipping of the zirconia veneering ceramic was observed. Monolithic zirconia may be an interesting alternative, but its clinical medium- to long-term outcomes have not been evaluated yet. Hence, metal ceramics seems to stay the golden standard for implant-supported multiple-unit FDPs.

KEYWORDS

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

1 | INTRODUCTION

In recent years, the variety of restorative materials for implant-supported reconstructions has significantly increased (Fehmer, Muhlemann, Hammerle, & Sailer, 2014). While metal ceramics were the golden standard for the fabrication of implant-supported reconstructions in the past, CAD/CAM technology allows for the use of less expensive materials and faster manufacturing procedures aiming to increase the general efficiency of the treatments nowadays (Benic, Muhlemann, Fehmer, Hammerle, & Sailer, 2016; Joda, Zarone, & Ferrari, 2017). As a consequence, the application of all-ceramics in general, and specifically zirconia as restorative material for implant-supported single crowns (SCs) and fixed dental prostheses (FDPs), has increased (Guess, Att, & Strub, 2012).

One advantage of the recent CAD/CAM ceramics such as zirconia is reduced treatment costs and treatment time (Joda et al., 2017). Another advantage is the improved aesthetics with the all-ceramic implant reconstructions as compared to metal-ceramic reconstructions. As an example, studies have shown that zirconia abutments supporting all-ceramic implant reconstructions exhibited superior soft tissue color outcomes compared with metal abutment supporting metal-ceramic reconstructions (Jung et al., 2008).

Yet, despite the large selection of materials available on the market today, the selection of the best possible restorative solution remains to be difficult for the clinicians. Up to date, the most investigated restorative material in the prosthodontic literature remains to be metal ceramics. Clinicians, however, increasingly tend to use zirconia for the fabrication of implant-supported SC and FDPs in their daily practices. The long-term behavior of more recent restorative materials such as zirconia, and their impact on the survival and complication rates of implant-supported reconstructions, still remains an open question. Hence, the long-term outcomes have to be elucidated in more detail and compared to the golden standard before considered a standard of care.

Two systematic reviews from 2012 reported on the survival and complication rates of implant-supported SCs and FDPs in general, yet not focusing on the type of material used for restoration (Jung, Zembic, Pjetursson, Zwahlen, & Thoma, 2012; Pjetursson, Thoma, Jung, Zwahlen, & Zembic, 2012). The systematic review of Pjetursson et al. reported an estimated 5-year survival rate of implant-supported FDPs of 95.4% (95% CI: 93.1%–96.9%). Regarding technical complications, fractures of the veneering material occurred in 13.5% (95% CI: 8.5%–20.8%), abutment or screw loosening occurred in 5.3% (95% CI: 3.6%–7.7%), and loss of retention occurred in 4.7% (95% CI: 2.6%–8.5%). The authors concluded that implant-supported FDPs are a valid and predictable treatment option and dentists should decide upon reliable materials for the implant-supported reconstructions.

For this reason, it was the aim of the present review to analyze the outcomes, that is, survival rates and technical, biologic and aesthetic complication rates of the zirconia-ceramic and/or monolithic zirconia implant-supported multiple-unit FDPs, as compared to the golden-standard, the metal-ceramic implant-supported multiple-unit FDPs.

2 | MATERIAL AND METHODS

This systematic review was registered at the National Institute for Health Research PROSPERO, International Prospective Register of Systematic Reviews (registration number CRD42017079072).

2.1 | Focused question

The focused question was determined according to the PICO strategy (Population, Intervention, Comparison, and Outcome) (Akobeng, 2005; Sackett, Richardson, Rosenberg, & Haynes, 2000).

- Population: Partially edentulous patients
- Intervention: Implant-supported fixed dental prostheses (FDPs) with veneered zirconia framework or monolithic zirconia as restoration material
- Comparison: FDPs with metal ceramic as restoration material
- Outcome: Survival and complication rates of the reconstructions

The focused question of the present review was: "In partially edentulous patients with implant-supported fixed dental prostheses (FDPs), do zirconia-ceramic and/or monolithic zirconia FDPs exhibit different prosthetic outcomes compared to metal-ceramic FDPs?"

2.2 | Search strategy

Electronic Medline (PubMed) search was performed for studies published until and including November 2016. The extracted data

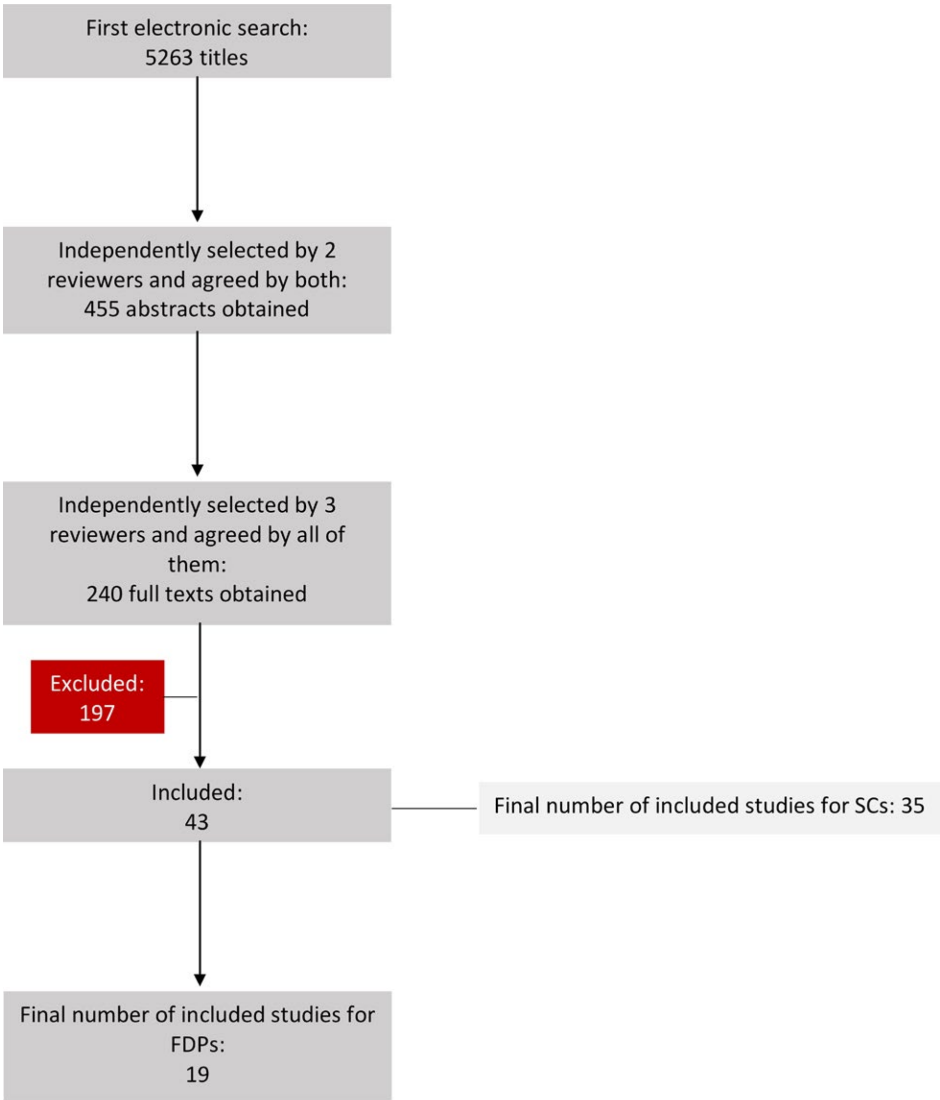

FIGURE 1 Search strategy

were used for conducting two systematic reviews and meta-analyses, one focusing on zirconia- and metal-ceramic implant-supported single crowns (SCs) and the second one focusing on zirconia- and metal-ceramic multiple-unit FDPs. The data were divided into the separate groups for SCs and FDPs during data extraction. Furthermore, a hand search was performed, taking into consideration all the reference lists of the included literature, and of the two relevant systematic reviews on implant-supported fixed reconstructions (Jung et al., 2012; Pjetursson et al., 2012), comprising publications from August 2006 up to August 2011 (Jung et al., 2012) and publications from 2004 up to August 2011 (Pjetursson et al., 2012).

2.3 | Search terms

The following search strategy was applied for the Pubmed search:

(((((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)

The search was limited to “clinical trial” and “review,” “abstract,” “free full text” and “full text” and to “humans.”

2.4 | Inclusion criteria

No language restrictions were applied; consequently, studies in all languages were included. This systematic review aimed to include

primarily RCTs, but also prospective cohort studies and case series and retrospective case series.

Studies were included if they met the following inclusion criteria:

- Human
- Clinical studies: that is, randomized controlled clinical trials, controlled trials, prospective cohort studies, prospective case series, retrospective studies
- patients were clinically examined
- At least 10 patients treated
- A mean follow-up time of at least 3 years
- Restoration type, SCs or multiple-unit FDPs, clearly reported
- Restorative materials described in detail
- Restorative materials metal ceramic or zirconia ceramic
- All-ceramic restorations with zirconia frameworks subsequently veneered, or monolithic zirconia restorations
- Studies that pooled the outcomes of different materials were included if more than 90% of reconstructions belonged to the same material group that is zirconia or metal-ceramic groups.

2.5 | Exclusion criteria

The following studies were excluded:

- Studies that did not report on the restorative material in detail
- Studies with pooled results of different restorative materials
- Studies with pooled results for SCs and FDPs that did not allow a distinction between the results of SCs and FDPs
- Studies including implant-supported full arch reconstructions in a higher proportion than 15%
- Studies on removable implant-supported reconstructions
- In vitro studies
- Animal trials
- Preclinical studies
- Studies with less than 10 patients treated
- Less than 3 years of mean follow-up time
- Studies that did not meet the above inclusion criteria

2.6 | Selection of studies

For the selection of the abstracts, two of the authors (NAV, SL) screened the titles independently. Whenever there was disagreement, it was solved by discussion. After having agreed on the abstracts to be included, the abstracts were screened by three of the authors (MS, NAV, SL) independently. Again, whenever there was a dissent the authors agreed by discussion. In case an abstract was not available in Pubmed, the abstract was extracted out of the printed article. The same three investigators (MS, NAV, SL) continued with the selection of the full-text articles, based on the agreed inclusion criteria on abstract level. Finally, the selected full-text articles were double-checked independently by the two senior authors of the present review (IS, BEP).

Additionally, the reference lists of all included studies and the references lists of the previously mentioned reviews (Jung et al., 2012; Pjetursson et al., 2012) were hand searched.

2.7 | Excluded studies

A total of 240 full-text articles were screened by the authors, out of which 197 articles were excluded (Figure 1). The detailed references and individual reasons for exclusion are given in the reference list of excluded literature. Main reasons for exclusion were lacking information on the type of material, no details or differentiation of the restoration type, and pooled results for either different material or different restoration types. Other reasons for exclusion were restoration material other than zirconia ceramic and metal ceramic, insufficient follow-up time, and <10 patients treated.

2.8 | Data extraction

After the extensive search of the literature, and after the additional hand search, in total, 43 studies could be included in the present systematic review (Figure 1). For the extraction of the data, a table was designed, containing 58 parameters that were to be extracted out of the studies.

The data extraction was performed by four reviewers (BEP, IS, MS, NAV). In order to follow a standardized method, in the beginning, every author extracted the data of three articles and these results were then discussed within the group. This way the same approach for data extraction by all reviewers could be guaranteed. It was distinguished between data for implant-supported SCs and multiple-unit FDPs and for the present meta-analysis, only data for the multiple-unit FDPs were included. Whenever a clear distinction of reconstruction types and/or materials was not possible, either the corresponding author was contacted for clarification, or the study was excluded due to the pooled data.

Data were extracted on follow-up period, the type/s of reconstruction material, the way of fixation of the reconstruction, the cement type, the region of the reconstruction in the oral cavity, the number of failure of the reconstructions as well as the number of biological, mechanical, and aesthetic complications. As mechanical complications, restoration fractures, abutment fractures, screw fractures and screw loosening, ceramic fractures, ceramic chippings, and loss of retention were included. The biological complications contained soft tissue complications and reported number of implants with significant bone loss. Besides aesthetic complications, aesthetic failures, as well as mucosal discolorations were extracted.

Of each included study, the available data were extracted. Studies that reported on the survival of the FDPs were used for the extraction of the survival rates. Studies that reported on the complications but not in detail on the survival were used for the extraction

TABLE 1 Study and patient characteristics of the reviewed studies on metal-ceramic FDP

Metal-ceramic fixed dental prostheses													
Study (Year)	Study Design	Planned no of patients	Number of patients at end of study	Sex M/F	Drop out %	Mean age	Age range	Setting	Implant system	Ant.	Post.	Max.	Mand.
Mangano, Iaculli, Piattelli, and Mangano (2015)	Retrospective	49	49	26/23	0	54.5 ± 3.1	22–70	Private practices	Mac System	n.r.	n.r.	n.r.	n.r.
Wittneben et al. (2014)	Retrospective	358	303	143/160	15	n.r.	n.r.	University	Straumann	n.r.	n.r.	n.r.	n.r.
Francetti, Azzola, Corbella, Taschieri, and Del Fabbro (2014)	Prospective case series study	22	19	10/12	14	n.r.	n.r.	Private clinic	Nobel Replace	n.r.	n.r.	5	13
Romeo, Storelli, Casano, Scanferla, and Botticelli (2014)	Prospective (RCT)	24	18	12/12	25	54.3 ± 11.3	32–75	University	Straumann	0	24	n.r.	n.r.
Mangano et al. (2014)	Prospective	642	606	356/286	6	n.r.	20–82	Private practice	Leone Implant System	n.r.	n.r.	n.r.	n.r.
Vanlioglu, Ozkan, and Kulak-Ozkan (2013)	Retrospective	95	95	46/49	0	41.2	n.r.	University	Straumann	0	n.r.	0	0
Perelli, Abundo, Corrente, and Saccone (2012)	Prospective	87	87	52/35	0	n.r.	n.r.	Private Practice	n.r.	n.r.	n.r.	n.r.	n.r.
Palmer, Howe, Palmer and, Wilson (2012)	Prospective	31	27	9/22	7	50 ± 15.8	18–70	University	MT Osseospeed Astra Tech AB	0	28	20	8
Nissan, Narobai, Gross, Ghelfan, and Chaushu (2011)	Retrospective on prospective cohort	38	38	16/22	0	58 ± 16	38–70	University	Biomet 3i internal hex	0	76	n.r.	n.r.
Wahlstrom, Sagulin, and Jansson (2010)	Retrospective	50	46	13/33	8	n.r.	n.r.	Public dental service	Astra Tech, Nobel Biocare	n.r.	n.r.	34	0
Romeo, Tomasi, Finini, Casentini, and Lops (2009)	Prospective	59	32	25/34	46	63	42–100	University + private practice	straumann	n.r.	n.r.	33	26
Ozkan, Ozcan, Akoglu, Ucankale, and Kulak-Ozkan (2007)	Prospective cohort	63	63	25/38	0	46.9	18–63	University setting	Straumann Camlog, Frialit	0	70	32	38
Romeo et al. (2006)	RCT	188	161	83/105	14	55.8	21–74	University setting	Straumann	n.r.	n.r.	n.r.	n.r.
Jemt et al. (2003)	Prospective	42	35	n.r.	17	53 ± 11.5	25–74	Multicenter	Brånemark	n.r.	n.r.	10	49
Bambini, Lo Muzio, and Procaccini (2001)	Retrospective	59	59	35/24	0	56.5	38–65	Private practice	Calcitek	n.r.	n.r.	n.r.	n.r.
Aparicio, Perales, and Rangert (2001)	Retrospective	25	25	10/15	0	54	n.r.	University	Nobel Biocare Brånemark	0	22	n.r.	n.r.

Note. n.r. stands for not reported.

of the complication rates, meanwhile no data on the survival were gained from these studies. From studies reporting in detail on implant single crowns and multiple-unit FDPs in the same cohort, solely the data on the FDPs were extracted for the present review. Hence, the numbers of patients and/or reconstructions may differ in the present data as compared to the originally included patients/reconstructions.

After the individual data extractions, the extracted data weres compared and in case of differing outcomes, corrections were discussed and made in consensus.

2.9 | Statistical analysis

In the present systematic review, like in previous reviews (Jung et al., 2012; Pjetursson et al., 2012), *survival* was defined as the FDP remaining in situ with or without modification for the entire 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 FDP 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:

- Exposure time of FDPs that could be followed for the whole observation time.
- Exposure time up to a failure of the FDPs that were lost due to failure during the observation time.
- Exposure time up to the end of observation time for FDPs that did not complete the observation period due to reasons such as death, change of address, refusal to participate, nonresponse, chronic illnesses, missed appointments, and work commitments.

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

Robust standard errors were calculated to obtain 95% confidence intervals of the summary estimates of the event rates. 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, 2003b). The 95% confidence intervals for the survival proportions were calculated by using the 95% confidence limits of the event rates. Multivariable Poisson regression was used to investigate formally whether event rates varied by material utilized and study design. For the present systematic review, the literature review and evidence synthesis were conducted following the PRISMA guidelines from 2009 with the exception of a formal quality assessment of the

TABLE 2 Study and patient characteristics of the reviewed studies on implant-supported zirconia-ceramic FDPs

Zirconia-ceramic fixed dental prostheses														
Study (Year)	Study Design	Planned no of patients	Number of patients at end of study	Sex	Drop out %	Drop-out number	Mean age	Age range	Setting	Implant system	Ant.	Post.	Max.	Mand.
Worni, Kolgeci, Rentsch-Kollar, Katsoulis, and Mericske-Stern (2015)	retrospective	95	90	52/43	5.3	5	59.1 ± 11.7	n.r.	University	Nobel Biocare	n.r.	n.r.	45	28
Kolgeci et al. (2014)	prospective	137	127	51/76	7.3	10	62.5 ± 13.4	n.r.	private practice	Nobel Replace	n.r.	n.r.	n.r.	n.r.
Larsson and Vult von Steyern (2010)	prospective	18	18	n.r.	0	0	n.r.	37–70	university	Astra Tech standard / ST Astra Tech	n.r.	n.r.	n.r.	n.r.

Note.. n.r. stands for not reported.

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 | Study characteristics

3.1.1 | Included Studies

A total of 19 studies were included in the systematic review. Sixteen of them reported on implant-supported metal-ceramic FDPs and three reported on implant-supported FDPs with zirconia framework. No randomized controlled clinical trials, comparing metal-ceramic, and zirconia-ceramic FDPs were available. Furthermore, no studies reporting on monolithic zirconia FDPs fulfilled the inclusion criteria of the present systematic review.

Sixteen of the included studies reported on metal-ceramic FDPs, while only three studies could be included on zirconia-ceramic FDPs. A larger amount of metal-ceramic FDPs were, hence, analyzed in this review.

Eleven of the included studies were prospective cohort studies and the remaining eight studies were retrospective in design (Tables 1 and 2). One of the included studies, furthermore, randomized the implant sites comparing 6-mm-long implants with 10-mm implants (Romeo et al., 2006). The studies reporting on implant-supported metal-ceramic FDPs were published between 2001 and 2015 with a median publication year of 2012. Two of the studies on zirconia implant-supported FDPs were published in 2014 and the remaining one in 2010.

The studies included patients between 18 and 100 years old. The information on number of patients who could not be followed for the entire study period was available for all included studies and was on average 8.8%. Only one of the included studies had a drop-out proportion exceeding 25% (Table 1).

The 16 included studies, analyzing the outcome of metal-ceramic implant-supported multiple-unit FDPs, included a total of 993 reconstructions supported by 2,289 implant abutments, from which 73% were cement-retained and only 27% screw-retained (Tables 3 and 4). The three included studies reporting on implant-supported multiple-unit FDPs with zirconia framework included a total of 175 reconstructions, from which only 15% were cement-retained and 85% screw-retained.

The studies on metal-ceramic FDPs reported on 2- to 6-unit FDPs, the studies on the zirconia-ceramic FDPs reported on 3- to 5-unit FDPs (Tables 1–4). One study on zirconia-ceramic FDPs included up to 12-unit FDPs (Kolgeci et al., 2014). The data in these studies were not in detail reported in correlation to the different number of units.

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

3.1.2 | Survival

Survival was defined as the FDPs remaining in situ with or without modification for the entire observation period. Fourteen of the included studies provided data on the survival of metal-ceramic implant-supported FDPs and three studies provided data on survival of zirconia implant-supported FDPs (Table 5). The first group consisted of 932 metal-ceramic FDPs with a mean follow-up of 6.3 years and the second group of 175 zirconia FDPs and a mean follow-up time of 5.1 years (Table 5).

Meta-analysis revealed that 15 out of the 932 metal-ceramic implant-supported FDPs originally inserted were lost. The annual failure rate was estimated at 0.26 (95% CI: 0.10 – 0.64) (Figure 2), translating into a 5-year survival rate for metal-ceramic implant-supported FDPs of 98.7% (95% CI: 96.8%–99.5%) (Table 5). From the 175 zirconia implant-supported FDPs, nine were known to be lost. For this group, the annual failure rate was estimated at 1.45 (95% CI: 1.06 – 1.98) (Figure 3), translating into a 5-year survival rate for zirconia implant-supported FDPs of 93.0% (95% CI: 90.6%–94.8%) (Table 5). The difference in survival rates between metal-ceramic and zirconia FDPs reached statistical significance ($p < 0.001$).

The reported survival rate was also analyzed according to study design. The 11 included prospective studies with 710 FDPs and the six retrospective studies with 397 FDPs (Tables 1–4) were analyzed separately. For the prospective studies, the estimated 5-year survival was 97.9% (95% CI: 94.0%–99.3%) and for the retrospective studies the estimated 5-year survival was 98.5% (95% CI: 94.8%–99.5%). The difference between the study designs did not reach statistical significance ($p = 0.714$).

3.1.3 | Success

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

Three studies including 371 metal-ceramic implant-supported FDPs reported on the total number of FDPs with biological or technical complications. The estimated 5-year complication rate for metal-ceramic FDPs was 15.1% (95% CI: 11.2%–20.4%) (Table 6). Hence, 84.9% of the metal-ceramic implant-supported FDPs were free of all complications over the entire observation period. None of the included studies on zirconia implant-supported FDPs reported on the total number of complications or the number of FDPs free of all complications.

3.2 | Technical complications

The total number of complications found at the metal-ceramic FDPs was 15.1% (95% CI: 11.2%–20.4%). None of the studies on the zirconia-ceramic FDPs reported the total number of complications.

Twelve studies reporting on metal-ceramic implant-supported FDPs and one study (Kolgeci et al., 2014) on zirconia implant-supported FDPs analyzed the incidence of fracture of abutments, abutment screws or occlusal screws. Not one single incidence

TABLE 3 Information on materials and procedures of metal-ceramic FDPs

Metal-ceramic fixed dental prostheses								
Study (Year)	**Material framework**	**Monolithic yes/no**	**Material veneering ceramic**	**Cemented**	**Screw retained**	**Total number of included FDPs**	**Examined FDPs in situ at end of observation**	**No. of units (if multiple unit)**
Mangano et al. (2015)	Metal-ceramic	No	n.r.	n.r.	n.r.	29	29	20: 2-units, 5: 3-units, 4: >3-units
Wittneben et al. (2014)	Metal-ceramic	No	Feldspathic porcelain	n.r.	n.r.	129	128	47: 2-units, 57: 3-units, 21: 4-units, 2: 5-units, 1: 6-units
Francetti et al. (2014)	Metal-ceramic	No	Ceramic	18	0	18	18	n.r.
Romeo et al. (2014)	Metal-ceramic	No	n.r.	n.r.	0	24	18	2 or 3-units (number not reported)
Mangano et al. (2014)	Metal-ceramic	No	n.r.	242	0	242	244	n.r.
Vanlioglu et al. (2013)	Metal-ceramic	No	Feldspathic porcelain	52	0	52	52	Only 3-unit
Perelli et al. (2012)	Metal-ceramic	No	n.r.	n.r.	n.r.	47	n.r.	n.r.
Palmer et al. (2012)	Metal-ceramic	No	n.r.	0	28	28	23	n.r.
Nissan et al. (2011)	Metal-ceramic	No	Noritake EX-3	38	38	76	76	2 or 3-units (number not reported)
Wahlstrom et al. (2010)	Metal-ceramic	No	Ceramic	n.r.	n.r.	34	n.r.	13: 2-units, 23: 3-units, 6: 4-units, 3: 5-units, 1: 6-units
Romeo et al. (2009)	Gold alloy	No	Ceramic	46	13	59	n.r.	n.r.
Ozkan et al. (2007)	Metal-ceramic	No	Feldspatic porcelain	n.r.	n.r.	70	70	14: 2-units, 47: 3-units, 9: 4-units
Romeo et al. (2006)	Metal-ceramic	No	n.r.	83	32	115	114	n.r.
Jemt et al. (2003)	Metal-ceramic gold	No	Feldspathic porcelain	0	21	21	18	n.r.
Bambini et al. (2001)	Metal-ceramic	No	Feldspathic porcelain	0	27	27	27	17: 2-units, 10: 3-unit
Aparicio et al. (2001)	Metal-ceramic	No	Ceramic	0	22	22	22	n.r.

Note. n.r. stands for not reported.

of such complications was reported for the material analyzed (Table 6). Abutment or occlusal screw loosening was, on the other hand, reported for 4.1% of the implant abutments supporting metal-ceramic FDPs. None of the included studies on zirconia implant-supported FDPs reported on abutment or occlusal screw loosening (Table 6).

The incidence of ceramic fractures or chippings was not reported in a standardized way and changed significantly depending on the definition utilized. Thirteen studies with 781 metal-ceramic implant-supported FDPs estimated a 5-year rate of pronounced ceramic fractures and chippings to be 11.6% compared with a significantly higher ($p < 0.001$) rate for extensive fracture and chipping for zirconia implant-supported FDPs of 50%, reported in a small study with only 13 zirconia implant-supported FDPs (Table 6). No difference was found regarding the rates for repairable fractures or chippings at the two types of FDPs (metal ceramics: 4.7% (0.9%–22.4%); zirconia ceramics: 2.5% (1.3%–4.9%)) (Table 6).

When analyzing only the FDPs that needed a repair because of ceramic fractures the complication rate dropped down to 4.7% for metal-ceramic implant-supported FDPs and 2.5% for zirconia implant-supported FDPs. The difference between the material groups did not reach statistical significance ($p = 0.481$) (Table 6). However, significantly ($p = 0.001$) more, that is 4.1%, of the zirconia implant-supported FDPs were lost due to ceramic or framework fractures compared to metal-ceramic implant-supported FDPs were only 0.2% of the restorations were lost due to material fractures (Table 6). For six studies, with 476 cemented metal-ceramic implant-supported FDPs the estimated a 5-year rate for loss of retention was 1.9%. The two studies including cemented zirconia implant-supported FDPs did not report on this complication.

3.3 | Biological complications

Peri-implant mucosal lesions were reported in various ways in different publications. The 5-year rate of peri-implantitis or soft tissue complications was estimated to be 3.1% for metal-ceramic implant-supported FDPs and based on one study (Kolgeci et al., 2014) reporting on 73 FDPs this complication was estimated to be significantly ($p = 0.030$) higher for zirconia implant-supported FDPs that is 10.1% (Table 6).

Furthermore, 1.0% of the implants supporting metal-ceramic FDPs experienced substantial bone loss, defined as marginal bone levels more than 2 mm below what can be expected as normal bone remodeling. None of the included studies on zirconia implant-supported FDPs reported on marginal bone loss (Table 6).

3.4 | Aesthetic complications

Two studies including 94 metal-ceramic implant-supported FDPs and one study (Kolgeci et al., 2014), with 73 zirconia implant-supported FDPs reported on aesthetic issues. The authors reported that none of included reconstructions had to be remade due to aesthetic reasons over the 5 years observation period (Table 6).

TABLE 4 Information on materials and procedures of zirconia-ceramic FDPs

Study (Year)	Material framework	Monolithic yes/no	Material veneering ceramic	Cemented	Screw retained	Total number of included FDPs	Examined FDPs in situ at end of observation	No. of units (if multiple unit)
Zirconia-ceramic fixed dental prostheses								
Worni et al. (2015)	Zirconia	No	Feldspathic porcelain	0	89	89	91	60: 3-units, 18: ≥4-units
Kolgeci et al. (2014)	Zirconia	No	Nobel Rondo, Cerabien, Creation	13	60	73	73	55: 3/4-units, 18: 5/12 units
Larsson and Vult von Steyern (2010)	Zirconia	No	Esprident Triceram (Dentaurum)	13	0	13	13	11: 2-units, 11: 3-units, 1: 4-units, 1: 5-units

Note. n.r. stands for not reported.

TABLE 5 Annual failure rates and survival of FPDs divided according to material utilized

Study (Year)	Total no. of FDPs	Mean follow-up time (years)	No. of failures	Total exposure time (years)	Estimatedannual failure rate[a] (per 100 FDP years)	Estimated survival after 5 years[a] (in percent)
Metal ceramic						
Mangano et al. (2015)	29	16	0	464	0	100
Wittneben et al. (2014)	129	10.8	2	1,365	0.15	99.3
Francetti et al. (2014)	18	6.8	0	123	0	100
Romeo et al. (2014)	24	4.3	1	99	1.01	95.1
Mangano et al. (2014)	242	5	2	1,210	0.17	99.2
Vanlioglu et al. (2013)	52	5	2	260	0.77	96.2
Perelli et al. (2012)	47	5	0	235	0	100
Palmer et al. (2012)	28	2.8	6	77	7.79	67.7
Nissan et al. (2011)	76	5.3	0	402	0	100
Romeo et al. (2009)	59	10	0	590	0	100
Ozkan et al. (2007)	70	2	0	210	0	100
Romeo et al. (2006)	115	5.5	1	637	0.16	99.2
Jemt et al. (2003)	21	4.8	1	102	0.98	95.2
Aparicio et al. (2001)	22	3	0	68	0	100
Total	**932**	**6.3**	**15**	5,842		
Summary estimate (95 % CI) [a]					**0.26 (0.10–0.64)**	**98.7** (96.8–99.5)
Zirconia ceramic						
Kolgeci et al. (2014)	73	3.2	4	234	1.71	91.8
Worni et al. (2015)	89	3.6	5	322	1.55	92.5
Larsson and Vult von Steyern (2010)	13	5	0	65	0	100
Total	**175**	**5.1**	**9**	**621**		
Summary estimate (95 % CI) [a]					**1.45 (1.06–1.98)**	**93.0 (90.6–94.8)**

Note. [a]Based on robust Poisson regression.

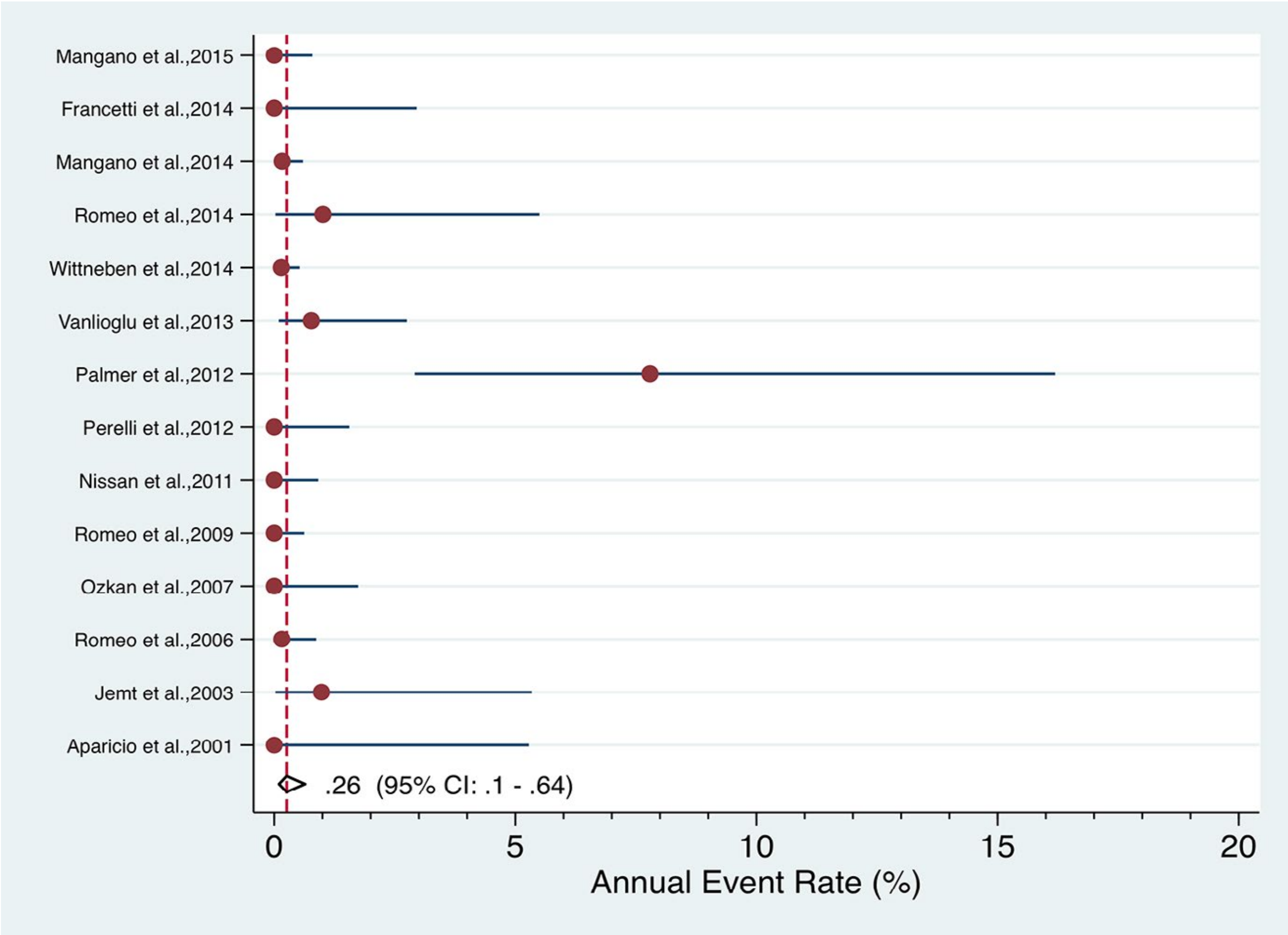

FIGURE 2 Annual failure rates (per 100 years) of implant-supported metal-ceramic FDPs

4 | DISCUSSION

The present systematic review showed that, in general, implant-supported FDPs exhibited very high 5-year survival rates. It was observed, however, that the 5-year survival rates of the zirconia-ceramic implant FDPs were significantly lower than the ones of the metal-ceramic implant FDPs. Catastrophic fracture of the FDP occurred significantly more often at the zirconia-ceramic FDPs than at metal-ceramic FDPs. The predominant technical complication at both types of FDPs was chipping and/or fracture of the veneering ceramic. This complication was more often observed at the zirconia-ceramic FDPs and, in addition, significantly more often led to loss of the FDP in the zirconia-ceramic group than in the metal-ceramic group.

Until today, metal-ceramics is the "golden standard" material of choice for the fabrication of multiple-unit implant- or tooth-borne FDPs (Creugers, Käyser, & van't Hof, 1994; Scurria, Bader, & Shuggars, 1998; Walton, 2002, 2003, 2015). More recently, zirconia-based reconstructions have increasingly been used instead, in an attempt to provide patients with metal-free reconstructions of higher aesthetics and lower price (Heintze & Rousson, 2010).

Yet, both teeth- and implant-supported zirconia-ceramic FDPs showed lower 5-year survival rates than the metal-ceramic FDPs (Pjetursson, Sailer, Makarov, Zwahlen, & Thoma, 2015, 2017), the difference reaching statistical significance in the present review. Frequent reason for failure was a catastrophic fracture of the zirconia framework itself. Another often observed reason for failure was extended chipping of the veneering ceramic (Sailer et al., 2017).

Chipping of the zirconia veneering ceramic has been a frequently reported problem since the introduction of the zirconia-based reconstructions (Heintze & Rousson, 2010). The frequency of zirconia veneering ceramic chipping in a systematic review has been reported to be 54% at tooth-supported reconstructions (Heintze & Rousson, 2010). Studies on implant-supported zirconia FDPs reported on rates up to 50% (Larsson & Vult von Steyern, 2016). Further developments of the zirconia veneering ceramics and of the veneering procedures have helped lower the initially high incidences of chipping, still, the problem remains to be the predominant technical complication.

In general, bilayer materials are prone to delamination or chipping as the material scientific research has shown (Zhang, Sailer, & Lawn, 2013). One possible, interesting alternative to bilayers is the application of monolithic types of reconstructions (Zhang et al., 2013). A few years ago, this was not possible with zirconia materials, as the aesthetics of the yttria-stabilized zirconia used for FDP framework fabrication was too poor.

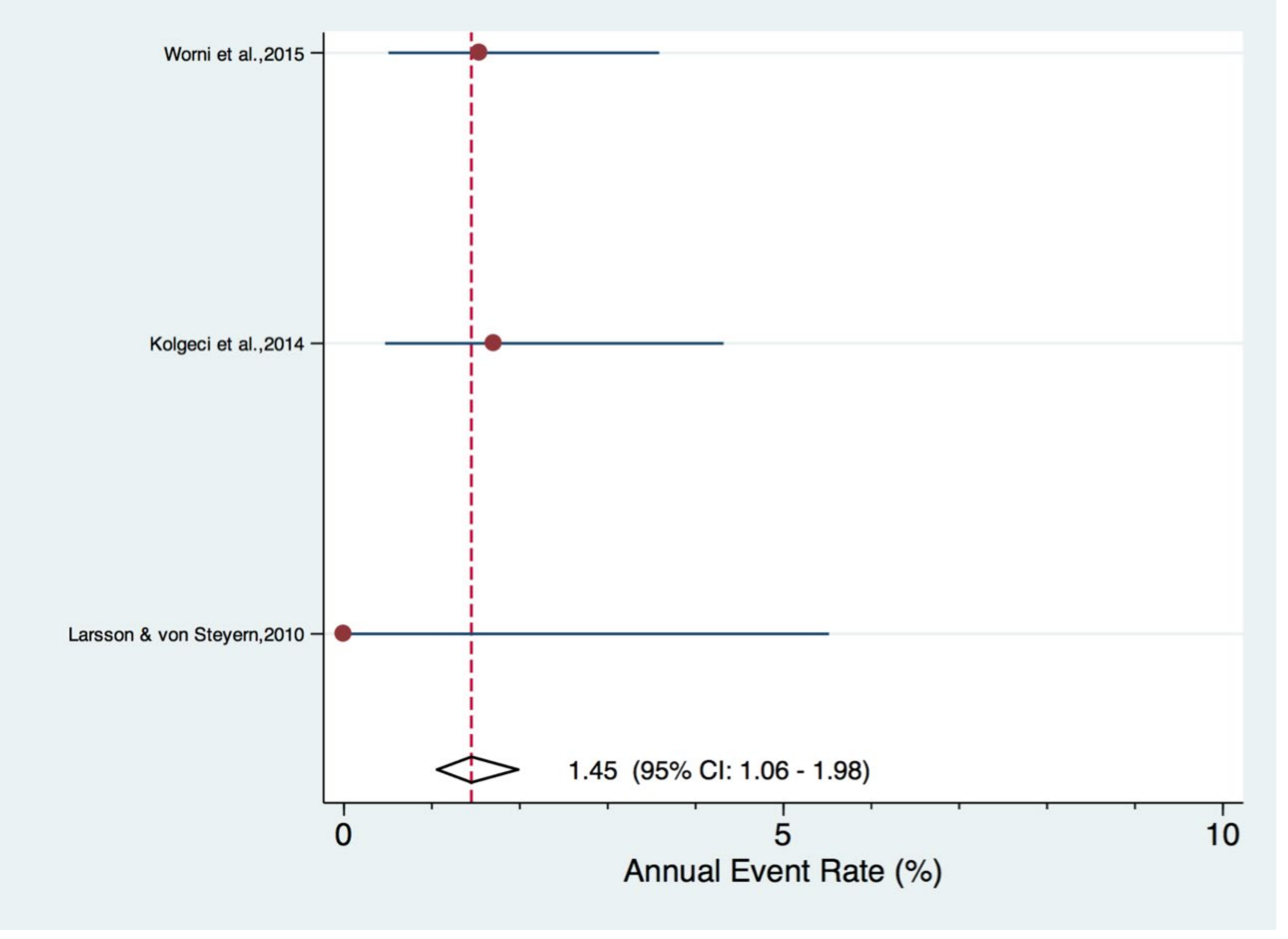

FIGURE 3 Annual failure rates (per 100 years) of implant-supported zirconia-ceramic FDPs

More recently, however, new more translucent and/or colored new types of zirconia ceramics were introduced reducing the need for veneering ceramic. Monolithic zirconia reconstructions may be a promising alternative to the zirconia-ceramic reconstructions and may exhibit lower rates of chipping of the ceramic. The literature on this topic is still scarce. Unfortunately, no studies on monolithic zirconia implant-supported reconstructions were available for the present review with follow-up periods of 3 years or more. For this reason, the present systematic review failed to analyze the above assumption, and the meta-analysis has to be repeated in a few years when more information is available.

Numerous preclinical and clinical studies on zirconia implants have proved its biocompatibility and indicated excellent soft tissue integration (Pieralli, Kohal, Jung, Vach, & Spies, 2017).

Future studies on monolithic zirconia are needed to analyze and document the biologic integration of the zirconia-based reconstructions in more detail, besides the general clinical outcomes.

The present systematic displayed exhibited some limitations of the available literature and the present results need to be interpreted with this in mind. First, and most importantly, the numbers of metal-ceramic and zirconia-ceramic FDPs included in this meta-analysis were highly differing. More information was available on metal-ceramic FDPs. Zirconia-ceramic FDPs seemed to suffer from more technical problems, yet, this result came from few studies and will need further observation. Furthermore, no RCTs comparing the two treatment options were available for this review. Finally, no studies on monolithic zirconia could be included at this point; hence, the interpretation of the results is limited to veneered zirconia. Reviews on tooth-supported FDPs made out of veneered zirconia, however, demonstrated similar outcomes (Heintze & Rousson, 2010; Schley et al., 2010). Therefore, the results obtained by the present meta-analysis are in accordance with previously published outcomes of the zirconia-ceramic FDPs. Future research should focus on the more recent monolithic zirconia reconstructions to evaluate their outcomes as compared to metal-ceramics.

Finally, it may be questioned why only one data base, that is, Medline was used for the literature search. In almost all previous reviews of the present team of reviewers, a very focussed literature search was firstly performed in Medline, followed by searches of additional sources like Embase, or the Cochrane Library. Yet, the number of additional studies, solely included through these additional sources and not identified before, was zero. Most studies not previously found through the main search in Medline resulted from hand searching the reference lists of significant publications, however. Therefore, the strategy at the present review was to focus on a rather

TABLE 6 Comparing annual failure and complication rates of metal-ceramic FDPs and zirconia-ceramic FDPs

Complication	Number of FDPs	Estimated annual complication rates (95 % CI)	Cumulative 5 year complication rates (95 % CI)	Number of FDPs	Estimated annual complication rates (95 % CI)	Cumulative 5 year complication rates (95 % CI)	p-value
	Metal-ceramic			Zirconia-ceramic			
Total number of FDPs with complications	371	3.28[a] (2.37–4.55)	15.1%[a] (11.2%–20.4%)	0	n.r.	n.r.	n.a.
Abutment fracture	1,641	0[a]	0%[a]	169	0[a]	0%[a]	n.a.
Abutment or occlusal screw fracture	1,571	0[a]	0%[a]	169	0[a]	0%[a]	n.a.
Abutment or occlusal screw loosening	1,359	0.84[a] (0.22–3.13)	4.1%[a] (1.1%–14.5%)	0	n.r.	n.r.	n.a.
Ceramic fracture or chipping	781	2.48[a] (1.40–4.39)	11.6%[a] (6.7%–19.7%)	13	13.85[a] (6.53–24.66)	50.0%[a] (29.1%–72.1%)	<0.001
Ceramic chipping with repair	427	0.95[a] (0.18–5.07)	4.7%[a] (0.9%–22.4%)	102	0.52[a] (0.27–1.00)	2.5%[a] (1.3%–4.9%)	0.481
Restoration lost due to ceramic fracture	966	0.05[a] (0.01–0.23)	0.2%[a] (0.05%–1.1%)	175	0.97[a] (0.38–2.48)	4.7%[a] (1.9%–11.7%)	0.001
Loss of retention of cemented FDPs	476	0.39[a] (0.21–0.72)	1.9%[a] (1.0%–3.6%)	0	n.r.	n.r.	n.a.
Soft tissue complications	445	0.64[a] (0.21–1.92)	3.1%[a] (1.0%–9.2%)	73	2.14[a] (0.70–4.92)	10.1%[a] (3.4%–21.8%)	0.030
Significant marginal bone loss	1,138	0.21[a] (0.06–1.41)	1.0%[a] (0.3%–3.3%)	0	n.r.	n.r.	n.a.
Aesthetic failures	94	0[a]	0%[a]	73	0[a]	0%[a]	n.a.

Notes. n.r. stands for not reported; n.a. stands for not analyzed.
[a]Based on robust Poisson regression.

open and rather unrestricted title search, avoiding limitations and filters during in order to be as inclusive as possible on the title level. The subsequent thorough screening of the titles, abstracts, and full-text articles, and the additional meticulous hand searching of all reference lists of previous reviews helped identify the included studies of the present and a second review (Pjetursson et al., 2018; ITI CC SR).

5 | CONCLUSIONS

For implant-supported FDPs conventionally veneered zirconia shall not be considered the material of first priority, due to persisting pronounced risk for fractures of the framework and chipping of the zirconia veneering ceramic. Monolithic zirconia may be an interesting alternative, but its clinical medium- to long-term outcomes have not been analyzed yet. Hence, until today, metal-ceramics appear to stay the golden standard for the implant-supported FDPs.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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