





A systematic review and meta-analysis evaluating the survival, the failure, and the complication rates of veneered and monolithic all-ceramic implant-supported single crowns

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Abstract

Objective: To assess the survival, failure, and complication rates of veneered and monolithic all-ceramic implant-supported single crowns (SCs).

Methods: Literature search was conducted in Medline (PubMed), Embase, and Cochrane Central Register of Controlled Trials until September 2020 for randomized, prospective, and retrospective clinical trials with follow-up time of at least 1 year, evaluating the outcome of veneered and/or monolithic all-ceramic SCs supported by titanium dental implants. Survival and complication rates were analyzed using robust Poisson's regression models.

Results: Forty-nine RCTs and prospective studies reporting on 57 material cohorts were included. Meta-analysis of the included studies indicated an estimated 3-year survival rate of veneered-reinforced glass-ceramic implant-supported SCs of 97.6% (95% CI: 87.0%–99.6%). The estimated 3-year survival rates were 97.0% (95% CI: 94.0%–98.5%) for monolithic-reinforced glass-ceramic implant SCs, 96.9% (95% CI: 93.4%–98.6%) for veneered densely sintered alumina SCs, 96.3% (95% CI: 93.9%–97.7%) for veneered zirconia SCs, 96.1% (95% CI: 93.4%–97.8%) for monolithic zirconia SCs and only 36.3% (95% CI: 0.04%–87.7%) for resin-matrix-ceramic (RMC) SCs. With the exception of RMC SCs ($p < 0.0001$), the differences in survival rates between the materials did not reach statistical significance. Veneered SCs showed significantly ($p = 0.017$) higher annual ceramic chipping rates (1.65%) compared with monolithic SCs (0.39%). The location of the SCs, anterior vs. posterior, did not influence survival and chipping rates.

Conclusions: With the exception of RMC SCs, veneered and monolithic implant-supported ceramic SCs showed favorable short-term survival and complication rates. Significantly higher rates for ceramic chipping, however, were reported for veneered compared with monolithic ceramic SCs.

KEYWORDS

biological, complications, fixed dental prostheses, implant crown, meta-analysis, monolithic, success, survival, systematic review, technical, veneered, zirconia framework

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1 | INTRODUCTION

Implant-supported single crowns (SC) are a valid treatment option for the replacement of missing teeth with 5-year survival rates of more than 90%, as reported in previous systematic reviews (Abou-Ayash et al., 2017; Jung et al., 2012; Larsson & Wennerberg, 2014; Pjetursson et al., 2018; Rabel et al., 2018). These positive clinical results have resulted in the frequent use of implant-supported SCs as an alternative to a tooth-supported multiple-unit fixed dental prostheses, an approach in line with today's pursuit of tooth conserving procedures.

A more recent factor that could influence the outcomes of the implant-supported SCs is the material that the crowns are made out of. While in the past metal-ceramics was predominantly used for the fabrication of the crowns, nowadays, a myriad of all-ceramic or hybrid-ceramic materials are available. Metal-ceramic restorations have dominated the clinical applications and are well documented with high 5-year SC survival rates of 95.8% (Jung et al., 2012). A systematic review by Jung and co-workers (Jung et al., 2012) on the clinical outcomes of implant-supported SCs reported a high 5-year SC survival rate of 96.3%. From the included 46 studies, only 4 studies investigated all-ceramic SCs, corresponding to only 10% of the reviewed patients. The studies reported satisfactory clinical outcomes for metal-ceramic crowns and high mechanical stability.

The first introduced all-ceramic materials (i.e., feldspathic ceramic, pressed leucite, and alumina-reinforced glass-ceramics) could not compete with the mechanical stability of metal-ceramics in the high load bearing sites in the dental arch. Their indication was, therefore, limited to the esthetically high-demanding areas in the beginning. The improvements in digital dental technologies offered alternative pathways to the conventional manufacturing processes, which facilitated the use of larger range of ceramic materials namely high-strength oxide ceramic (zirconia [ZrO₂] and alumina [Al₂O₃]), reinforced glass-ceramics (lithium disilicate [LiSi₂] and zirconia-reinforced lithium silicate [LiSi]), and resin-matrix-ceramics (RMC) (resin-based composites and polymer-infiltrated ceramic network [PICN]) (Spitznagel et al., 2018). As the digital workflows get more efficient and effective (Mühlemann et al., 2018), the indications for the all-ceramic restorations were more and more widened.

High strength zirconia frameworks, veneered with ceramics for esthetic purposes (i.e., veneered zirconia), are a well-documented all-ceramic alternative to metal-ceramics for implant-supported restorations today Pjetursson et al., 2018; Rabel et al., 2018). The systematic review by Pjetursson et al. (2018), comparing veneered zirconia and metal-ceramic implant-supported SCs, reported a 97.6% (95% confidence interval (CI): 94.3–99.0) and a 98.3% (95% CI: 96.8–99.1) 5-year survival rates, respectively, for the two types of SCs. Both, the biological and the technical complication rates of the veneered zirconia and the metal-ceramic SCs were similar. However, fracture of the veneering layer was the predominant technical problem of both veneered types of restorations (Pjetursson et al., 2018).

Another systematic review compared the outcomes of oxide-ceramic and glass-ceramic implant-supported SCs (Rabel et al., 2018). The authors reported good overall estimated 5-year survival rates of

the all-ceramic implant-supported SCs (93% (95% CI: 86.6%–96.4%)), yet again, high rates of veneering ceramic chipping reaching 9.0% (95% CI: 5.4%–14.8%) over a period of 5 years (Rabel et al., 2018).

In order to overcome the technical problems experienced with all types of veneered restorations, more recently, monolithic, that is, un-veneered, micro-veneered, or partially veneered, types of restorations were presented (Caramês et al., 2019; Cheng et al., 2019; Rammelsberg et al., 2020). However, a clear distinction between the definitions of monolithic, micro-veneered, and conventionally veneered designs is lacking. In the present systematic review, micro-veneered all-ceramic restorations were defined as minimally veneered (≤ 0.5 mm) solely in the non-functional areas, whereas monolithic restorations were considered without any ceramic layer. These monolithic types of restorations may offer two main advantages. Firstly, the increase in the efficiency of the laboratory procedures by enabling a faster fabrication of the restorations (Joda & Brägger, 2014, 2015, 2016). Secondly, improvement in clinical outcomes by reducing the number of ceramic fractures which persist as one of the predominant problems observed with veneered restorations (Pjetursson et al., 2018; Rabel et al., 2018). Still, one should keep in mind that the clinical importance of chipping may vary depending on the location and characteristics of the ceramic fractures.

Yet, systematic reviews analyzing the influence of the crown design (monolithic/ micro-veneered/ veneered) on the survival rates and the technical complication rates of implant-supported SCs were not able to indicate significant results due to lack of reports on monolithic and micro-veneered restorations (Pjetursson et al., 2018; Rabel et al., 2018). Hence, the clinical longevity of those restorations remained to be elucidated. In the meantime, a pronounced amount of short-term clinical studies on monolithic, micro-veneered, and veneered all-ceramic implant restorations has been published.

The aim of the present systematic review, therefore, was to analyse the survival, failure, and the complication rates of monolithic/micro-veneered, and conventionally veneered of all-ceramic implant-supported SCs.

2 | MATERIALS AND METHODS

2.1 | Study design

This systematic review was designed as an update of two previous systematic reviews (Pjetursson et al., 2018; Rabel et al., 2018).

The study protocol of this systematic review followed the guidelines for Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009). This report is in compliance with the appropriate EQUATOR (<http://www.equator-network.org>) guidelines. Furthermore, to improve searching databases for clinical questions, the PICO framework was applied (Scharadt et al., 2007). PICO stands for patient/population (P), intervention (I), comparison (C), and outcome (O). For this systematic review, the "PICO" question was defined as follows:

- Population: Partially edentulous patients who received implant-supported SCs in the anterior and posterior regions.
- Intervention: Titanium dental implants restored with monolithic or micro-veneered all-ceramic SCs.
- Comparison: Titanium dental implants restored with veneered all-ceramic SCs.
- Outcome: Survival, failure, and complication rates of the restorations.

The focus question was “In partially edentulous patients do monolithic all-ceramic implant-supported SCs exhibit differences in survival, failure, and complication rates when compared to veneered all-ceramic implant-supported SCs?”.

Ethical approval was not required for this systematic review.

2.2 | Search strategy

As this systematic review was an update of previous reviews, the search strategies for the present review were adopted from the two respective previous systematic reviews (Pjetursson et al., 2018; Rabel et al., 2018). Two independent searches were conducted in three databases, MEDLINE via PubMed (<http://www.ncbi.nlm.nih.gov/pubmed>), EMBASE (<https://www.embase.com>), and the Cochrane Central Register of Controlled Trials (CENTRAL) (<http://www.thecochranelibrary.com>) by the authors of the corresponding reviews duplicating the same strategy. The search strategies are explained in detail in the previous publications (Pjetursson et al., 2018; Rabel et al., 2018). The electronic search dates are summarized in Figure 1.

2.3 | Search terms

The search terms and the combinations can be seen in Figure 1. Some free-text terms were additionally tagged with an asterisk as truncation symbol to improve the search sensitivity.

The publications found through the searches were imported into a reference management software (EndNote X9, Thomson Reuter, New York, USA).

2.4 | Eligibility criteria

The inclusion criteria for the clinical investigations were as follow:

1. Randomized controlled clinical trials (RCTs) or prospective clinical trials published in the English language.
2. At least 10 patients included in the study.
3. A follow-up time of at least 1 year after inserting the restoration.
4. Detailed information on the restoration material used.
5. Restoration type clearly described and data from SCs reported separately from other types of included restorations.
6. If there are multiple publications on the same patient cohort, only the publication with the longest follow-up time was included.
7. SCs, made of ceramic materials, monolithic or veneered, namely zirconia, glass-ceramics (lithium disilicate and leucite-reinforced glass-ceramics), and resin-matrix ceramics (RMC)
8. All brands, kinds of titanium dental implants
9. Sufficient reporting on the detailed clinical outcomes (survival, technical) of SCs.

The clinical studies with following characteristics were excluded.

1. Not meeting all inclusion criteria
2. Retrospective studies, retrospective case series, technical reports, and case reports
3. Studies that pool outcomes of different restoration types and materials
4. Studies reporting on metal-ceramic, metal-resin, polyether ether ketone (PEEK) implant restorations
5. Studies reporting on ceramic implants
6. Poor reporting on drop-outs and number of patients at follow-up.

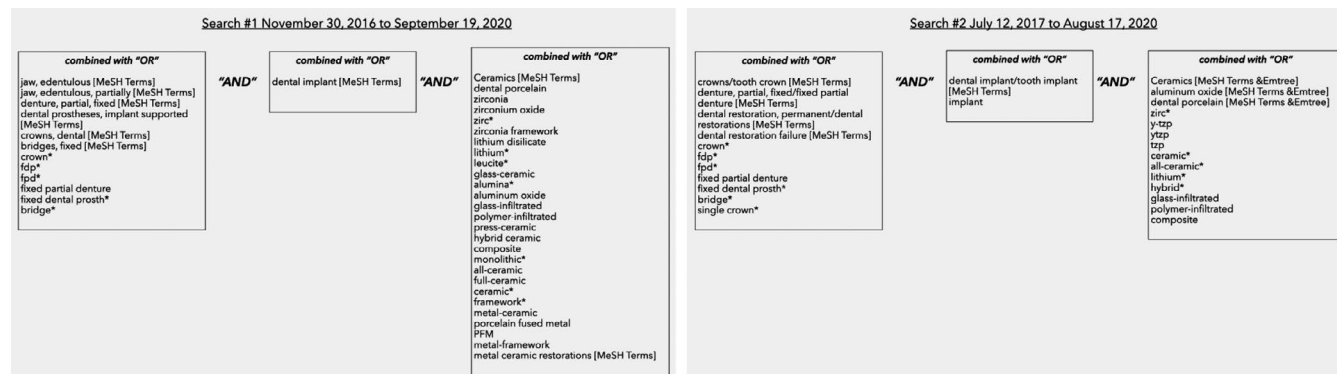


FIGURE 1 Summary of the search terms that were used for two independent electronic literature searches. The blocks are addressing the restoration type, the restoration support and the restoration material

2.5 | Selection of studies

The records of the two electronic searches were imported to the reference management software, and subsequently, the duplicates were removed. Two reviewers (DK and AL) screened independently the titles, thereafter the abstracts. Disagreements were resolved by discussion, and the articles were then obtained in full text for full-text screening. In addition, the full texts of the included studies from the Rabel et al., 2018 and Pjetursson et al., 2018 systematic reviews were screened for their eligibility by the reviewers DK and BEP. Furthermore, the excluded studies list and the complete reference lists of those systematic reviews were screened. Full-text articles were evaluated by two reviewers (DK and BEP) independently, and the selection of the eligible studies was done based on the inclusion/exclusion criteria. The included studies were double checked in terms of study centers, ethical committee approval number, and full author lists by the third reviewer (AL) in order to detect multiple publications that might be reporting on the same patient cohort.

2.6 | Data extraction

Two reviewers (DK and BEP) independently extracted the data of the included articles. Authors were calibrated prior to the data extraction in order to establish consistency in the process.

The data extraction tables were created based on the focus question of the systematic review and included both qualitative and quantitative data. The study characteristics as author, year, study setting, study design, mean follow-up time, total exposure time, total number of included patients, number of patients at the end of the follow-up period, number of patients dropped-out, number of implants, abutments, and SCs at the baseline and at the end of the follow-up period, the number of drop-outs were recorded. The restoration characteristics and the number of SCs based on retention type (screw retention/cement) and region (anterior/ posterior) were extracted. The material characteristics namely the restoration design (veneered/ micro-veneered/ monolithic) and abutment, framework, veneering ceramic materials/brands/fabrication methods were recorded.

2.7 | Outcome Measures

Crown survival was defined as the SCs remaining in situ, with or without modification, for the entire observation period. The failure therefore in the present systematic review was considered when the SC was reported to be lost, removed, and/or remade. Accordingly, the overall failure rate of SCs includes the number of SCs that were lost and/or needed to be remade due to reasons such as implant loss, ceramic fracture, repeated loss of retention, repeated screw loosening, esthetic, and biological complications. The failures that happened due to ceramic fractures (overall failure rates due to ceramic fracture) were further extracted and then subcategorized as “failure

due to core fractures,” “failure due to catastrophic veneer fractures,” and “failure due to abutment fractures” when the data was available. By doing this, the chippings that are repairable and/or polishable were considered as a technical complication and the data were extracted accordingly, as ceramic chippings. Screw loosening and retention loss were other technical complications. Screw-loosening data were extracted when the loss of torque of the implant abutment screw and/or prosthetic screw reported. Meanwhile, loss of retention was considered in the present systematic review as the technical complications that was due to the cement layer problems either with the intraoral or the extraoral cementation.

Biological outcomes namely significant bone loss as reported >2 mm and soft tissue complications such as peri-implantitis, peri-implant mucositis, gingival hyperplasia, fistula, and mucosal recession were extracted.

Following the independent data extraction, the extraction sheets were reviewed for any disagreement, and revision was repeated until all disagreements were resolved. The authors of the articles that were lacking some information yet as judged to be noteworthy were contacted by e-mail or telephone for additional data.

2.8 | Quality assessment of the included studies

DK and AL made the quality assessment of the included studies. The quality assessment for RCTs and non-randomized studies were performed with the Newcastle–Ottawa Scale (NOS). According to the NOS, studies with scores <5 were considered as low quality, whereas scores with 5–7 were considered as moderate quality and >7 as high quality.

2.9 | Statistics

In the present systematic review, 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 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 in 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 distributed for a given sum of SC exposure and Poisson regression were used with a logarithmic link-function and total exposure time per study as an offset variable (Kirkwood & Sterne 2003a). To assess heterogeneity of the study-specific event rates, the Spearman goodness-of-fit statistics and associated p-value were calculated. To reduce the effect of heterogeneity, robust standard errors were calculated to obtain 95% confidence intervals of the summary estimates of the event rates (White 1980, 1982).

The three-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 2003a). 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, the design of the restoration (monolithic/veneered), and the position of the crowns in the dental arch (anterior/posterior). All analyses were performed using Stata®, version 15.0 (Stata Corp., College Station, TX, USA).

3 | RESULTS

3.1 | Screening process

The searches resulted in a total of 1633 records (Figure 2). After the duplicate removal, 1194 references were screened by title. Out of these, 243 studies were further screened by abstract, and 163 excluded at the abstract level. Eighty full-text articles were assessed for eligibility and subsequently 25 studies were identified as eligible for inclusion based on the electronic search. Additional 44 full-text articles, included in the systematic reviews by Rabel et al. (2018) and

Pjetursson et al. (2018), were screened based on the present systematic review's eligibility criteria. Seven additional studies were identified for full-text assessment after the hand search on the excluded study tables of the aforementioned systematic reviews. Accordingly, from the 51 evaluated full-text articles, 24 were found to be eligible for inclusion (Figure 2). These articles were added to the 25 previously included full-text articles. Hence, a total number of 49 studies were included for the qualitative and quantitative analysis in this review (Figure 2).

The detailed reasons for exclusion of the full-text articles were given in a supplementary table (Table S1).

3.2 | Included studies

The included 49 studies were reporting on 57 material cohorts (Table 1). Four of the included studies (Heierle et al., 2019; Kraus et al., 2019; Paolantoni et al., 2016; Wittneben et al., 2020) reported on SCs made of two different material combinations, and one study included patients restored with implant-supported SCs made out of five different material combinations (Rammelsberg et al., 2020). Twenty-four of the included cohorts reported on veneered zirconia abutments or on zirconia SCs supported by titanium or ceramic abutments ($n=969$), eight cohorts on monolithic or micro-veneered zirconia implant-supported SCs ($n=394$), five cohorts on veneered lithium disilicate or leucite-reinforced glass-ceramic implant-supported SCs ($n=110$), 14 cohorts on monolithic or micro-veneered lithium disilicate or leucite-reinforced glass-ceramic implant-supported SCs ($n=484$), four cohorts on veneered densely sintered alumina implant-supported SCs ($n=128$), and two on RMC implant-supported SCs ($n=75$) (Table 1). Twenty of the included studies were RCTs (Table 2; Table S2) comparing directly veneered zirconia customized and stock

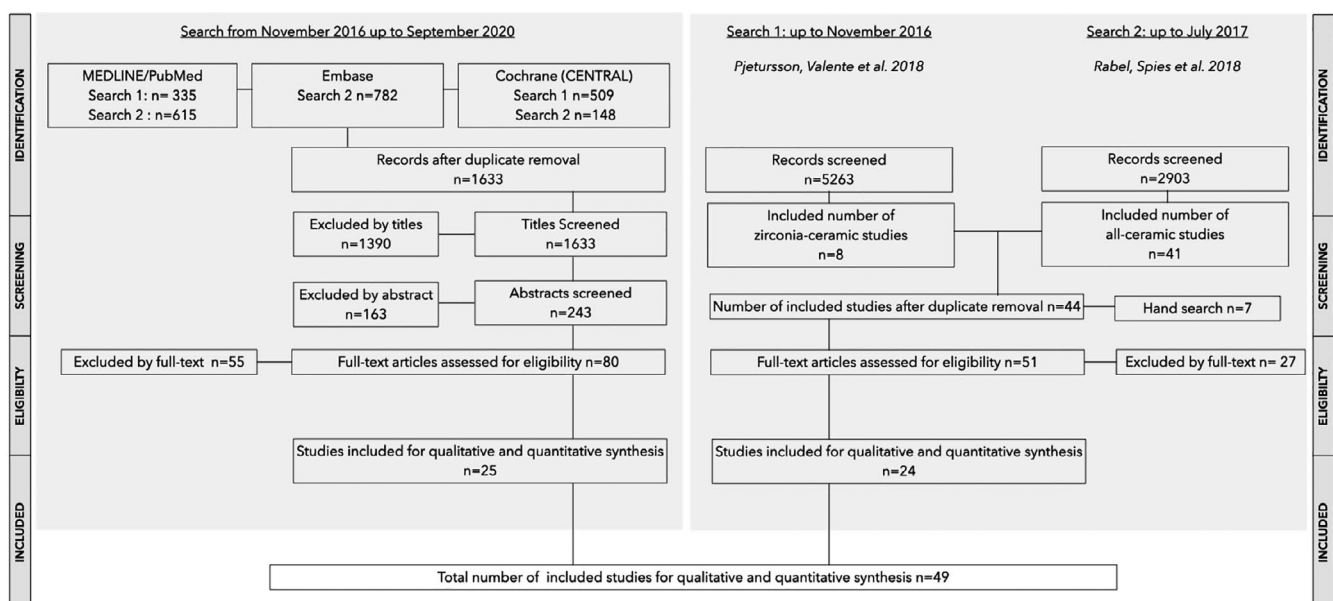


FIGURE 2 Search strategy—For summary of the excluded full-text articles see Table S1

zirconia abutments with cemented ceramic SCs (Wittneben et al., 2020), esthetic outcomes for screw-retained SCs with or without using provisional crowns for tissue conditioning (Furze et al., 2019), metal-ceramic and resin-matrix ceramic SCs (Agustín-Panadero et al., 2020), monolithic zirconia and porcelain-fused-to-metal (PFM) implant-supported SCs (Mühlemann et al., 2020), cemented and screw-retained SCs on customized zirconia abutments (Heierle et al., 2019), 11 mm implants used in combination with sinus floor elevation and 6mm implants without bone augmentation (Guljé et al., 2019b), screw-retained monolithic zirconia and cemented PFM SCs (Weigl, Saarepera, et al., 2019), submucosal veneered zirconia abutments and non-veneered zirconia abutments (Laass et al., 2019), immediate, non-detached glass-ceramic individualized abutments and dis/reconnections (Erhan Çömlekoğlu et al., 2018), monolithic zirconia SCs and short-span FDPs (Cheng et al., 2019), cemented and screw-retained zirconia-based implant-supported SCs (Kraus et al., 2019), tooth- and implant-supported veneered zirconia single SCs (Cantner et al., 2019), cemented and screw-retained CAD/CAM zirconia abutments for esthetically located implant-supported SCs (Amorfini et al., 2018), digital and analog procedures for manufacturing of implant-supported SCs (Mangano & Veronesi, 2018), customized zirconia and titanium abutments (Bösch et al., 2018), immediately loaded one- and two-piece implants (Bomicke et al., 2017), two-piece and one-piece zirconia abutments (Paolantoni et al., 2016), bonding of a RMC restorative material to zirconia stock abutments and zirconia customized abutments (Schepke et al., 2016), zirconia and titanium abutments (Zembic et al., 2013), and zirconia and metal-ceramic implant-supported SCs (Hosseini et al., 2011) (Table S2). The remaining 29 studies were prospective cohort studies (Andersson et al., 1998; Cantner et al., 2019; Canullo, 2007; Cheng et al., 2019; Cooper et al., 2016; Fenner et al., 2016; Gierthmuehlen et al., 2020; Guarnieri et al., 2015; Guljé et al., 2019a; Guncu et al., 2016; Henriksson & Jemt, 2003; Hosseini et al., 2011; Hosseini et al., 2013; Joda et al., 2017; Kolgeci et al., 2014; Koller et al., 2020; Linkevicius et al., 2018; Lops et al., 2013; Ma et al., 2019; Meijndert et al., 2020; Nothdurft et al., 2014; Ormianer & Schirotti, 2006; Peron & Romanos, 2020; Pieri et al., 2013; Pol et al., 2020; Rammelsberg et al., 2020; Teichmann et al., 2017; Vandeweghe et al., 2012; Vanlioglu et al., 2012; Weigl, Trimpou, et al., 2019; Zembic et al., 2013; Zembic et al., 2015). As none of the included RCTs address the focused question of the present systematic review, they were addressed as prospective studies and analyzed as such.

The studies reporting on veneered zirconia implant-supported SCs were published between 2011 and 2020 (median 2018), for monolithic zirconia implant-supported SCs the studies were published between 2018 and 2020 (median 2019), for veneered-reinforced glass-ceramic implant-supported SCs were published between 2015 and 2019 (median 2019), for monolithic-reinforced glass-ceramic implant-supported SCs were published between 2007 and 2020 (median 2017.5), for densely sintered alumina implant-supported SCs were published between 1998 and 2016 (median 2004.5) and the two studies reporting on RMC implant-supported SCs were published in 2016 and 2020.

The average age of the patients included in the different studies ranged from 27.9 to 62.5 years. The proportion of patients who could not be followed for the entire study period was available for all included studies and ranged from 0% to 41% (median 4%), and only two of the included studies had a drop-out proportion of more than 25% (Table 2).

From the 969 included veneered zirconia implant-supported SCs, 55.4% were cement-retained and 44.6% screw-retained. The respected percentages of the 394 included monolithic zirconia implant-supported SCs were 27% for cemented and 73% for screw-retained. From the 110 included veneered-reinforced glass-ceramic implant-supported SCs, 70.5% were cemented and 29.5% were screw-retained, from the 484 included monolithic-reinforced glass-ceramic implant-supported SCs, 61.5% were cemented and 38.5% were screw-retained, from the 128 included densely sintered alumina implant-supported SCs, 90.1% were cemented and 9.9% were screw-retained, and all the included RMC SCs were cemented (Table 2).

Evaluating the overall distribution of the implant-supported SCs in the oral cavity, 37% of the included SCs were located in the anterior area and 63% in the posterior area. For the veneered zirconia SCs, this distribution was 34% anterior and 66% posterior, for monolithic zirconia SCs, it was 22% anterior and 78% posterior, for veneered-reinforced glass-ceramic SCs, it was 62% anterior and 38% posterior, and for monolithic-reinforced glass-ceramic SCs, it was 49% anterior and 51% posterior. Finally, for densely sintered alumina implant-supported SCs, the distribution of the restorations was 83% anterior and 17% posterior, and all of the included RMC SCs were inserted in the posterior area (Table 2).

Thirty-four of the included studies were conducted in an institutional environment, such as university or specialized implant clinics, 10 in private practice setting, and the remaining five studies were a cooperation between universities and private practices (Table 2).

3.3 | Survival and failure rates

Twenty-three studies reporting on 952 SCs with a mean follow-up time of 3.8 years provided data on the survival of veneered zirconia implant-supported SCs, 8 studies including 394 SCs with a mean follow-up time of 1.6 years provided data on monolithic zirconia implant-supported SCs, 4 studies reporting on 93 SCs with a mean follow-up time of 8.1 years provided data on veneered-reinforced glass-ceramic implant-supported SCs, 13 studies including 452 SCs with a mean follow-up time of 2.6 years provided data on monolithic-reinforced glass-ceramic implant-supported SCs, 4 studies reporting on 128 crowns with a mean follow-up time of 3.7 years provided data on densely sintered alumina implant-supported SCs, and 2 studies including 75 crowns with a mean follow-up time of 1.8 years provided data on RMC SCs (Table 3).

The meta-analysis revealed an estimated annual failure rate of 0.80% (95% CI: 0.14%–4.64%) (Figure 3), translating into a 3-year survival rate of 97.6% (95% CI: 87.0%–99.6%) (Table 3) for

TABLE 1 Information on materials of SCs, abutment and implants, manufacturing/processing techniques of SCs and abutments of the included studies

Study	Author	Year	Restoration veneered (v) micro-veneered (micro-v) monolithic (m)	Ceramic-core Abutment (Ab) framework (f) Material	Brand	Manufacturing method	Veneering Material	Brand	
Veneered Zr SC									
	Meijndert et al.	2020	v	Ab & f	Zr	nr	nr	Fluorapatite GC	IPS e.max Ceram, Ivoclar
	Rammelsberg et al. Group A	2020	v	f	Zr	nr	nr	nr	nr
	Wittneben et al. Group B	2020	v	Ab	Zr	CARES, Straumann	CAD/CAM	Fluorapatite GC	IPS e.max Ceram, Ivoclar
	Cantner et al.	2019	v	f	Zr	IPS e.max ZirCAD, Ivoclar	CAD/CAM	LdS	IPS e.max Press, Ivoclar
	Furze et al.	2019	v	Ab	Zr	CARES, Straumann	CAD/CAM	nr	nr
	Guljé et al.	2019a	v	f	Zr	nr	nr	nr	nr
	Guljé et al.	2019b	v	f	Zr	nr	nr	nr	nr
	Heierle et al. Group A	2019	v	Ab	Zr	CARES, Straumann	CAD/CAM	nr	nr
	Ma et al.	2019	v	Ab	Zr	CER-ZR, Southern Implants	nr	GC	Zirox, Wieland Dental
	Kraus et al. Group A	2019	v	Ab	Zr	Atlantis, Dentsply Sirona	centCAD/CAM	feldspathic	Creation ZI-F, Willi Geller
	Weigl et al.	2019b	v	f	Zr	n.r.	CAD/CAM	GC	nr
	Amorfini et al.	2018	v	Ab & f	Zr	CARES, Straumann	centCAD/CAM	nr	nr
	Bösch et al.	2018	v	f	Zr	CARES, Straumann	centCAD/CAM	GC	nr
	Bömicke et al.	2017	v	f	Zr	Procera, Nobel	centCAD/CAM	silicate ceramic	NobelRondo Zirconia, Nobel
	Güncü et al.	2016	v	f	Zr	Lava, 3 M ESPE	CAD/CAM	leucite-reinforced feldspathic	VM9 (VITA Zahnfabrik)
	Paolantoni Group B	2016	v	f	Zr	ART Anchorage, Thommen	nr	nr	nr
	Kolgeci et al.	2014	v	f	Zr	Procera, Nobel	centCAD/CAM	nr	NobelRondo & Creation & Cerabien

Processing method	Abutment Material	Brand	Manufacturing Method	Retention Screw-retained (s) Cemented (c)	Cement type	Cement Brand	Implant	
							Material	Implant Brand
nr	Zr	nr	nr	s & c	GIC	Fuji Plus, GC Europe	Ti	Straumann
nr	Zr & Ti & LDS & Au	nr	Stock & customized	nr	nr	nr	Ti	Straumann & Nobel Biocare
hand-layered	Zr	CARES, Straumann	centCAD/CAM	s	na	na	Ti	Straumann
press	Zr	IPS e.max ZirCAD, Ivoclar	CAD/CAM	s & c	Resin & GIC	Multilink Implant & Fuji Plus & Ketac Cem	Ti	Camlog
nr	Zr	CARES, Straumann	centCAD/CAM	s	na	na	Ti	Straumann
nr	Ti	Atlantis, Dentsply Sirona	centCAD/CAM	c	nr	nr	Ti	Astra Tech
nr	Ti	Atlantis, Dentsply Sirona	centCAD/CAM	c	nr	nr		Astra Tech
nr	Zr	CARES, Straumann	centCAD/CAM	s	na	na	Ti	Straumann
Hand-layered	Zr	CER-ZR, Southern Implants	CAD/CAM	s	na	na	Ti	Southern Implants
nr	Zr	Atlantis, Dentsply Sirona	centCAD/CAM	s	na	na	Ti	Astra Tech
nr	Zr	Ankylos CERCON Balance	CAD/CAM	c	Provisional	RelyX Temp NE, 3 M ESPE	Ti	Ankylos
nr	Zr & Ti	CARES & synOcta, Straumann	centCAD/CAM & stock	s & c	GIC	RelyX Luting, 3 M ESPE	Ti	Straumann
nr	Zr & Ti	CARES & synOcta, Straumann	centCAD/CAM & stock	s	na	na	Ti	Straumann
Hand-layered	Ti	Nobel Replace, Nobel	Stock	c	GIC	Ketac Cem, 3 M ESPE	Ti	Nobel Biocare
Hand-layered	Ti	TiDesign, Astra Tech AB	nr	c	Resin-modGIC	Fuji Plus, GC Europe	Ti	Astra Tech®
nr	Zr	ART Anchorage, Thommen	CAD/CAM	s	nr	nr	Ti	Thommen Medical
nr	Zr & Ti	nr	nr	s & c	Resin	Panavia F, Kuraray Noritake	Ti	Nobel Biocare

TABLE 1 (Continued)

Study		Restoration veneered (v) micro-veneered (micro-v) monolithic (m)	Ceramic-core Abutment (Ab) framework (f) Material		Brand	Manufacturing method	Veneering Material	Brand
Author	Year		Ab	Zr				
Nothdurft et al.	2014	v	f	Zr	CERCON base, DeguDent	CAD/CAM	Silicate ceramic	Ceramkiss, Degudent
Hosseini et al.	2013	v	f	Zr	Procera, Nobel	centCAD/CAM	Leucite GC & fluorapatite GC	IPS Empress 2 & IPS e.max Ceram
Lops et al.	2013	v	f	Zr	Lava, 3 M ESPE	CAD/CAM	nr	nr
Pieri et al.	2013	v	f	Zr	nr	CAD/CAM	nr	nr
Zembic et al.	2013	v	Ab & f	Zr	Procera, Nobel	centCAD/CAM	nr	nr
Vandeweghe et al.	2012	v	Ab	Zr	CER-ZR45, Southern Implants	CAD/CAM	nr	nr
Hosseini et al.	2011	v	f	Zr	Procera, Nobel & KaVo, Kavo	CAD/CAM	feldspathic & fluorapatite GC	HeraCeram & IPS e.max Ceram
Monolithic Zr SCs								
Mühlemann et al.	2020	m	f	Zr	CARES, Straumann	centCAD/CAM	na	na
Rammelsberg et al. Group B	2020	micro-v	f	Zr	nr	CAD/CAM	nr	nr
Rammelsberg et al. Group C	2020	m	f	Zr	nr	CAD/CAM	na	na
Cheng et al.	2019	micro-v	f	Zr	Ceramil Zi & Zolid, Amann Girrbach	CAD/CAM	nr	nr
Koenig et al.	2019	m	f	Zr	Lava Plus, 3 M ESPE	CAD/CAM	na	na
Pol et al.	2019	m	f	Zr	Procera, Nobel	centCAD/CAM	na	na
Weigl et al.	2019a	m	f	Zr	nr	CAD/CAM	na	na
Mangano & Veronesi	2018	m	f	Zr	Katana, Kuraray Noritake	CAD/CAM	na	na

Veneered LiSi₂ and Leucite SCs

Processing method	Abutment Material	Brand	Manufacturing Method	Retention Screw-retained (s) Cemented (c)	Cement type	Cement Brand	Implant	
							Material	Implant Brand
nr	Zr	CERCON, DENTSPLY	Stock & CAD/CAM	c	Resin-modGIC	GC FujiCEM	Ti	XiVE (Dentsply Friadent)
nr	Zr & Ti	nr	nr	c	Resin	Panavia, Kuraray Noritake	Ti	Astra Tech, Dentsply Implants
nr	Zr	ZirDesign, Astra	Stock	c	nr	TempBond Clear, Kerr Dental	Ti	Astra Tech, Dentsply Implants)
nr	Zr & Ti	nr	Stock & customized	c	nr	nr	Ti	Astra Tech & Xive (Dentsply Implants)
nr	Zr	Procera, Nobel	centCAD/CAM	s & c	Resin & Resin-modGIC	Panavia & RelyX Unicem & Ketac Cem	Ti	Branemark RP, Nobel
nr	Zr	CER-ZR45, Southern Implants	CAD/CAM	s	na	na	Ti	nr
nr	Zr	ZirDesign, Astra	Stock & CAD/CAM	c	resin & ZP	Panavia & DeTrey Zinc	Ti	Astra Tech (Dentsply Implants)
na	Ti	Variobase, Straumann	Stock	s	Resin	Multilink Hybrid Abutment, Ivoclar	Roxolid	Straumann
na	Zr & Ti & LDS & Au	nr	nr	nr	nr	nr	Ti	Straumann & Nobel Biocare
na	Zr & Ti & LDS & Au	nr	nr	nr	nr	nr	Ti	Straumann & Nobel Biocare
nr	Ti	synOcta & Variobase, Straumann	Stock	s & c	Resin	Premier Implant & RelyX Unicem	Ti	Straumann
na	Ti	Medentika	nr	s & c	Resin	RelyX Ultimate & Multilink Hybrid	Ti	Nobel Biocare & Straumann
na	Ti & Zr	Procera Hybrid, Nobel	nr	s	nr	nr	Ti	Nobel Biocare
na	Ti	Titanium base, Ankylos	Stock	s	ZP	RelyX Temp NE, 3 M Espe	Ti	Ankylos (Dentsply Implants)
na	Zr	Leone	Stock	c	nr	nr	Ti	Exacone

(Continues)

TABLE 1 (Continued)

Study		Restoration veneered (v) micro-veneered (micro-v) monolithic (m)	Ceramic-core Abutment (Ab) framework (f) Material	Brand	Manufacturing method	Veneering Material	Brand
Author	Year						
Heierle et al. Group B	2019	v	f	LdS	IPS e.max press, Ivoclar	nr	nr
Laass et al.	2019	v	f	LdS	IPS e.max Press, Ivoclar	Press	nr
Kraus et al. Group B	2019	v	f	LdS	E.max, Ivoclar	nr	Fluorapatite GC IPS e.max Ceram, Ivoclar
Teichmann et al.	2017	v	f	LdS	IPS e.max Press, Ivoclar	Press	Fluorapatite GC IPS Eris, Ivoclar
Zembic et al.	2015	v	f	leucite	Empress I, Ivoclar Vivadent,	Press	nr
Monolithic LiSi ₂ and Leucite SCs							
Gierthmuehlen et al.	2020	m	f	LdS	IPS e.max Press, Ivoclar	Press	na
Koller et al.	2020	m	f	LdS	IPS e.max CAD, Ivoclar	CAD/CAM	na
Rammelsberg et al. Group D	2020	micro-v	f	LdS	nr	nr	na
Rammelsberg et al. Group E	2020	m	f	LdS	nr	nr	na
Wittneben et al. Group A	2020	micro-v	f	Fluorapatite	IPS e.max ZirPress, Ivoclar	Press	Fluorapatite GC IPS e.max Ceram, Ivoclar
Cömlekoglu et al.	2018	m	f	Leucite	Empress CAD, Ivoclar	CAD/CAM	na
Linkevicius et al.	2018	m	f	LdS	IPS e.max, Ivoclar	CAD/CAM	na
Joda et al.	2017	m	f	LdS	IPS e.max CAD, Ivoclar	centCAD/CAM	na
Cooper et al.	2016	m & micro-v	f	LdS	E.max, Ivoclar	Press	nr
Paolantoni et al. Group A	2016	m	f	LdS	Empress II, Ivoclar	Press	na
Peron & Romanos	2016	m	f	LdS	nr	nr	na
Guarnieri	2015	m	f	Leucite	IPS Empress, Ivoclar	Press	na
Vanlioglu et al.	2012	m	f	Leucite	Empress II, Ivoclar	Press	na
Canullo et al.	2007	m	f	LiSi ₂	Generic Pentrol	Press	na

Processing method	Abutment Material	Brand	Manufacturing Method	Retention Screw-retained (s) Cemented (c)	Cement type	Cement Brand	Implant	
							Material	Implant Brand
nr	Zr	CARES, Straumann	centCAD/CAM	c	Resin	RelyX Unicem, 3 M Espe	Ti	Straumann
nr	Zr	Atlantis, Dentsply Sirona	centCAD/CAM	c	Resin	Panavia 21, Kuraray Noritake	Ti	Astra Tech (Dentsply Implants)
nr	Zr	Atlantis, Dentsply Sirona	centCAD/CAM	c	Resin	Panavia 21, Kuraray Noritake	Ti	Astra Tech (Dentsply Implants)
hand-layered	Al ₂ O ₃ & Ti & Zr	Alumina & Titanium, Nobel	stock	c	GIC & Resin	Ketac-Cem & Variolink II	Ti	Nobel Biocare & Steri-Oss
nr	Zr	Metoxit, Thayngen	stock	c	Resin	Panavia TC, Kuraray Noritake	Ti	Nobel Biocare
na	Ti	nr	nr	s	Resin	Multilink Implant, Ivoclar	Ti	Nobel Biocare & Xive (Dentsply Sirona)
na	Ti	Ziterion	nr	s	Resin	Multilink, Ivoclar	Ti & Y-TZP	Ziterion
na	Zr & Ti & LDS & Au	nr	nr	nr	nr	nr	Ti	Straumann & Nobel Biocare
na	Zr & Ti & LDS & Au	nr	nr	nr	nr	nr	Ti	Straumann & Nobel Biocare
hand-layered	Zr	IPS e.max, Ivoclar	stock	s	nr	nr	Ti	Straumann
na	Ti & LiSi ₂	E.max CAD, Ivoclar	CAD/CAM	c	Resin	Variolink II, Ivoclar	Ti	Camlog
na	Ti	nr	nr	s	Resin	LinkAce,GC	Ti	MIS Implant
na	Ti	Variobase, Straumann	Stock	s	Resin	Multilink Implant, Ivoclar	Ti	Straumann
nr	Zr	Atlantis, Dentsply	centCAD/CAM	c	Resin	RelyX Unicem, 3 M ESPE	Ti	Astra Tech (Dentsply Sirona) & Nobel Biocare & BIOMET 3i
na	Zr	ART, Thommen	nr	c	Resin	Relyx Unicem 2, 3 M ESPE	Ti	Thommen Medical
na	Ti	nr	nr	s & c	nr	nr	Ti	Zimmer Dental
na	Zr	nr	nr	nr	nr	nr	Ti	BioHorizons
nr	Zr	Zirkohnzahn, Steger	nr	c	Resin	Variolink II, Ivoclar	Ti	Astra Tech, Dentsply Sirona & Straumann
nr	Ti & Zr	ProUnic, Impladent	nr	c	nr	Nimetic-Cem, 3 M ESPE	Ti	TSA implants, Impladent

TABLE 1 (Continued)

Study	Author	Year	Restoration veneered (v) micro-veneered (micro-v) monolithic (m)	Ceramic-core Abutment (Ab) framework (f) Material	Brand	Manufacturing method	Veneering Material	Brand
Bi-layered Al ₂ O ₃								
	Fenner et al.	2016	v	Ab & f Al ₂ O ₃	Procera, Nobel	centCAD/CAM	nr	nr
	Ormianer et al.	2006	v	f AlZr	PureForm, Zimmer Dental	stock & customized	nr	Vitadur Alpha, Vident
	Henrikson & Jemt	2003	v	Ab & f Al ₂ O ₃	Procera, Nobel	centCAD/CAM	nr	nr
	Andersson et al.	1998	v	f Al ₂ O ₃	CeraOne, Nobel	nr	nr	nr
RNC								
	Augustín-Pandero et al.	2020	m	f RMC	Lava Ultimate, 3 M ESPE	CAD/CAM	na	na
	Schepke et al.	2016	m	f RMC	Lava Ultimate, 3 M ESPE	CAD/CAM	na	na

Abbreviations: Al₂O₃, alumina; Au, gold; GC, glass-ceramics; GIC, glass-ionomer cement; LdS, lithium disilicate; nr, not reported; na, not applicable; RMC, resinmatrix ceramic; Ti, titanium; Zr, zirconia; ZP, zinc-phosphate cement.

veneered-reinforced glass-ceramic implant-supported SCs, annual failure rate of 1.02% (95% CI: 0.51%–2.05%) (Figure 4) and 3-year survival rate of 97.0% (95% CI: 94.0%–98.5%) for monolithic-reinforced glass-ceramic implant-supported SCs, annual failure rate of 1.05% (95% CI: 0.49%–2.29%) (Figure 5) and 3-year survival rate of 96.9% (95% CI: 93.4%–98.6%) for densely sintered alumina implant-supported SCs, annual failure rate of 1.27% (95% CI: 0.77%–2.10%) (Figure 6) and 3-year survival rate of 96.3% (95% CI: 93.9%–97.7%) for veneered zirconia implant-supported SCs, annual failure rate of 1.31% (95% CI: 0.76%–2.27%) (Figure 7) and 3-year survival rate of 96.1% (95% CI: 93.4%–97.8%) for monolithic zirconia implant-supported SCs, and annual failure rate of 33.8% (95% CI: 4.36%–261.6%) (Figure 8) and 3-year survival rate of 36.3% (95% CI: 0.04%–87.7%) for RMC implant-supported SCs (Table 3). Investigating formally the relative failure rates of different types of implant-supported SCs, when the monolithic zirconia SCs were taken as reference, there was no statistically significant difference between the SC materials with the exception of the RMC SCs with an annual failure rate of 33.8% (Table 4).

Investigating the number of implant-supported SCs that failed due to ceramic fractures such as catastrophic fracture of the veneering material, fracture of the core or fracture of the ceramic abutment, and the lowest fracture rate was reported for densely sintered alumina implant-supported SCs. None of the 128 included SCs were lost due to fractures over an average observation period of 3.7 years. The annual fracture rate for monolithic zirconia SCs was 0.58%, for monolithic-reinforced glass-ceramic SCs was 0.60%, for

veneered-reinforced glass-ceramic SCs was 0.62%, and for veneered zirconia SCs was 0.98%. RMC SCs, however, showed statistically significantly higher ($p < 0.0001$) annual fracture rate or 6.08% (Table 5).

Meta-analysis, comparing the overall failure rates and fracture rates of monolithic and veneered implant-supported SCs (Table 6), monolithic and veneered zirconia implant-supported SCs (Table 7), monolithic and veneered-reinforced glass-ceramic implant-supported SCs (Table 8), veneered zirconia and veneered-reinforced glass-ceramic implant-supported SCs (Table 9), and monolithic zirconia and monolithic-reinforced glass-ceramic implant-supported SCs (Table 10), did not reveal any statistical significant differences between the materials compared. Furthermore, the overall failure rates and number of failures due to ceramic fractures were analyzed in relation to the position of the implant-supported SCs in the mouth (anterior vs. posterior) for monolithic and veneered zirconia ceramic SCs and for monolithic and veneered-reinforced glass-ceramic implant-supported SCs (Table 11). With the exception of monolithic-reinforced glass-ceramic reporting no failure due to ceramic fractures in the posterior area, the location of the SCs in the dental arch did not significantly influence the failure or fracture rates for any of the crown materials evaluated (Table 11). Meta-analysis evaluating the number of SCs that failed due to fracture of the core material concluded with low annual failure rates ranging from 0% to 0.25% with the exception of RMC with an annual failure rate of 6.08% (Table 12). The same applied for SCs that were lost due to fracture of implant abutment with an annual failure rate ranging between 0% and 0.5% (Table 12).

Processing method	Abutment Material	Brand	Manufacturing Method	Retention Screw-retained (s) Cemented (c)	Cement type	Cement Brand	Implant	
							Material	Implant Brand
nr	Al2O3	synOcta In-Ceram, Straumann	nr	s & c	Resin	Panavia, Kuraray Noritake	Ti	Straumann
hand-layered	Ti	nr	nr	c	GIC & Resin	Ketac-Cem & Panavia	Ti	Zimmer Dental
nr	Al2O3	Procera, Nobel	centCAD/CAM	s & c	nr	nr	Ti	Nobel Biocare
nr	Ti	nr	nr	c	nr	nr	nr	nr
na	Ti	nr	nr	c	Resin	RelyX Ultimate, 3 M ESPE	Ti	Kohno Straight implants, Sweden & Martina
na	Zr	ZirDesign & ATLANTIS, Dentsply	centCAD/CAM	c	Resin	RelyX Ultimate, 3 M ESPE	Ti	Astra Tech, Dentsply Sirona

3.4 | Overall complication rate

Twenty-six of the included studies, reporting on 888 implant-supported SCs, evaluated the total number of complications or the number of restorations free of all complications. The overall annual complication rate for the 888 SCs was 4.2%, ranging from 1.7% to 15.5% (Table 12). The annual complication rate of 1.7% was reported for monolithic-reinforced glass-ceramic SCs, 2.6% for veneered-reinforced glass-ceramics SCs, 3.6% for monolithic zirconia SCs, 4.5% for veneered zirconia SCs, and 14.1% for densely sintered alumina SCs. The highest annual complication rate (15.5%) was reported for RMC implant-supported SCs (Table 12). Meta-analysis comparing the overall complication rate of monolithic and veneered-reinforced glass-ceramic SCs and monolithic and veneered zirconia ceramic SCs did not reveal any statistically significant difference (Tables 6-10). However, the overall annual complication rate of 3.9% for the veneered SCs was tendentially higher than the annual complication rate of 1.8% for monolithic SCs ($p = 0.061$) (Table 6).

3.5 | Technical complications

Forty-five studies, reporting on 1725 implant-supported SCs, analyzed the incidence of ceramic chipping of the ceramic surface. The

estimated average annual chipping rate was 1.25%, ranging from 0% to 1.82%. No surface chippings were reported for RMC SCs, but they showed the annual core fracture rate of 5.90% (Table 12). Veneered SCs generally showed higher annual ceramic chipping rates than monolithic SCs (Tables 6-8), and meta-analysis formally comparing the annual chipping rates for veneered SCs (1.65%), and monolithic SCs (0.39%) concluded a statistically significant difference ($p = 0.017$) between the two crown designs (Table 6). The location of the implant-supported SC in the dental arch, anterior vs. posterior, did not significantly influence the annual chipping rate (Table 11).

Thirty-two studies with 1153 implant-supported SCs reported an annual rate of 0.44% for loosening of the abutment or prosthetic screws (Table 12). The highest screw-loosening rate (2.25%) was reported for monolithic zirconia SCs. The difference between the screw-loosening rates of monolithic zirconia SCs and all the other SCs types reached statistically significant difference ($p < 0.02$) (Tables 7, 10, 12).

Twenty-five studies with 829 cemented implant-supported SCs reported an annual complication rate of 1.97% for loss of retention (Table 12). The highest annual rate of retention loss (28.19%) was reported for RMC SCs. This problem was mainly related to one study (Schepke et al., 2016), in which majority of the resin-matrix ceramic SCs were remade out of different restorative material due to cementation failures. The second-highest rate of loss of retention, 4.44%, was reported for monolithic zirconia implant-supported SCs. This result was also related to one study

TABLE 2 Study, patient, and restoration characteristics of the included studies

Study				Patient				
Author	Year	Design	Setting	Initial (n)	End of follow-up (n)	Drop-out (n)	Drop-out (%)	Mean age (y)
Veneered Zr SCs								
Meijndert et al.	2020	Pro	U	60	50	10	17	36,9
Rammelsberg et al. Group A	2020	Pro	U	404	nr	nr	23	57,8
Wittneben et al. Group B	2020	RCT	U	20	20	0	0	nr
Cantner et al.	2019	Pro	PP	118	105	13	11	nr
Furze et al.	2019	RCT	PP	19	19	0	0	53,4
Guljé et al.	2019a	RCT	U & PP	38	36	2	5	49
Guljé et al.	2019b	Pro	U & PP	21	21	0	0	57,3
Heierle et al. Group A	2019	RCT	U	34	27	7	21	nr
Kraus et al. Group A	2019	RCT	U	44	40	4	9	51,4
Ma et al.	2019	Pro	U	27	16	9	33	47,1
Weigl et al.	2019	RCT	U	21	21	0	0	44
Amorfini et al.	2018	RCT	U & PP	40	30	10	25	48
Bösch et al.	2018	RCT	PP	29	29	0	0	43,7
Bömicke et al.	2017	RCT	U	38	35	3	8	52,9
Güncü et al.	2016	Pro	U & PP	24	24	0	0	44,1
Paolantoni et al. Gruppe B	2016	RCT	U	65	65	0	0	53
Kolgeci et al.	2014	Pro	PP	137	127	10	7	62,5
Nothdurft et al.	2014	Pro	U	24	23	1	4	nr
Hosseini et al.	2013	Pro	U	59	57	2	3	27,9
Lops et al.	2013	Pro	U	85	81	4	5	54
Pieri et al.	2013	Pro	U	29	29	0	0	45,3
Zembic et al.	2013	RCT	U	22	18	4	18	41,3
Vandeweghe et al.	2012	Pro	U	14	14	0	0	55
Hosseini et al.	2011	RCT	U	36	36	0	0	28,1
Monoithic Zr SCs								
Mühlemann et al.	2020	RCT	U	39	33	0	6	57,7
Rammelsberg et al. Group B	2020	Pro	U	404	nr	nr	23	57,8
Rammelsberg et al. Group C	2020	Pro	U	404	nr	nr	23	57,8
Cheng et al.	2019	RCT	U	20	20	0	0	48,1
Koenig et al.	2019	Pro	U	47	44	3	0	54,3
Pol et al.	2019	Pro	U	30	30	0	0	53
Weigl et al.	2019	RCT	U	22	22	0	0	43
Mangano & Veronesi	2018	RCT	PP	25	25	0	0	51,6
Veneered LiSi ₂ and Leucite SCs								
Heierle et al. Group B	2019	RCT	U	34	27	7	21	nr

Implants		SCs						
Initial (n)	Failed (n)	Initial (n)	SCs anterior (n)	SCs posterior (n)	End of follow-up (n)	Drop-out (n)	Screw-Retained (n)	Cemented (n)
60	0	60	54	6		10	33	27
92	3	92	nr	nr	nr	nr	nr	nr
20	0	20	nr	nr	20	nr	20	0
114	0	114	0	114	nr	nr	53	61
19	0	19	19	0	19	0	19	0
41	1AF	41	0	41	39	nr	0	41
31	0	31	0	31	31	0	0	31
17	nr	17	17	0	13	nr	17	0
24	0	24	7	17	20	2	24	0
28	2BF	26	nr	nr	nr	9	26	0
21	0	21	0	21	21	nr	0	21
32	0	32	17	15	30	2	16	16
13	0	13	3	9	12	0	13	0
38	1BF	38	0	38	nr	3	0	38
23	0	24	0	24	24	0	0	24
45	0	45	45	0	45	0	45	29
289	2	120	nr	nr	115	nr	108	12
39	0	39	0	39	37	2	0	39
61	0	61	49	12	nr	2	0	61
38	0	38	na	37	37	2	0	38
29	0	29	29	0	29	0	0	29
12	1AF	12	2	10	nr	nr	2	10
15	0	15	5	10	15	0	15	0
38	0	38	0	38	38	0	0	38
39	1AF	39	0	39	38	0	39	0
42	1	42	nr	nr	nr	nr	nr	nr
152	0	152	nr	nr	nr	nr	nr	nr
36	1	36	nr	nr	36	0	11	25
48	2	48	0	48	nr	nr	44	4
30	0	30	0	30	30	0	30	0
22	0	22	0	22	22	0	22	0
25	0	25	0	25	24	0	0	25
17	nr	17	17	0	14	nr	0	17

TABLE 2 (Continued)

Study				Patient				
Author	Year	Design	Setting	Initial (n)	End of follow-up (n)	Drop-out (n)	Drop-out (%)	Mean age (y)
Kraus et al. Group B	2019	RCT	U	44	40	4	9	51,4
Laass et al.	2019	RCT	U	20	16	4	20	46
Teichmann et al.	2017	Pro	U	14	12	2	14	40,7
Zembic et al.	2015	Pro	U	27	16	11	41	nr
Monolithic LiSi ₂ and Leucite SCs								
Gierthmuehlen et al.	2020	Pro	U	28	27	1	4	49,9
Koller et al.	2020	Pro	U	22	22	0	0	46
Rammelsberg et al. Group D	2020	Pro	U	404	nr	nr	23	57,8
Rammelsberg et al. Group E	2020	Pro	U	404	nr	nr	23	57,8
Wittneben et al. Group A	2020	RCT	U	20	19	1	5	nr
Cömlekoglu et al.	2019	RCT	U	16	16	0	0	36,1
Linkevicius et al.	2018	Pro	PP	56	55	1	2	47,3
Joda et al.	2017	Pro	U	44	44	0	0	58,1
Cooper et al.	2016	Pro	U & PP	141	110	31	22	45
Paolantoni Gruppe A et al.	2016	RCT	U	65	65	0	0	53
Peron & Romanos et al.	2016	Pro	PP	25	25	0	0	43,3
Guarnieri	2015	Pro	PP	21	21	0	0	34
Vanlioglu et al.	2012	Pro	U	12	12	0	0	33,2
Canullo et al.	2007	Pro	PP	25	25	0	0	52,3
Veneered Al ₂ O ₃								
Fenner et al.	2016	Pro	U	36	29	7	19	48
Ormianer et al.	2006	Pro	PP	18	18	0	0	42,2
Henrikson & Jamt	2003	Pro	U	20	19	1	5	29
Andersson et al.	1998	Pro	U	57	53	4	7	31,8
RNC SCs								
Augustín-Pandero et al.	2020	RCT	U	42	32	10	24	nr
Schepke et al.	2016	RCT	U	50	50	0	0	47,7

Abbreviations: AF, failed implant after loading; BF, failed implant before loading; nr, not reported; na, not applicable; Pro, prospective clinical study; PP, private practice setting; RCT, randomized controlled trial; U, university setting.

(Koenig et al., 2019) where 7 out of 48 SCs lost retention and the authors reported changing the cementation protocol during the study period due to this problem.

3.6 | Biological complications

Peri-implant mucosal lesions or soft tissue complications were reported in various ways by different authors. Twenty-one of the included studies with 822 implant-supported SCs reported a mean

overall annual rate for soft tissue complication of 2.58%, ranging from 1.1% to 11.8% (Table 12). The lowest annual soft tissue complication rate of 1.1% was reported for monolithic-reinforced glass-ceramic SCs, followed by veneered-reinforced glass-ceramics SCs (1.57%), veneered zirconia SCs (2.73%), and monolithic zirconia SCs (3.9%). Significantly ($p < 0.0001$) higher soft tissue complication rates, 6.9% and 11.8% respectively, were reported for RMC and densely sintered alumina SCs (Table 12).

Twenty of the included studies reported on the number of implants with significant (> 2 mm) bone loss. The way bone loss is

Implants		SCs						
Initial (n)	Failed (n)	Initial (n)	SCs anterior (n)	SCs posterior (n)	End of follow-up (n)	Drop-out (n)	Screw-Retained (n)	Cemented (n)
20	1AF	20	4	16	16	2	0	20
20	0	20	10	10	16	nr	0	20
32	0	22	10	7	17	15	0	17
54	0	54	24	7	31	23	31	0
45	0	45	0	45	44	1	45	0
15	1AF	15	2	13	14	0	0	15
3	2	3	nr	nr	nr	nr	nr	nr
7	0	7	nr	nr	nr	nr	nr	nr
20	0	20	nr	nr	18	nr	0	20
32	0	32	32	0	nr	nr	0	32
56	0	56	0	55	55	1	56	0
50	0	50	0	50	50	0	50	0
128	2	128	95	33	128	0	0	128
29	0	29	29	0	29	0	0	29
26	0	26	5	21	26	0	24	2
21	1BF	20	20	0	20	0	nr	nr
23	0	23	23	0	23	0	0	23
30	0	30	16	14	30	0	0	30
13	nr	17	nr	nr	13	4	nr	nr
22	0	22	14	8	22	0	0	22
24	0	24	24	0	23	1	11	13
55	0	65	nr	nr	55	5	0	62
25	1	25	0	25	nr		0	25
50	0	50	0	50	7	0	0	50

evaluated on radiographs and reported seems to be more standardized than the soft tissue evaluation. The reported incidence of annual rate of bone loss ranged only from 0.31% to 2% with an average annual complication rate of 0.52% (Table 12).

3.7 | Quality assessment of the included studies

The quality assessment of the included RCTs and prospective studies was conducted with the Newcastle–Ottawa Scale (NOS) for

cohort investigations (Table 13). Most of the studies were judged to have moderate-to-high methodological quality (NOS Score 6, 7, or 8 points from 8). Two studies lacked reporting on conflict of interest (Cooper et al., 2016; Vanlioglu et al., 2012). Therefore, methodological quality was judged to be moderate in some of the studies (NOS Score 6-7/9). A maximum score of eight stars (NOS) could be assigned to the investigations that were succeeded by 8 criteria as follows: (1) representativeness of cases, (2) ascertainment of exposure, (3) demonstration outcome of interest not present at start of study, (4–5) comparability in age of the patients and implants location, (6)

TABLE 3 Annual failure rates and 3-year survival of all-ceramic implant-supported single crowns (SCs).

Study	Year of publication	Total no. of crowns	Mean follow-up time	No. of failures	Total crown exposure time	Estimated annual failure rate ^a (per 100 SC years)	Estimated survival after 3 years ^a (in percent)
Veneered zirconia SCs							
Wittneben et al. Group B	2020	20	3	2	60	3.3%	90.5%
Meijndert et al.	2020	60	4.5	1	271	0.4%	98.9%
Rammelsberg et al. Group A	2020	92	5.3	10	488	2.0%	94.0%
Furze et al.	2019	19	3	0	57	0%	100%
Weigl et al.	2019b	21	1	0	21	0%	100%
Ma et al.	2019	26	4	2	105	1.9%	94.4%
Guljé et al.	2019a	41	4.6	3	188	1.6%	95.3%
Guljé et al.	2019b	31	5	0	155	0%	100%
Kraus et al. Group A	2019	24	2.5	4	61	6.3%	82.1%
Canter et al.	2019	114	3.5	0	399	0%	100%
Amorfini et al.	2018	32	9.9	1	316	0.3%	99.1%
Bösch et al.	2018	13	1.5	1	19	5.1%	85.4%
Bömicke et al.	2017	38	2.2	8	85	9.0%	75.4%
Güncü et al.	2016	24	3.9	2	94	2.1%	93.8%
Paolantoni et al. Group B	2016	45	4	2	180	1.1%	96.7%
Kolgeci L et al.	2014	120	3.2	5	385	1.3%	96.2%
Nothdurft et al.	2014	39	2.9	2	116	1.7%	95.0%
Hosseini et al.	2013	61	3.1	1	189	0.5%	98.4%
Lops et al.	2013	38	4.9	0	185	0%	100%
Pieri et al.	2013	29	5	0	145	0%	100%
Zembic et al.	2013	12	4.7	1	56	1.8%	94.8%
Vandeweghe et al.	2012	15	1	1	15	6.4%	81.9%
Hosseini et al.	2011	38	1.1	0	43	0%	100%
Total		952	3.8	46	3633		
Summary estimate (95% CI) ^a						1.27% (0.77%–2.10%)	96.3% (93.9%–97.7%)
Monolithic Zirconia SCs							
Rammelsberg et al. Group B	2020	42	2.2	1	92	1.1%	96.8%
Rammelsberg et al. Group C	2020	152	1.8	2	274	0.7%	97.8%
Mühlemann et al.	2020	39	1.0	1	39	2.5%	92.6%
Koenig et al.	2019	48	1.9	2	93	2.1%	93.8%
Weigl et al.	2019a	22	1.0	0	22	0%	100%
Pol et al.	2019	30	1.0	0	30	0%	100%
Cheng et al.	2019	36	1.0	1	36	2.7%	92.0%
Mangano & Veronesi	2018	25	1.0	1	25	3.9%	88.7%
Total		394	1.6	8	611		
Summary estimate (95% CI) ^a						1.31% (0.76%–2.27%)	96.1% (93.4%–97.8%)
Veneered-reinforced glass-ceramic SCs							
Laass et al.	2019	20	4.5	1	89	1.1%	96.7%
Kraus et al. Group B	2019	20	2.7	4	53	7.3%	79.7%
Teichmann et al.	2017	22	11.9	1	262	0.4%	98.9%
Zembic et al.	2015	31	11.3	0	350	0%	100%
Total		93	8.1	6	754		

TABLE 3 (Continued)

Study	Year of publication	Total no. of crowns	Mean follow-up time	No. of failures	Total crown exposure time	Estimated annual failure rate ^a (per 100 SC years)	Estimated survival after 3 years ^a (in percent)
Summary estimate (95% CI) ^a						0.80% (0.14%–4.64%)	97.6% (87.0%–99.6%)
Monolithic-reinforced glass-ceramic SCs							
Koller et al.	2020	15	6.7	1	101	1.0%	97.1%
Gierthmuehlen et al.	2020	45	1.1	0	49	0%	100%
Wittneben et al. Group A	2020	20	2.8	1	56	1.8%	94.8%
Rammelsberg et al. Group D	2020	3	4.3	2	13	14.3%	63.0%
Rammelsberg et al. Group E	2020	7	4.5	1	32	3.1%	91.1%
Linkevicius et al.	2018	56	1.0	0	56	0%	100%
Joda et al.	2017	50	2.0	0	100	0%	100%
Cooper et al.	2016	128	2.4	2	307	0.6%	98.1%
Paolantoni et al. Group A	2016	29	4.0	3	116	2.6%	92.5%
Peron & Romanos	2016	26	1.1	2	29	6.7%	81.3%
Guarnieri et al.	2015	20	5.0	0	100	0%	100%
Vanlioglu et al.	2012	23	5.0	0	115	0%	100%
Canullo	2007	30	3.3	0	100	0%	100%
Total		452	2.6	12	1174		
Summary estimate (95% CI) ^a						1.02% (0.51%–2.05%)	97.0% (94.0%–98.5%)
Veneered densely sintered alumina SCs							
Fenner et al.	2016	17	7.2	0	122	0%	100%
Ormianer et al.	2006	22	1.5	1	33	3.0%	91.3%
Henriksson & Jemt	2003	24	1.0	0	24	0%	100%
Andersson et al.	1998	65	4.5	4	295	1.3%	96.0%
Total		128	3.7	5	474		
Summary estimate (95% CI) ^a						1.05% (0.49%–2.29%)	96.9% (93.4%–98.6%)
Resin-matrix ceramic SCs							
Augustín-Pandero et al.	2020	25	3.9	7	98	6.9%	80.7%
Schepke et al.	2016	50	0.7	43	35	57.7%	7.6%
Total		75	1.8	55	133		
Summary estimate 95% CI) ^a						33.8% (4.36%–261.6%)	36.3% (0.04%–87.7%)

Note: C.I. stands for "confidence interval."

^aBased on robust Poisson regression.

assessment of outcome, (7) follow-up long enough, and (8) adequacy of follow-up (Table 13).

4 | DISCUSSION

The present systematic review and meta-analysis showed that the implant-supported SCs made of different all-ceramic materials with veneered or monolithic designs have similar 3-year survival rates and low annual failure rates with the exception of RMC SCs. The main technical problem leading to failure of the SCs was identified as ceramic fractures, that is, catastrophic veneer fracture, core fracture

and ceramic abutment fracture for the veneered and monolithic-reinforced glass-ceramic, and zirconia restorations, whereas RMC SCs predominantly failed due to core fractures and repeated loss of retention.

The monolithic design of the implant-supported SCs was revealed to influence significantly the annual ceramic chipping rates ($p = 0.017$), monolithic zirconia, and monolithic-reinforced glass-ceramic SCs showed lower annual ceramic chipping rate than veneered ones. The monolithic zirconia implant-supported SCs, however, demonstrated more frequently the loss of retention (fracture of the luting cement) and screw loosening compared with veneered zirconia SCs. Moreover, the anterior/posterior position of the

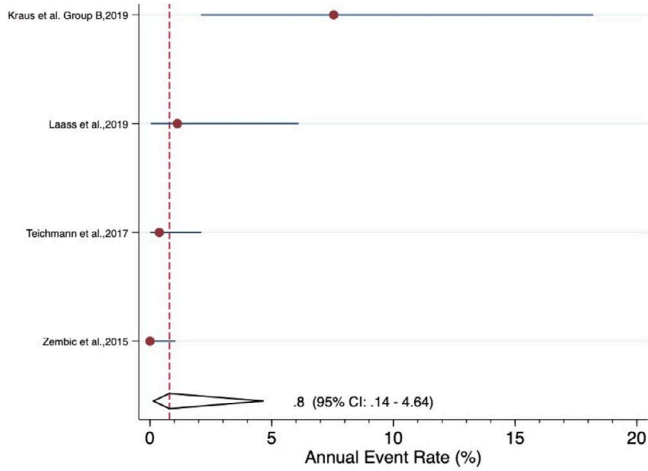


FIGURE 3 Forrest plot for the annual failure rate of veneered-reinforced glass-ceramic implant-supported SCs

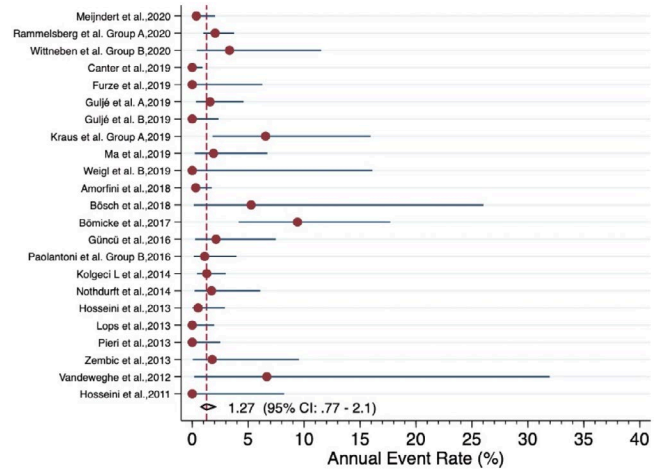


FIGURE 6 Forrest plot for the annual failure rate of veneered zirconia implant-supported SCs

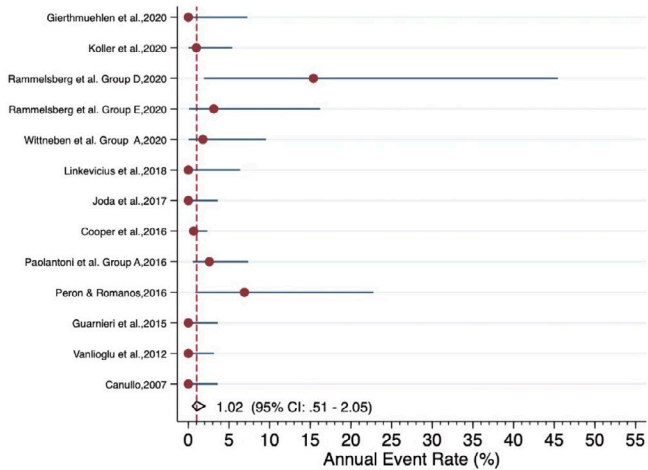


FIGURE 4 Forrest plot for the annual failure rate of monolithic-reinforced glass-ceramic implant-supported SCs

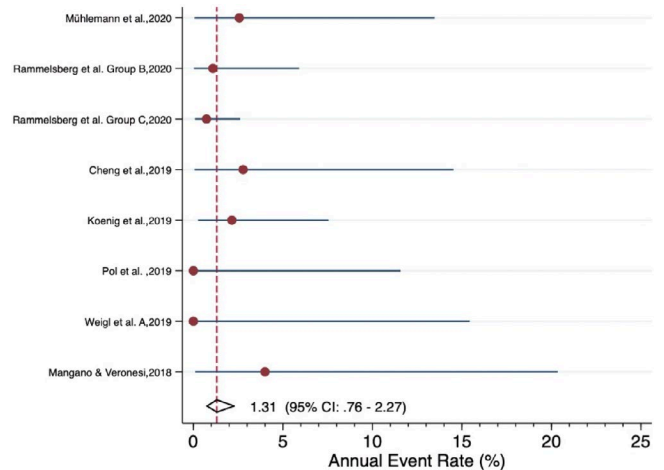


FIGURE 7 Forrest plot for the annual failure rate of monolithic zirconia implant-supported SCs

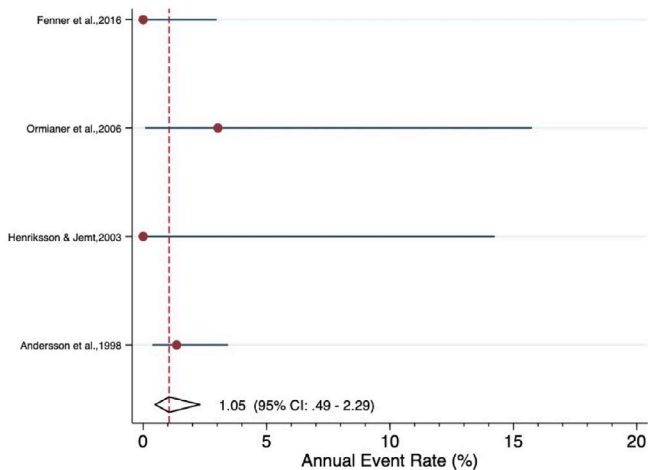


FIGURE 5 Forrest plot for the annual failure rate of veneered densely sintered alumina implant-supported SCs

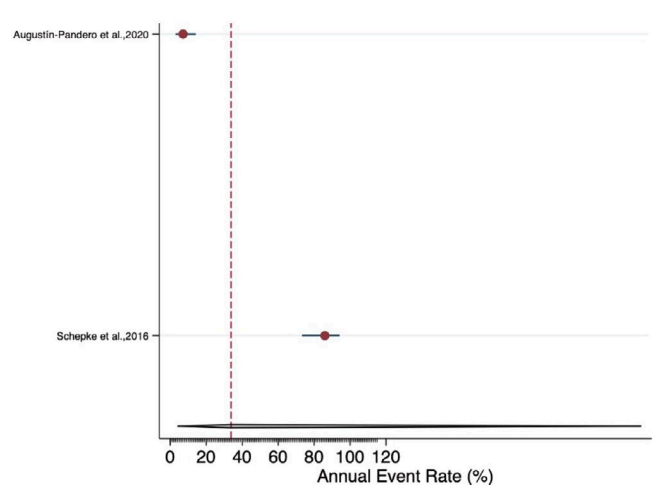


FIGURE 8 Funnel plot for the annual failure rate of resin-matrix ceramic implant-supported SCs

TABLE 4 Summary of annual failure rates, relative failure rates, and survival estimates for SCs with implant-supported monolithic zirconia crowns as reference

Type of SCs	Total number of SCs	Total SCs exposure time	Mean SCs follow-up time	Estimated annual failure rate [*] (95% CI)	3-year survival summary estimate [*] (95% CI)	Relative failure rate ^{**} (95% CI)	p-value ^{**}
Monolithic zirconia SCs	394	611	1.6	1.31% (0.76%–2.27%)	96.1% (93.4%–97.8%)	1.00 (Ref.)	
Monolithic-reinforced glass-ceramic SCs	452	1174	2.6	1.02% (0.51%–2.05%)	97.0% (94.0%–98.5%)	0.78 (0.33–1.83)	p = 0.568
Veneered zirconia SCs	952	3633	3.8	1.27% (0.77%–2.1%)	96.3% (93.9%–97.7%)	0.97 (0.47–1.98)	p = 0.927
Veneered-reinforced glass-ceramic SCs	93	754	8.1	0.80% (0.14%–4.64%)	97.6% (87.0%–99.6%)	0.61 (0.12–3.09)	p = 0.548
Veneered densely sintered alumina SCs	128	474	3.7	1.05% (0.49%–02.29%)	96.9% (93.4%–98.6%)	0.81 (0.34–1.89)	p = 0.619
Resin Nano Ceramic SCs	75	133	1.8	33.8% (4.36%–261.6%)	36.3% (0.04%–87.7%)	25.8 (5.48–121.56)	p < 0.0001

Note: C.I. stands for “confidence interval.”

*Based on robust Poisson regression.; **Based on multivariable robust Poisson regression including all types of SCs.

TABLE 5 Summary of annual failure rates due to ceramic fractures, relative failure rates and failure estimate for SCs with implant-supported monolithic zirconia crowns as reference.

Type of SCs	Total number of SCs	Total SCs exposure time	Mean SCs follow-up time	Estimated annual failure rate [*] (95% CI)	3-year failure summary estimate [*] (95% CI)	Relative failure rate ^{**} (95% CI)	p-value ^{**}
Monolithic zirconia SCs	346	518	1.5	0.58% (0.26%–1.31%)	1.72% (0.77%–3.84%)	1.00 (Ref.)	
Monolithic-reinforced glass-ceramic SCs	449	1161	2.6	0.60% (0.19%–1.89%)	1.79% (0.57%–5.52%)	1.04 (0.27–3.98)	p = 0.953
Veneered zirconia SCs	892	3362	3.8	0.98% (0.55%–1.76%)	2.90% (1.63%–5.14%)	1.69 (0.65–4.40)	p = 0.278
Veneered-reinforced glass-ceramic SCs	110	801	7.3	0.62% (0.17%–2.27%)	1.86% (0.51%–6.58%)	1.08 (0.27–4.33)	p = 0.916
Veneered densely sintered alumina SCs	128	474	3.7	0% (0%–9.27%)	0% (0%–22.57%)	1.67 ⁻⁷ (3.34 ⁻⁸ –8.40 ⁻⁷)	p < 0.0001
Resin Nano Ceramic SCs	75	133	1.8	6.08% (5.97%–6.19%)	16.68% (16.41%–16.95%)	25.8 (5.48–121.56)	p < 0.0001

Note: C.I. stands for “confidence interval.”

*Based on robust Poisson regression.; **Based on multivariable robust Poisson regression including all types of SCs.

TABLE 6 Comparison of annual failure and complication rates for veneered and monolithic implant-supported SCs

Failures/Complications	n studies	Veneered Estimated annual failure rate* (95% CI)	n studies	Monolithic Estimated annual failure rate* (95% CI)	p-value
Overall failure rate	27	1.18* (0.72–1.94)	21	1.12* (0.70–1.78)	p = 0.869
Overall failure rate due to ceramic fractures	27	0.91* (0.53–1.56)	19	0.60* (0.26–1.35)	p = 0.386
Failures due to core fractures	26	0.14* (0.04–0.42)	17	0.22* (0.03–1.54)	p = 0.662
Failures due to catastrophic veneer fractures	27	0.60* (0.28–1.29)	19	0.32* (0.10–1.02)	p = 0.371
Failures due to abutment fractures	28	0.28* (0.11–0.69)	19	0.13* (0.02–0.72)	p = 0.426
Overall complication rate	14	3.92* (2.34–6.52)	9	1.83* (0.97–3.45)	p = 0.061
Ceramic chippings	24	1.65* (0.90–3.01)	18	0.39* (0.14–1.10)	p = 0.017
Screw loosening	16	0.51* (0.23–1.17)	12	0.27* (0.08–0.94)	p = 0.394
Loss of retention	13	0.15* (0.05–0.43)	9	0.94* (0.21–4.22)	p = 0.045
Soft tissue complications	15	2.58* (1.25–5.27)	4	1.24* (0.60–2.56)	p = 0.138
Bone loss >2 mm	12	0.39* (0.17–0.89)	7	0.62* (0.17–2.22)	p = 0.530

Note: C.I. stands for “confidence interval.”

*Based on robust Poisson regression.

TABLE 7 Comparison of annual failure and complication rates for veneered and monolithic zirconia implant-supported SCs

Failures/Complications	n studies	Veneered Estimated annual failure rate* (95% CI)	n studies	Monolithic Estimated annual failure rate* (95% CI)	p-value
Overall failure rate	23	1.27* (0.77–2.10)	8	1.31* (0.76–2.27)	<i>p</i> = 0.928
Overall failure rate due to ceramic fractures	22	0.98* (0.55–1.76)	7	0.57* (0.26–1.31)	<i>p</i> = 0.282
Failures due to core fractures	21	0.17* (0.06–0.53)	5	0* (0–11.90)	<i>p</i> < 0.0001
Failures due to catastrophic veneer fractures	22	0.71* (0.33–1.55)	7	0.19* (0.02–2.03)	<i>p</i> = 0.275
Failures due to abutment fractures	23	0.23* (0.07–0.76)	7	0.39* (0.13–1.16)	<i>p</i> = 0.517
Overall complication rate	11	4.63* (2.67–8.02)	2	3.64* (0.43–30.85)	<i>p</i> = 0.777
Ceramic chippings	19	1.84* (0.93–3.64)	7	0.39* (0.07–2.00)	<i>p</i> = 0.071
Screw loosening	14	0.53* (0.20–1.43)	3	2.27* (0.80–6.42)	<i>p</i> = 0.030
Loss of retention	10	0.20* (0.08–0.54)	3	4.55* (1.41–14.66)	<i>p</i> < 0.0001
Soft tissue complications	13	2.77* (1.26–6.07)	1	4.00* (0.10–20.35)	<i>p</i> = 0.356
Bone loss >2 mm	11	0.31* (0.10–0.95)	3	1.00* (0.16–6.07)	<i>p</i> = 0.530

Note: C.I. stands for "confidence interval."

*Based on robust Poisson regression.

TABLE 8 Comparison of annual failure and complication rates for veneered and monolithic-reinforced glass-ceramic implant-supported SCs.

Failures/Complications	n studies	Veneered Estimated annual failure rate* (95% CI)	n studies	Monolithic Estimated annual failure rate* (95% CI)	p-value
Overall failure rate	4	0.80* (0.14–4.64)	13	1.02* (0.51–2.05)	<i>p</i> = 0.775
Overall failure rate due to ceramic fractures	5	0.62* (0.17–2.26)	12	0.60* (0.19–1.89)	<i>p</i> = 0.967
Failures due to core fractures	5	0* (0–4.16)	12	0.25* (0.03–1.81)	<i>p</i> < 0.0001
Failures due to catastrophic veneer fractures	5	0.13* (0.01–1.38)	12	0.38* (0.10–1.49)	<i>p</i> = 0.402
Failures due to abutment fractures	5	0.50* (0.12–2.02)	12	0* (0–7.52)	<i>p</i> < 0.0001
Overall complication rate	3	2.64* (0.94–7.44)	7	1.72* (0.83–3.54)	<i>p</i> = 0.459
Ceramic chippings	5	1.00* (0.66–1.51)	11	0.40* (0.10–1.55)	<i>p</i> = 0.196
Screw loosening	2	0.46* (0.21–1.01)	9	0.10* (0.01–0.74)	<i>p</i> = 0.149
Loss of retention	3	0* (0–3.94)	6	0.25* (0.06–1.07)	<i>p</i> < 0.0001
Soft tissue complications	2	1.59* (0.64–3.94)	3	1.10* (0.41–2.92)	<i>p</i> = 0.527
Bone loss >2mm	1	0.76* (0.09–2.73)	4	0.53* (0.08–3.31)	<i>p</i> = 0.682

Note: C.I. stands for "confidence interval"

*Based on robust Poisson regression.

SC showed no influence on the survival and complication rates for any prosthetic material and crown design.

The previously reported high short-term (3 to 5 years) survival rates for zirconia, reinforced glass-ceramic, and alumina implant-supported SCs (Pjetursson et al., 2018; Rabel et al., 2018) is affirmed by the present systematic review. Moreover, the result by Rabel et al. (2018) reporting no statistical difference in terms of survival rates between the oxide ceramics and the glass-ceramics is in accordance with the present systematic review's findings. RMC SCs on the contrary showed unfavorable 3-year estimated survival rate of 36.3%, and the difference was statistically significant ($p < 0.0001$). This result thought to be due to the fact that only two of the included

studies investigated RMC SCs in which one reported repeated loss of retention concerning the majority of the SCs (43 out of 50 SCs) in a short follow-up period (Schepke et al., 2016). Eventually, the investigators replaced all initially included SCs with lithium disilicate SCs (Schepke et al., 2018). In the second study, Augustin-Pandero and co-workers (Agustín-Panadero et al., 2020) reported an annual failure rate of 6.9%, and the main reason for failures was crown material fractures.

Since the first introduction of dental implants, clinical outcomes of implant-supported restorations improved significantly thanks to the positive learning curve in implant dentistry (Pjetursson et al., 2014), improvements and innovations in biomaterials and

TABLE 9 Comparison of annual failure and complication rates for veneered-reinforced glass-ceramic and veneered zirconia implant-supported SCs

Failures/Complications	n studies	Veneered Zir Estimated annual failure rate* (95% CI)	n studies	Veneered LDS Estimated annual failure rate* (95% CI)	p-value
Overall failure rate	23	1.27* (0.77–2.10)	4	0.80* (0.14–4.64)	$p = 0.577$
Overall failure rate due to ceramic fractures	22	0.98* (0.55–1.76)	5	0.62* (0.17–2.26)	$p = 0.449$
Failures due to core fractures	21	0.17* (0.06–0.53)	5	0* (0–4.16)	$p < 0.0001$
Failures due to catastrophic veneer fractures	22	0.71* (0.33–1.55)	5	0.13* (0.01–1.38)	$p = 0.141$
Failures due to abutment fractures	23	0.23* (0.07–0.76)	5	0.50* (0.12–2.02)	$p = 0.382$
Overall complication rate	11	4.63* (2.67–8.02)	3	2.64* (0.94–7.44)	$p = 0.287$
Ceramic chippings	19	1.84* (0.93–3.64)	5	1.00* (0.66–1.51)	$p = 0.123$
Screw loosening	14	0.53* (0.20–1.43)	2	0.46* (0.21–1.01)	$p = 0.797$
Loss of retention	10	0.20* (0.08–0.54)	3	0* (0–3.94)	$p < 0.0001$
Soft tissue complications	13	2.77* (1.26–6.07)	2	1.59* (0.64–3.94)	$p = 0.289$
Bone loss >2 mm	11	0.31* (0.10–0.95)	1	0.76* (0.09–2.73)	$p = 0.114$

Note: C.I. stands for “confidence interval”.

*Based on robust Poisson regression.

TABLE 10 Comparison of annual failure and complication rates for monolithic-reinforced glass-ceramic or monolithic zirconia implant-supported SCs.

Failures/Complications	n studies	Monolithic Zir Estimated annual failure rate* (95% CI)	n studies	Monolithic LDS Estimated annual failure rate* (95% CI)	p-value
Overall failure rate	8	1.31* (0.76–2.27)	13	1.02* (0.51–2.05)	$p = 0.574$
Overall failure rate due to ceramic fractures	7	0.57* (0.26–1.31)	12	0.60* (0.19–1.89)	$p = 0.954$
Failures due to core fractures	5	0* (0–11.90)	12	0.25* (0.03–1.81)	$p < 0.0001$
Failures due to catastrophic veneer fractures	7	0.19* (0.02–2.03)	12	0.38* (0.10–1.49)	$p = 0.614$
Failures due to abutment fractures	7	0.39* (0.13–1.16)	12	0* (0–7.52)	$p < 0.0001$
Overall complication rate	2	3.64* (0.43–30.85)	7	1.72* (0.83–3.54)	$p = 0.403$
Ceramic chippings	7	0.39* (0.07–2.00)	11	0.40* (0.10–1.55)	$p = 0.975$
Screw loosening	3	2.27* (0.80–6.42)	9	0.10* (0.01–0.74)	$p = 0.005$
Loss of retention	3	4.55* (1.41–14.66)	6	0.25* (0.06–1.07)	$p = 0.001$
Soft tissue complications	1	4.00* (0.10–20.35)	3	1.10* (0.41–2.92)	$p = 0.006$
Bone loss >2 mm	3	1.00* (0.16–6.07)	4	0.53* (0.08–3.31)	$p = 0.591$

Note: C.I. stands for “confidence interval”.

*Based on robust Poisson regression.

better handling/processing of the restorative materials (Larsson & Wennerberg, 2014). Even though chipping of the veneering ceramic still remains as one of the important concerns for implant-supported SCs, reported to be observed less and less in the more recent publications (Larsson & Wennerberg, 2014). Due to the short follow-up period of monolithic zirconia restorations (mean follow-up:1.6 year), in the present meta-analysis, 3-year estimation for the survival and complications rates was done. Interestingly, the chipping rates for all-ceramic SCs were notably lower than reported by Rabel et al. (2018) which reported 5-year chipping rates of 11.8% for veneered zirconia, 3.5% for veneered-reinforced glass-ceramic, and 6% for monolithic-reinforced glass-ceramic. No significant difference was detected

among the material groups in the same systematic review, whereas the 3-year estimated chipping rates based on present meta-analysis were 5.4% for veneered zirconia SCs, 3% for veneered-reinforced glass-ceramic and 1.2% for monolithic-reinforced glass-ceramic, with no statistically significant difference. The chipping rate differences between the two meta-analysis can be explained by the quality of the included studies, as the retrospective studies were excluded in the present meta-analysis and the improved handling of the restorative materials namely zirconia over the years. Moreover, in the present systematic review, the failure due to ceramic fractures was separately reported while the ceramic chipping that was considered as technical complication was solely the ceramic fractures that

TABLE 11 Annual overall failure rates, annual ceramic fracture rates and ceramic chipping rates according to the position in the dental arch (anterior and posterior)

Failures complications	Number of studies	Anterior		Posterior		p-value
		Estimated annual failure rate (95% CI)	Number of studies	Estimated annual failure rate (95% CI)	Number of studies	
Overall failure rate	14	1.08* (0.45–2.62)	24	1.45* (0.69–3.09)		$p = 0.610$
Overall failure rate due to ceramic fractures	14	0.46* (0.15–1.47)	24	0.65* (0.20–2.10)		$p = 0.678$
Ceramic chippings	8	0.77* (0.37–1.58)	20	1.28* (0.52–3.17)		$p = 0.371$
Monolithic zirconia						
Overall failure rate	0	n.r.	4	1.72* (0.61–4.87)		n.a.
Overall failure rate due to ceramic fractures	0	n.r.	4	0.86* (0.11–6.79)		n.a.
Ceramic chippings	0	n.r.	4	0.86* (0.11–6.79)		n.a.
Veneered zirconia						
Overall failure rate	6	1.93* (0.49–7.61)	12	1.51* (0.55–4.17)		$p = 0.770$
Overall failure rate due to ceramic fractures	6	0.72* (0.22–2.35)	12	0.87* (0.23–3.22)		$p = 0.838$
Ceramic chippings	3	1.19* (0.45–3.12)	10	1.70* (0.64–4.52)		$p = 0.583$
Monolithic LDS						
Overall failure rate	5	1.04* (0.33–3.34)	5	0.70* (0.08–6.28)		$p = 0.739$
Overall failure rate due to ceramic fractures	5	0.63* (0.10–4.06)	5	0* (0–7.08)		$p < 0.0001$
Ceramic chippings	3	0*	4	0*		n.a.
Veneered LDS						
Overall failure rate	3	0.25* (0.01–4.67)	3	1.96* (0.38–10.18)		$p = 0.179$
Overall failure rate due to ceramic fractures	3	0*	3	0*		n.a.
Ceramic chippings	2	1.28* (0.88–1.86)	2	0* (0–4.46)		$p < 0.0001$

Note: n.r. stands for "not reported"; C.I. stands for "confidence interval."

*Based on robust Poisson regression.

TABLE 12 Overview of biological and technical complications of different types of implant-supported SCs

Complications Failures	Number of abutments or SCs	Estimated annual failure/complication rates (95% CI)	Number of abutments or SCs	Estimated annual failure/complication rates (95% CI)	Number of abutments or SCs	Estimated annual failure/complication rates (95% CI)
	Overall results Estimated annual failure rate* (95% CI)	Monolithic zirconia SCs Estimated annual failure rate* (95% CI)	Monolithic-reinforced glass-ceramic SCs Estimated annual failure rate* (95% CI)			
Overall complication rate	888	4.21* (2.65–6.60)	55	3.57* (0.43–26.55)	348	1.70* (0.83–3.48)
Overall failures due to ceramic fractures	1783	0.75* (0.43–1.28)	194	0.41* (0.05–3.51)	449	0.60* (0.19–1.87)
Failure due to core fractures	1674	0.32* (0.13–0.79)	152	0* (0–11.2)	474	0.25* (0.03–1.79)
Failure due to abutment fractures	1941	0.23* (0.10–0.50)	346	0.39* (0.13–1.16)	423	0* (0–5.96)
Ceramic chippings	1725	1.25* (0.69–2.26)	346	0.39* (0.07–1.98)	373	0.40* (0.10–1.54)
Screw loosening	1153	0.44* (0.23–0.82)	88	2.25* (0.80–6.22)	413	0.10* (0.01–0.73)
Loss of retention	829	1.97* (0.49–7.87)	54	4.44* (1.40–13.63)	195	0.25* (0.06–1.07)
Soft tissue complications	822	2.58* (1.43–4.65)	25	3.9* (0.1–18.4)	192	1.1* (0.4–2.9)
Bone loss >2 mm	614	0.52* (0.28–0.98)	100	1.00* (0.16–5.89)	117	0.52* (0.08–3.26)

Note: n.a. stands for "not available"; n.r. stands for "not reported"; C.I. stands for "confidence interval."

*Based on robust Poisson regression.

are repairable and/or polishable. However, a distinction as major chipping/minor chipping/surface roughness when it comes to chipping as a technical complication was not made due to lack of uniformity throughout the included studies regarding the definitions. This approach shows a difference when compared to the previous systematic review by Rabel et al. (2018).

In the present systematic review, the data obtained through included clinical studies allowed to make a direct comparison between the prosthetic materials, that is, zirconia and reinforced-glass-ceramic that are available both monolithic/micro-veneered and veneered crown designs. The statistical analysis comparing directly the monolithic and veneered implant-supported SCs was done based on material groups that have both monolithic and veneered designs, hence the alumina and RMC SCs were excluded from this analysis (Table 6-11).

Based on the present meta-analysis, the loss of retention was observed as an important technical complication. Loss of retention was significantly higher for overall analysis of monolithic compared veneered SCs, which can be due to a single study reporting 7 loss of retention events by Koenig et al on 48 monolithic zirconia SCs while the other studies remained eventless in this aspect. Furthermore, according to an in vitro study by Pitta et al. (2020) the cementation protocol and cement preference plays an important role on the mechanical stability of the SCs supported by titanium bases (Pitta et al., 2020).

Monolithic zirconia and monolithic-reinforced glass-ceramics, as they enable the complete digital work-flow, are becoming more

and more widely used for implant-supported SCs. Accordingly, identifying the predominant reasons for their failure and complication is important. The failure due to core fracture was significantly higher for the monolithic-reinforced glass-ceramics ($p < 0.0001$), whereas monolithic zirconia SCs failed more due to abutment fracture ($p < 0.0001$), which can be explained by the mechanical properties as higher stiffness of zirconia which resulted of the transfer of the forces to less strong components of implant-crown assembly. Loss of retention was similarly higher for monolithic zirconia SCs, which can be explained with the same mechanism.

The influence of anterior-posterior position of the SCs was analyzed in terms of annual failure rate, annual failure rate due to ceramic fracture, and ceramic chipping. The difference between anterior SCs and posterior SCs did not reach statistical significance for either overall prosthetic materials or any specific prosthetic material except for reinforced glass-ceramic SCs. Posterior monolithic-reinforced glass-ceramics showed significantly less annual overall failure rate due to ceramic fracture than anterior ones, 0% and 0.63% ($p < 0.0001$), respectively. As none of the monolithic zirconia studies included anterior SCs, this analysis was not possible for monolithic zirconia material. This finding is not in accordance with the systematic review by Rabel et al. (2018), in which the posterior all-ceramic implant-supported SCs demonstrated significantly higher 5-year chipping rate than anterior SCs. This difference can be explained by the difference in statistical analysis approaches. In the meta-analysis by Rabel et al. (2018), the comparison between anterior and posterior SCs was done based on pooled data from all

Number of abutments or SCs	Estimated annual failure/complication rates (95% CI)	Number of abutments or SCs	Estimated annual failure/complication rates (95% CI)	Number of abutments or SCs	Estimated annual failure/complication rates (95% CI)	Number of abutments or SCs	Estimated annual failure/complication rates (95% CI)
Veneered zirconia SCs Estimated annual failure rate* (95% CI)		Veneered-reinforced glass-ceramic SCs Estimated annual failure rate* (95% CI)		Veneered densely sintered alumina SCs Estimated annual failure rate* (95% CI)		Resin-matrix ceramic SCs Estimated annual failure rate* (95% CI)	
317	4.52* (2.63–7.71)	71	2.61* (0.93–7.17)	22	14.1* (5.0–27.3)	75	15.54* (12.6–19.1)
892	0.77* (0.39–1.53)	110	0.12* (0.01–1.37)	63	0* (0–5.60)	75	6.08* (5.97–6.19)
800	0.17* (0.06–0.53)	110	0* (0–4.0)	63	0* (0–5.60)	75	5.90* (5.80–6.01)
924	0.23* (0.07–0.76)	110	0.50* (0.12–2.00)	63	0* (0–5.60)	75	0* (0–5.25)
743	1.82* (0.93–3.57)	110	1.00* (0.66–1.50)	128	0.64* (0.28–1.48)	25	0* (0–3.6)
473	0.53* (0.20–1.42)	51	0.45* (0.21–1.00)	128	0.42* (0.13–1.36)	0	n.a.
443	0.20* (0.08–0.54)	40	0* (0–3.8)	22	0* (0–10)	75	28.19* (4.95–88.47)
513	2.73* (1.25–5.89)	42	1.57* (0.64–3.86)	24	11.8* (2.6–27.6)	25	6.9* (2.9–13.2)
350	0.31* (0.10–0.94)	22	0.8* (0.1–2.7)	0	n.r.	25	2.0* (0.2–6.9)

TABLE 13 (Continued)

Study	Selection			Comparability			Outcome		Score		
	Year	Representativeness of cases	Selection of controls (RCT - control group of exposure from the same cohort)	Ascertainment of exposure	Demonstration outcome of interest not present at start of study	Age	Location	Assessment of outcome		Follow-up long enough	Adequacy of follow-up
Weigl et al.	2019	*	*	*	*	*	*	*	*	*	7
Pol et al.	2019	*	*	*	*	*	*	*	*	*	7
Cheng et al.	2019	*	*	*	*	*	*	*	*	*	7
Mangano & Veronesi	2018	*	*	*	*	*	*	*	*	*	7
Laass et al.	2019	*	*	*	*	*	*	*	*	*	8
Heierle et al. Group B	2019	*	*	*	*	*	*	*	*	*	6
Kraus et al. Group B	2019	*	*	*	*	*	*	*	*	*	7
Teichmann et al.	2017	*	*	*	*	*	*	*	*	*	8
Zembic et al.	2015	*	*	*	*	*	*	*	*	*	8
Koller et al.	2020	*	*	*	*	*	*	*	*	*	7
Gierthmuehlen et al.	2020	*	*	*	*	*	*	*	*	*	8
Wittneben et al. Group A	2020	*	*	*	*	*	*	*	*	*	7
Rammelsberg et al. Group D	2020	*	*	*	*	*	*	*	*	*	8
Rammelsberg et al. Group E	2020	*	*	*	*	*	*	*	*	*	8
Cömlekoglu et al.	2019	*	*	*	*	*	*	*	*	*	7
Linkevicius et al.	2018	*	*	*	*	*	*	*	*	*	6
Joda et al.	2017	*	*	*	*	*	*	*	*	*	6
Cooper et al.	2016	*	*	*	*	*	*	*	*	*	7
Paolantoni Gruppe A et al.	2016	*	*	*	*	*	*	*	*	*	8
Peron & Romanos et al.	2016	*	*	*	*	*	*	*	*	*	7
Guarnieri	2015	*	*	*	*	*	*	*	*	*	8
Vanlioglu et al.	2012	*	*	*	*	*	*	*	*	*	6
Canullo et al.	2007	*	*	*	*	*	*	*	*	*	8
Fenner et al.	2016	*	*	*	*	*	*	*	*	*	7
Ormianer et al.	2006	*	*	*	*	*	*	*	*	*	7
Henrikson & Jamt	2003	*	*	*	*	*	*	*	*	*	7
Andersson et al.	1998	*	*	*	*	*	*	*	*	*	8
Augustin-Pandero et al.	2020	*	*	*	*	*	*	*	*	*	8
Schepke et al.	2016	*	*	*	*	*	*	*	*	*	6

Note: Asterisk (*) means criteria is fulfilled and every asterisk stands for one score.

included prosthetic all-ceramic materials, whereas in the present systematic review, the analysis was done both separately for each material that has both a veneered and monolithic design as well as for the overall materials namely monolithic and veneered zirconia and reinforced glass-ceramics.

In the present systematic review, only the studies investigated SCs supported by titanium dental implants were included. SCs supported by zirconia implants reported by Rabel et al. (2018) to be more prone to technical complications namely chipping rate. Accordingly, the rationale behind the exclusion of the studies that investigated zirconia implant-supported SCs was to avoid any confounding factor that might influence the clinical behavior of different prosthetic materials.

The scientific evidence procured by this systematic review is based on studies that were assessed as moderate-to-high quality based on Newcastle–Ottawa scale. All included studies were either RCTs ($n = 20$) or prospective studies ($n = 29$) therefore at lower risk of bias compared with retrospective studies (Papageorgiou et al., 2015). As none of the included RCTs were directly addressing the focus question of the present SR, they were considered as prospective cohort studies rather than RCTs and therefore assessed by the Newcastle–Ottawa scale for quality assessment and not with the Cochrane Risk of Bias Tool that is designed for RCTs. However, the included studies were predominantly small and this might introduce small-study effects (Cappelleri et al., 1996).

5 | CONCLUSIONS

Based on the data identified by this systematic review, veneered and monolithic implant-supported ceramic SCs showed high short-term survival rates and low complication rates. Significantly higher rates of ceramic chipping were reported for veneered SCs when compared to monolithic SCs, with the exception of RMC SCs. The location of the implant-supported ceramic SCs, anterior vs. posterior, did not influence survival and chipping rates. However, conclusions on the long-term clinical performance of the presently evaluated type of restorations should not be drawn based on short-to-medium term clinical studies included in the present systematic review.

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CONFLICT OF INTEREST

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

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