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All-ceramic or metal-ceramic tooth-supported fixed dental prostheses (FDPs)? A systematic review of the survival and complication rates. Part I: Single crowns (SCs)☆

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ABSTRACT

Objective. To assess the 5-year survival of metal-ceramic and all-ceramic tooth-supported single crowns (SCs) and to describe the incidence of biological, technical and esthetic complications.

Methods. Medline (PubMed), Embase, Cochrane Central Register of Controlled Trials (CENTRAL) searches (2006–2013) were performed for clinical studies focusing on tooth-supported fixed dental prostheses (FDPs) with a mean follow-up of at least 3 years. This was complimented by an additional hand search and the inclusion of 34 studies from a previous systematic review [1,2]. Survival and complication rates were analyzed using robust Poisson's regression models to obtain summary estimates of 5-year proportions.

Results. Sixty-seven studies reporting on 4663 metal-ceramic and 9434 all-ceramic SCs fulfilled the inclusion criteria. Seventeen studies reported on metal-ceramic crowns, and 54 studies reported on all-ceramic crowns. Meta-analysis of the included studies indicated an estimated survival rate of metal-ceramic SCs of 94.7% (95% CI: 94.1–96.9%) after 5 years. This was similar to the estimated 5-year survival rate of leucit or lithium-disilicate reinforced glass ceramic SCs (96.6%; 95% CI: 94.9–96.7%), of glass infiltrated alumina SCs (94.6%; 95% CI: 92.7–96%) and densely sintered alumina and zirconia SCs (96%; 95% CI: 93.8–97.5%; 92.1%; 95% CI: 82.8–95.6%). In contrast, the 5-year survival rates of feldspathic/silica-based ceramic crowns were lower ($p < 0.001$). When the outcomes in anterior and posterior regions

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were compared feldspathic/silica-based ceramic and zirconia crowns exhibited significantly lower survival rates in the posterior region ($p < 0.0001$), the other crown types performed similarly. Densely sintered zirconia SCs were more frequently lost due to veneering ceramic fractures than metal-ceramic SCs ($p < 0.001$), and had significantly more loss of retention ($p < 0.001$). In total higher 5 year rates of framework fracture were reported for the all-ceramic SCs than for metal-ceramic SCs.

Conclusions. Survival rates of most types of all-ceramic SCs were similar to those reported for metal-ceramic SCs, both in anterior and posterior regions. Weaker feldspathic/silica-based ceramics should be limited to applications in the anterior region. Zirconia-based SCs should not be considered as primary option due to their high incidence of technical problems.

Contents

1. Introduction

All-ceramic fixed dental prostheses (FDPs) are considered an established treatment alternative to metal-ceramic FDPs in daily clinical practice. The main reason to use of the all-ceramics instead of metal-ceramics is based on more favorable esthetics [3]. All-ceramic materials mimic very naturally the optical properties of teeth. Another more recent factor influencing the choice of materials and leading to an increasing use of all-ceramics is treatment costs, mostly due to the pronounced raise of the costs for high precious metals like gold [4].

The main shortcoming of the firstly introduced ceramics like, e.g. feldspathic glass ceramic, yet, was low mechanical stability, which limited the indications for all-ceramic reconstructions to anterior regions and to single-unit FDPs [1]. In the past years, numerous new dental ceramic materials were developed with the aim to increase the overall stability of the all-ceramic reconstructions, while still maintaining the esthetic benefit. Among those materials, leucite or lithium-disilicate leucit or lithium-disilicate reinforced glass ceramics and oxide ceramics such as alumina and zirconia appeared to be very promising for different indications. Reconstructions made of these more recently developed ceramics were placed at posterior sites and even included multiple-unit FDPs [5].

Subsequently performed clinical studies confirmed the assumption that these mechanically more stable ceramic materials would perform better than the firstly developed ones when used for tooth-borne FDPs. The clinical outcomes of the more recent ceramics were far better than the ones of the first generation of dental ceramics [1,2].

A systematic review of the literature demonstrated significantly higher survival rates of SCs, e.g. made out of leucit or lithium-disilicate reinforced glass ceramics compared to SCs made out of feldspathic ceramics (95.4% vs. 87.5%). Tooth-borne SCs made out of densely sintered alumina exhibited the highest survival rates (96.4%) compared to all other all-ceramic SCs. Furthermore, all-ceramic crowns exhibited similar survival rates as metal-ceramic crowns (93.3% vs. 95.6%) [1]. In conclusion, improvements in terms of material properties such as mechanical stability of the ceramics had a positive effect on the clinical outcomes of all-ceramic reconstructions.

The clinical follow-up of the studies on all-ceramic FDPs, however, was rather short. At time of the above-mentioned systematic review a limited amount of studies was available, most of the published studies did not exceed 5 years of clinical follow-up. In order to be able to draw clinical conclusions with respect to the outcomes of all-ceramic reconstructions, more clinical research with longer observation periods was needed. In addition, the available clinical research indicated that despite of all material improvements catastrophic fractures remained to be one major issue of all-ceramic reconstructions. In addition, this problem was more often found in the posterior region, or for multiple-unit FDPs where high load occurred [1].

Hence, until recently, it was not possible to recommend all-ceramic single or multiple-unit FDPs as clinically equivalent treatment alternative to metal ceramic FDPs. Metal-ceramics remained to be the "gold standard" type of reconstruction. Yet, a high number of new manuscripts of all-ceramic and metal-ceramic single- and multiple-unit FDPs was published since the previously mentioned systematic review. The more recent studies either reported on the all-ceramic or metal-ceramic FDPs analyzed before but with longer observation periods, or on new all-ceramic FDPs made out of improved ceramic materials.

Therefore, the aim of the present systematic review was to analyze the outcomes of all-ceramic and metal-ceramic FDPs, i.e. of single crowns and of multiple-unit FDPs, and to assess whether or not all-ceramic FDPs achieve similar long-term results as FDPs made out of metal-ceramics.

The objectives of this systematic review, therefore, were:

(1) To update the previous systematic review [1] on tooth-supported FDPs with an additional literature search including retrospective and prospective studies from 2007 to 2013.
(2) To obtain overall robust estimates of the long-term survival and complication rates of all-ceramic crowns over an observation period of at least 3 years.
(3) To compare the survival and complication rates of all-ceramic crowns with the ones of metal-ceramic crowns (gold standard).

The present part 1 of the review presents the outcomes of all-ceramic versus metal-ceramic single crowns. Part 2 of the review analyzed the outcomes of the multiple-unit FDPs.

2. Materials and methods

2.1. *Search strategy and study selection*

The present review followed the same search methodology as the previous one [1].

2.1.1. *Focused questions*

"What are the survival and complication rates of tooth-supported FDPs after a mean observation period of at least 3 years?" "Are the survival and complications rates of metal-ceramic and all-ceramic tooth-supported FDPs similar after a mean observation period of at least 3 years?"

2.1.1.1. PICO. The population, intervention, comparison and outcomes, i.e. the "PICO" for this systematic review was defined as follows:

Population: Subjects with anterior and\or posterior tooth-supported fixed dental prostheses [FDP].

Intervention: All-ceramic FDPs

Comparison: Metal-ceramic FDPs

Outcomes: Clinical survival rates, and technical and\or biological complication rates.

A literature search in databases PubMed, Embase, Cochrane Central Register of Controlled Trials (CENTRAL) search was performed. The search was limited to human studies in dental journals written in English language. Articles published from 1st of December 2006 up to and including the 31st of December 2013 were included. The following detailed search terms were used and the search strategy was as follows:

P and I: crowns[MeSH] OR crown[MeSH] OR dental crowns[MeSH] OR crowns, dental[MeSH] OR Denture, Partial, Fixed[Mesh])) OR (crown*[all fields] OR fixed partial denture*[all fields] OR FPD[all fields] OR FPDs[all fields] OR fixed dental prosthesis[all fields] OR fixed dental prostheses[all fields] OR FDP[all fields] OR FDPs[all fields] OR bridge*[all fields].

C: Ceramic[MeSH] OR ceramics[MeSH] OR metal ceramic restorations[MeSH])) OR (ceramic*[All Fields] OR all-ceramic[all fields] OR Dental Porcelain[All Fields] OR metal-ceramic[All Fields].

O: Survival[Mesh] OR survival rate[Mesh] OR survival analysis[Mesh] OR dental restoration failure[Mesh] OR prosthesis failure[Mesh] OR treatment failure[Mesh].

The combination in the builder was set as "P & I AND C AND O".

The electronic search was complemented by manual searches of the bibliographies of all full text articles and related reviews, selected from the electronic search. The search was independently performed by two researches (IS and NAM). Any disagreement was resolved in consensus between the authors.

Up to the level of data extraction, the literature was evaluated for both single crowns and multiple-unit FDPs at the same time. At full text level the manuscripts were split according to the reconstruction type.

2.2. Inclusion criteria

Besides the mentioned RCTs, this systematic review was based on prospective or retrospective cohort studies, or case series.

The additional inclusion criteria for study selection were:

- Studies with a minimum mean follow-up period of 3 years.
- Included patients had been examined clinically at the follow-up visits, i.e. publications based on patient records only, on questionnaires or interviews were excluded.
- Studies reported details on the characteristics of the reconstructions, on materials and methods and on the results.
- Studies had to include and follow-up at least 10 patients.
- Publications which combined findings of tooth and implant supported reconstructions where at least 90% was tooth supported reconstructions.

The final selection based on inclusion/exclusion criteria was made for the full text articles. For this purpose Sections 2–4 of these studies were screened. This step was again carried out by two readers (IS, NAM) and double-checked. Any questions that came up during the screening were discussed to aim for consensus.

2.3. Exclusion criteria

The following study types were excluded:

- in vitro or animal studies;
- studies with less than 3 years of follow-up; and
- studies based on chart reviews or interviews.

2.4. Selection of studies

Titles and abstracts of the searches were independently screened by two reviewers (IS & NAM) for possible inclusion in the review. Furthermore, the full text of all studies of possible relevance was then obtained and split into literature on single crowns (part 1 of the review) and literature on multiple-unit FDPs (part 2 of the review).

The literature on single crowns was independently assessed by three of the reviewers (IS, BEP & NAM). Any disagreement regarding inclusion was resolved by discussion.

2.5. Data extraction

Data on the following parameters were extracted: author(s), year of publication, study design, planned number of patients, actual number of patients at end of study, drop-out rate, mean age, age range, operators, material framework, brand name of framework material, veneering material, brand name of veneering material, type of manufacturing procedure, number of FDPs, number of abutment teeth, number of (non)vital abutment teeth, number of pontics, location of FDP (anterior, posterior, maxilla, mandible), reported mean follow-up, follow-up range, published FDP survival rate, number of FDPs lost (anterior, posterior), reported biological complications (caries, periodontal, root fracture), reported technical complications (framework fracture, minor chipping, major chipping, loss of retention), esthetic complications (marginal discoloration), reported number of patients free of complications. Based on the included studies, the FDP survival rate was calculated. In addition, the number of events for all technical, biological and esthetic complications was extracted and the corresponding total exposure time of the reconstruction was calculated.

Data was extracted independently by two reviewers (IS & NAM) using a data extraction form. Disagreement regarding data extraction was resolved by consensus of three reviewers (IS, BEP & NAM).

2.6. Statistical analysis

For the statistical analysis the new data of the present review, encompassing the 33 studies was combined with the previous data of the 34 studies published in Pjetursson et al., 2007.

Hence, the data included in the present analysis was published from 1990 until the end of 2013.

Survival was defined as the FDP remaining in situ with or without modification for the observation period.

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:

(1) Exposure time of FDPs that could be followed for the whole observation time.
(2) Exposure time up to a failure of the FDPs that were lost due to failure during the observation time.
(3) 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, non-response, 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 with a logarithmic link-function and total exposure time per study as an offset variable were used [6].

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. If the goodness-of-fit p-value was below 0.05 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 [7]. 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 formally compare construction subtypes and to assess other study characteristics. All analyses were performed using Stata®, version 13.1.

Table 1 – Study and patient characteristics of the reviewed studies for all-ceramic crowns.

Study	Year of publication	Core material	Study design	No. of patients in study	Age range	Mean age	Setting	Drop-out (in percent)
Gehrt et al.	2013	Lithium disilicate glass ceramic	Prospective	41	34	n.r.	University	10%
Monaco et al.	2013	Densely sintered zirconia	Retrosp.	398	48.6	18–84	Private practice	0%
Passia et al.	2013	Densely sintered zirconia	RCT	123	42.7	24–73	University	37%
Rinke et al.	2013	Densely sintered zirconia	Prosp.	53	49.6	29–70	Private practice	8%
Sagitkaya et al.	2012	Densely sintered zirconia	RCT	42	n.r.	n.r.	University	0%
Sorrentino et al.	2012	Densely sintered alumina	Retrosp.	112	n.r.	18–69	University	1%
Ortorp et al.	2012	Densely sintered zirconia	Retrosp.	169	n.r.	n.r.	Private practice	32%
Vigolo & Mutinelli	2012	Densely sintered zirconia	Prosp.	20	32	19–55	Private practice	3%
Wolleb et al.	2012	Leucit reinforced glass ceramic	Retrosp.	52	61.3	34–84	University	14%
Cortellini & Canale	2012	Lithium-disilicate glass ceramic	Prospective	76	36	20–61	Private practice	0%
Beier et al.	2012	Feldspathic/silica-based ceramic	Retrosp.	302	46.5	n.r.	University	0%
Rinke et al.	2011	Glass-infiltrated alumina	Retrosp.	80	n.r.	n.r.	Private practice	0%
Cehreli et al.	2011	Feldspathic/silica-based ceramic Glass-infiltrated alumina	RCT	33	n.r.	n.r.	University	0%
Kokubo et al.	2011	Glass-infiltrated alumina	Prospective	39	50.9	n.r.	Private practice	13%
Beuer et al.	2010	Densely sintered zirconia	Prospective	38	50.9	27–71	University	0%
Schmitt et al.	2010	Densely sintered zirconia	Prosp.	10	42.1	n.r.	University	10%
Vanoorbeek et al.	2010	Densely sintered alumina	Prosp.	130	N.r.	18–70	University	27%
Kokubo et al.	2009	Densely sintered alumina	Prospective	57	46.4	20–70	University	19%
Valenti & Valenti	2009	Lithium disilicate glass ceramic	Retrosp.	146	n.r.	n.r.	Private practice	1%
Signore et al.	2009	Lithium disilicate glass ceramic	Retrosp.	200	37.6	19–66	University	4%

Table 1 (*Continued*)

Study	Year of publication	Core material	Study design	No. of patients in study	Age range	Mean age	Setting	Drop-out (in percent)
Toksavul & Toman	2007	Lithium disilicate glass ceramic	Prospective	21	38.3	18–60	University	0%
Burke	2007	Feldspathic/silica-based ceramic	Prospective	16	37.5	22–51	University	17%
Malament et al.	2006[*] 2001	Glass-infiltrated alumina Feldspathic/silica-based ceramic Leucit reinforced glass ceramic	Prospective	n.r.	n.r.	n.r.	Private practice	n.r.
Galindo et al.	2006	Densely sintered alumina	Prospective	50	22–75	n.r.	University	22%
Naert et al.	2005	Densely sintered alumina	Prospective	165	17–75	57	University	27%
Walter el al.	2005	Densely sintered alumina	Prospective	70	n.r.	38.8	University	6%
Marquardt & Strub	2006	Lithium disilicate reinforced glass ceramic	Prospective	43	22–65	39.9	University	0%
Bindl & Mörmann	2004	Glass-infiltrated alumina Feldspathic/silica-based ceramic	Prospective	29	30–77	53	University	17%
Fradeani & Redemagni	2002	Leucit reinforced glass ceramic	Retrospective	59	18–68	41	Private practice	8%
Bindl & Mörmann	2002	Glass-infiltrated alumina	Prospective	21	n.r.	n.r.	University	n.r.
Fradeani et al.	2002	Glass-infiltrated alumina	Retrospective	13	n.r.	48	Private practice	n.r.
van Dijken et al.	2001	Leucit reinforced glass ceramic	Prospective	110	26–81	53	University	0%
Scherrer et al.	2001	Feldspathic/silica-based ceramic Glass-infiltrated alumina	Prospective	95	n.r.	n.r.	University	14%
Segal	2001	Glass-infiltrated alumina	Retrospective	253	n.r.	n.r.	Private practice	n.r.
Ödmann et al.	2001	Densely sintered alumina	Prospective	50	19–79	53	Private practice	18%
McLaren & White	2000	Glass-infiltrated alumina	Prospective	107	n.r.	n.r.	Private practice	10%

Haselton et al.	2000	Glass-infiltrated alumina	Retrospective	71	18–77	47.3	University	42%
Edelhoff et al.	2000	Leucit reinforced glass ceramic	Retrospective	110	n.r.	n.r.	University	n.r.
Erpenstein et al.	2000	Feldspathic/silica-based ceramic	Retrospective	88	n.r.	40.4	Private practice	n.r.
Sjögren et al.	1999	Feldspathic/silica-based ceramic	Retrospective	48	24–69	50.2	Private practice	40%
Sjögren et al.	1999	Leucit reinforced glass ceramic	Retrospective	63	34–79	54.7	Private practice	27%
Oden et al.	1998	Densely sintered alumina	Prospective	58	n.r.	n.r.	University & Private practice	3%
Sorensen et al.	1998	Leucit reinforced glass ceramic	Prospective	33	17–69	n.r.	University	0%
Studer et al.	1998	Leucit reinforced glass ceramic	Prospective	71	n.r.	n.r.	University	17%
Pröbster	1997	Glass-infiltrated alumina	Prospective	22	n.r.	42	University & Private practice	11%
Scotti et al.	1995	Glass-infiltrated alumina	Prospective	45	n.r.	44.2	University & Private practice	0%
Hüls	1995	Glass-infiltrated alumina	Prospective	92	21–72	44.2	University	11%
Kelsey et al.	1995	Feldspathic/silica-based ceramic	Prospective	n.r.	n.r.	>19	University	9%
Bieniek	1992	Feldspathic/silica-based ceramic	Retrospective	60	26–30	n.r.	University	8%
Cheung et al.	1991	Feldspathic/silica-based ceramic	Retrospective	n.r.	17–73	37.7	University	66%

n.r. stands for “not reported”.
* Update from 2006 based on personal communication with the senior author.

3. Results

From this extensive new search, one randomized controlled clinical trial (RCT) was available comparing all-ceramic single crowns with conventional metal-ceramic crowns [8]. This RCT compared zirconia-based SCs with metal-ceramic SCs [8]. No further RCT comparing all-ceramic and metal-ceramic crowns was available. However, one RCT compared crowns made of feldspathic ceramic and glass-infiltrated alumina [9]. Finally, one RCT compared two types of metal-ceramic crowns [10].

Fig. 1 describes the process of identifying the 71 full text articles selected from an initial yield of 580 titles that were found published in the period from the 1st of December 2006 to the 31st of December 2013.

From these, 41 full text articles were allocated to the "single crown" group, whereas 37 were allocated to the group reporting on "multiple-unit FDPs".

3.1. *Study characteristics*

3.1.1. *Included studies*

The final number of the new studies included in the analyses resulted as 33 studies. Information on the survival proportions of the single crowns was extracted from these included 33 studies. In addition, the data from 34 publications from the previous systematic review [1] was included in the analyses.

The details on the previously included studies as well as the references are given in Pjetursson et al., 2007, and in Tables 1 and 2. The newly included 33 studies on all-ceramic and/or metal-ceramic single crowns were published between 2006 and 2013 (Tables 1 and 2).

Out of these studies, four were designed as RCTs. However, only one RCT compared all-ceramic (zirconia-based) and metal-ceramic crowns. All other RCTs compared either two different types of all-ceramics or of metal-ceramics, or all-ceramic and resin-based single crowns.

Furthermore, 14 "new" studies were reporting on metal-ceramic crowns, four on crowns made out of feldspathic/silica-based ceramics (jacket crowns, 3G OPC, Noritake feldspathic, Dicor), six on reinforced glass-ceramic crowns (one study on Empress 1 [11], the remaining on Empress 2 or E.max), three on glass-infiltrated alumina crowns (InCeram), three on densely sintered alumina crowns (Procera) and, finally, eight on densely sintered zirconia crowns (various CAD/CAM manufacturing procedures) (Table 1).

The studies included patients between the age of 17 and 81. The proportion of patients who could not be followed for the complete study period was available for 27 studies and ranged from 0% to 66% (Tables 1 and 2).

3.1.2. *Excluded studies*

During the full-text evaluation of the total of 41 single crown studies, eight were excluded. Two articles (Ortorp et al., 2009; Walton et al., 2009) were multiple publications on the same patient cohorts and were, therefore, excluded. Three manuscripts (Mansour et al., 2008; Groten et al., 2010; Rinke et al., 2011) reported on observation periods of less than 3 years. One study (Cagidiaco et al., 2008) gave no detailed

Table 2 – Study and patient characteristics of the reviewed studies for metal-ceramic crowns.

Study	Year of publication	Core material	Study design	No. of patients in study	Age range	Mean age	Setting	Drop-out (in percent)
Passia et al.	2013	PFM	RCT	100	41	21–64	University	19%
Reitemeier et al.	2013, 2005	PFM	Prosp.	95	n.r.	15–65	Private practice	15%
Walton	2013	PFM	Retrosp.	670	n.r.	14–81	University	5%
Rinke et al.	2013	PFM	Prosp.	53	49.6	29–70	Private practice	8%
Wolleb et al.	2012	PFM	Retrosp.	52	61.3	34–84	University	14%
Ortorp et al.	2012	PFM	Retrosp.	55	60.1	37–83	Private practice	3%
Vigolo & Mutinelli	2012	PFM	Prosp.	20	32	19–55	Private practice	5%
Abou Tara et al.	2011	PFM	Prospective	39	52.5	n.r.	University	3%
Naumannet al.	2011	PFM	RCT	52	44	n.r.	University	8%
Boeckler et al.	2009	PFM	Prosp.	21	49.4	26–67	University	14%
Napankangas et al.	2008	PFM	Retrosp.	102	59.6	43–91	University	51%
Gungor et al.	2007	PFM	Prospective	260	n.r.	28–56	University	23%
Eliasson et al.	2007	PFM	Retrosp.	45	n.r.	n.r.	University	7%
De Backer et al.	2007	PFM	Retrosp.	456	41	18–82	University	21%
Brägger et al.	2007	PFM	Retrosp.	12	n.r.	19	University	30%
Marklund et al.	2003	PFM	Prosp.	18	33–69	51	Private practice	0%
Jokstad & Mjör	1996	PFM	Prosp.	61	n.r.	n.r.	Private practice	35%

n.r. stands for "not reported".
PFM stands for porcelain fused to metal.

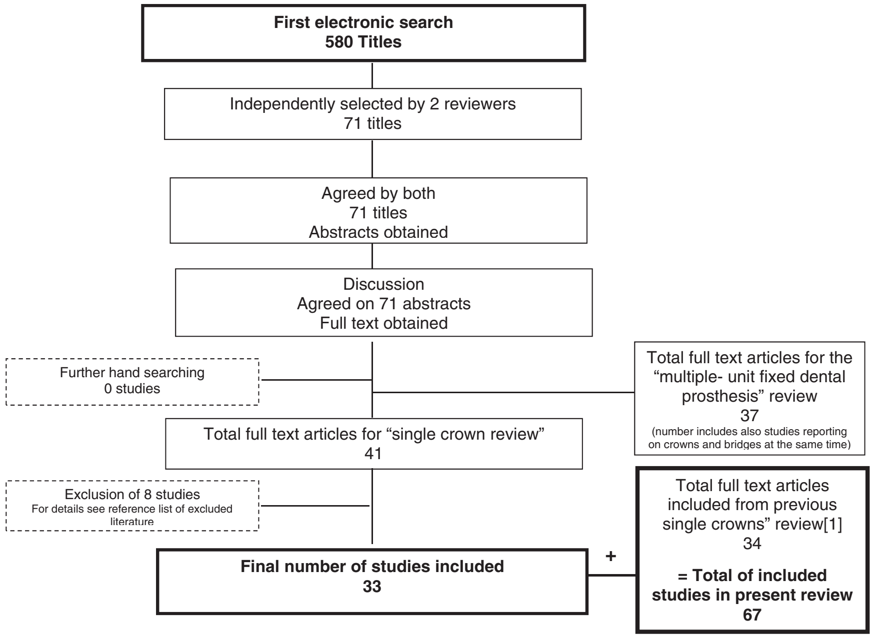

Fig. 1 – Search strategy and included studies on single crowns.

information on crown material and did not report on the details of the outcomes. In one study (Silva et al., 2011) the reported data was not specified between implant and tooth abutments, single crowns and bridges. The last study (Burke et al., 2009) was based on a chart review and, therefore, was excluded.

3.1.3. *Crown survival*

Overall, in the 17 studies reporting on metal-ceramic crowns with a mean follow-up of 7.3 years an estimated annual failure rate of 0.88 was reported, translated into an estimated 5-year survival of metal-ceramic crowns of 95.7%. In comparison, all-ceramic crowns had an annual failure rate ranging between 0.69 and 1.96, translating into overall estimated 5-year survival rates ranging between 90.7% and 96.6%. This was based on 55 studies on all-ceramic crowns included in the analysis (Table 3).

The survival rates of all-ceramic crowns differed for the various types of ceramics. Ten studies reported on the first types of feldspathic/silica based ceramics and rendered an estimated 5-year survival rate of 90.7%. This survival rate was significantly lower than the one reported for the gold-standard, metal-ceramic crowns (Tables 3 and 4).

The 12 studies reporting on leucit or lithium-disilicate reinforced glass ceramics showed an estimated 5-year survival rate of 96.6%, which was similar to the survival rate of metal-ceramic crowns. The same applied for crowns made out of glass-infiltrated alumina (15 studies with an estimated 5-year survival of 94.6%) and out of densely sintered alumina (eight studies with an estimated 5-year survival of 96.0%) (Tables 3 and 4, Figs. 2–7).

SCs made out of zirconia had a significantly lower estimated 5-year survival rate compared to metal-ceramic crowns ($p = 0.05$). The zirconia-based crowns reached an estimated 5-year survival rate of 91.2% (Tables 3 and 4, Fig. 7).

3.1.4. *Anterior vs. posterior regions*

When the outcomes of anterior and posterior single crowns were compared no statistically significant differences of the survival rates were found for metal-ceramic crowns, and for leucit or lithium-disilicate reinforced glass ceramic crowns, alumina and zirconia based crowns ($p > 0.05$).

Crowns made out of feldspathic or silica based ceramics, however, exhibited significantly lower survival rates in the posterior region than in the anterior (87.8% vs. 94.6%, $p < 0.0001$) (Table 5).

3.2. *Technical and biological complications*

Tables 6 and 7 display an overview of the incidences, the estimated annual complication rates and the cumulative complication rates of technical and biological complications for metal-ceramic SCs and the different types of all-ceramic crowns, as well as the statistical differences between the crown types.

3.2.1. *Technical complications*

Framework fracture, ceramic fracture, ceramic chipping, marginal discoloration, loss of retention and poor esthetics were technical problems reported for single crowns.

Ceramic chipping was a common problem, and overall occurred similarly for metal-ceramics and at the all-ceramic crowns. Furthermore, for metal-ceramic crowns, ceramic chipping was the most frequent technical complication with a cumulative 5-year event rate of 2.6% (95% CI: 1.3–5.2%). For all-ceramic crowns a tendency to more chippings of the veneering ceramic was observed for alumina and zirconia-based SCs than for all other ceramic crowns.

Framework fracture rarely occurred for metal-ceramic crowns (cumulative 5-year complication rate 0.03%; 95% CI

Table 3 – Annual failure rates and survival of single crowns.

Part 1

Study	Year of publication	Total no. of crowns	Mean follow-up time	No. of failure	Total crown exposure time	Estimated annual failure rate (per 100 crown years)	Estimated survival after 5 years (in percent)
Metal ceramic							
Passia et al.	2013	100	4.3	9	434	2.07	90.2%
Reitemeier et al.	2013	190	9.6	10	1832	0.55	97.3%
Walton	2013	2211	9.2	83	13,505	0.61	97.0%
Rinke et al.	2013	50	3	1	146	0.68	96.6%
Wolleb et al.	2012	249	5.3	3	1310	0.23	98.9%
Ortorp et al.	2012	90	4.5	8	408	1.96	90.7%
Vigolo & Mutinelli	2012	20	4.8	0	95	0	100%
Abou Tara et al.	2011	60	3.9	1	235	0.43	97.9%
Naumann et al.	2011	52	3.4	6	176	3.41	84.3%
Boeckler et al.	2009	41	2.8	2	114	1.75	91.6%
Näpänkangas & Raustia	2008	100	18.2	21	1820	1.15	94.4%
Gungor et al.	2007	260	7	7	1400	0.50	97.5%
Eliasson et al.	2007	12	4.3	0	51	0	100%
De Backer et al.	2007	1037	10	116	10,370	1.12	94.6%
Brägger et al.	2007	106	17	28	1598	1.75	91.6%
Marklund et al.	2003	42	5	3	190	1.58	92.4%
Jokstad & Mjör	1996	43	10	0	281	0	100%
Total		4663	7.3	298	33,965		
Summary estimate (95% CI)*						0.88 (0.63–1.22)	95.7% (94.1–96.9%)
Feldspathic/silica-based ceramic							
Beier et al.	2012	470	8.5	39	3995	0.98	95.2%
Burke	2007	59	3.9	3	187	1.60	92.3%
Malament & Socransky	2006	1061	7.9	177	8407	2.11	90.0%
Bindl & Mörmann	2004	18	3.4	1	67	1.49	92.8%
Scherrer et al.	2001	30	3.4	4	102	3.92	82.2%
Erpenstein et al.	2000	173	7	42	1210	3.47	84.1%
Sjögren et al.	1999	98	6.1	13	599	2.17	89.7%
Kelsey et al.	1995	101	4	16	388	4.12	81.4%
Bieniek	1992	164	3.6	8	641	1.25	94.0%
Cheung	1991	34	3.3	5	114	4.39	80.3%
Total		2208	7.1	308	15,710		
Summary estimate (95% CI)*						1.96 (1.44–2.67)	90.7% (87.5–93.1%)

Leucit/Lithium disilicate reinforced glass ceramics							
Gehrt et al.	2013	104	6.6	4	623	0.64	96.8%
Cortellini & Canale	2012	22	3.5	1	78	1.28	93.8%
Valenti & Valenti	2009	263	4.9	6	1283	0.47	97.7%
Signore et al.	2009	538	5.3	8	2851	0.28	98.6%
Toksavul & Toman	2007	79	3.5	1	273	0.37	98.2%
Malament & Socransky	2006	954	3.9	33	3732	0.88	95.7%
Marquardt & Strub	2006	27	3.2	0	105	0	100%
Fradeani & Redemagni	2002	125	7.3	6	908	0.66	96.8%
Edelhoff et al.	2000	250	4.2	5	1048	0.48	97.6%
Sjögren et al.	1999	110	3.6	6	396	1.52	92.7%
Sorensen et al.	1998	75	3	1	224	0.45	97.8%
Studer et al.	1998	142	5	14	710	1.97	90.6%
Total		2689	4.5	85	12,231		
Summary estimate (95% CI)*						0.69 (0.46–1.05)	96.6% (94.9–97.7%)
Glass-infiltrated alumina							
Cehreli et al.	2011	50	3.3	3	165	1.82	91.3%
Rinke et al.	2011	272	13.5	43	3672	1.17	94.3%
Cehreli et al. B	2011	51	3.4	2	172	1.16	94.4%
Kokubo et al.	2011	101	4.6	7	464	1.51	92.7%
Malament & Socransky	2006	312	7.2	34	2235	1.52	92.7%
Bindl & Mörmann	2004	18	3.4	1	67	1.49	92.8%
Bindl & Mörmann	2002	43	3.2	3	142	2.11	90.0%
Fradeani et al.	2002	40	4.2	1	167	0.60	97.1%
Segal	2001	546	3	5	1519	0.33	98.4%
Scherrer et al.	2001	120	3	12	344	3.49	84.0%
McLaren & White	2000	223	3.6	9	811	1.11	94.6%
Haselton et al.	2000	80	3	2	240	0.83	95.9%
Pröbster	1997	135	3.3	4	446	0.90	95.6%
Scotti et al.	1995	63	3.1	1	195	0.51	97.5%
Hüls	1995	335	3	3	1005	0.30	98.5%
Total		2389	4.9	130	11,644		
Summary estimate (95% CI)*						1.12 (0.83–1.51)	94.6% (92.7–96.0%)

Table 3 (*Continued*)

Part 2

Study	Year of publication	Total no. of crowns	Mean follow-up time	No. of failure	Total crown exposure time	Estimated annual failure rate (in percent)	Estimated survival after 5 years (in percent)
Densely sintered alumina							
Vanoorbeek et al.	2010	141	2.7	3	377	0.80	96.1%
Sorrentino et al.	2012	128	5.9	3	760	0.39	98.0%
Kokubo et al.	2009	101	4.4	9	441	2.04	90.3%
Galindo et al.	2006	135	4.6	5	619	0.81	96.0%
Naert et al.	2005	300	3	2	886	0.23	98.9%
Walter el al.	2005	107	6	6	597	1.01	95.1%
Ödmann & Andersson	2001	87	7.6	5	662	0.76	96.3%
Oden et al.	1998	100	5	6	487	1.23	94.0%
Total		1099	4.4	39	4829		
Summary estimate (95% CI)*						0.81 (0.51–1.27)	96.0% (93.8–97.5%)
Densely sintered zirconia							
Monaco et al.	2013	472	3.6	16	1708	0.94	95.4%
Passia et al.	2013	123	3.9	28	483	5.80	74.8%
Rinke et al.	2013	55	3	2	158	1.27	93.9%
Sagitkaya et al.	2012	74	3.9	4	286	1.40	93.2%
Örtorp et al.	2012	216	4.1	19	890	2.13	89.9%
Vigolo & Mutinelli	2012	20	4.4	2	89	2.25	89.4%
Vigolo & Mutinelli	2012	20	4.8	1	96	1.04	94.9%
Beuer et al.	2010	50	2.9	0	146	0	100%
Schmitt et al.	2010	19	3.3	0	62	0	100%
Total		1049	3.7	72	3918		
Summary estimate (95% CI)*						1.84 (0.89–3.77)	91.2% (82.8–95.6%)
Total		14,156	5.8	938	82,462		

* Based on robust Poisson regression.

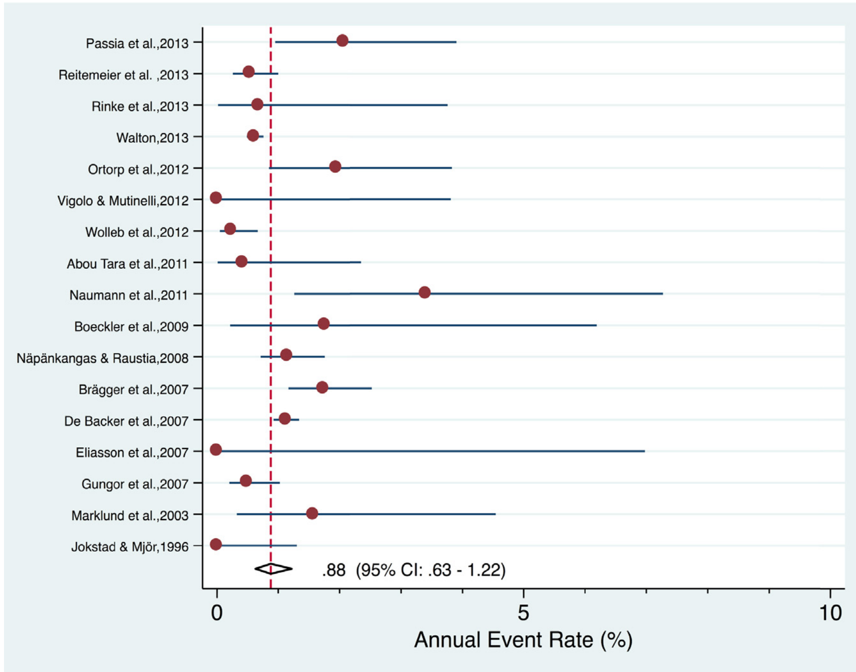

Fig. 2 – Annual failure rate of metal ceramic SCs.

0.002– 0.3%) (Table 7). Overall, this problem occurred significantly more often for ceramic crowns, irrespective of the type of ceramic used ($p < .0001$, $p = .03$) (Table 6). The incidence of framework fracture was associated with the mechanical stability of the ceramic material. Weaker ceramics like early feldspathic/silica based ceramics exhibited a high 5-year framework fracture rate of 6.7% (95% CI 2.4–17.7%). For leucit or lithium-disilicate reinforced glass ceramics framework fractures occurred at a rate of 2.3% (95% CI 1.0–5.5%) of the crowns and for zirconia-based single crowns at a rate of 0.4% only (95% CI 0.1–1.7%).

With the exception of zirconia-based crowns, loss of retention was not a predominant technical problem. Zirconia based crowns exhibited significantly more loss of retention than metal ceramic crowns (estimated 5-year complication rate 4.7%; 95% CI 1.7–13.1%) ($p < .0001$) (Tables 6 and 7).

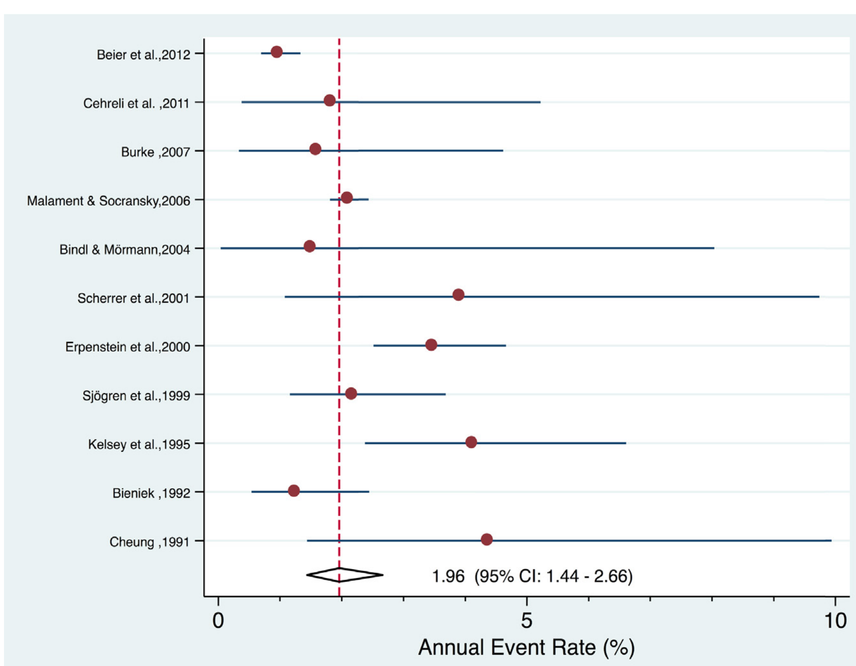

Fig. 3 – Annual failure rate of glass ceramic SCs.

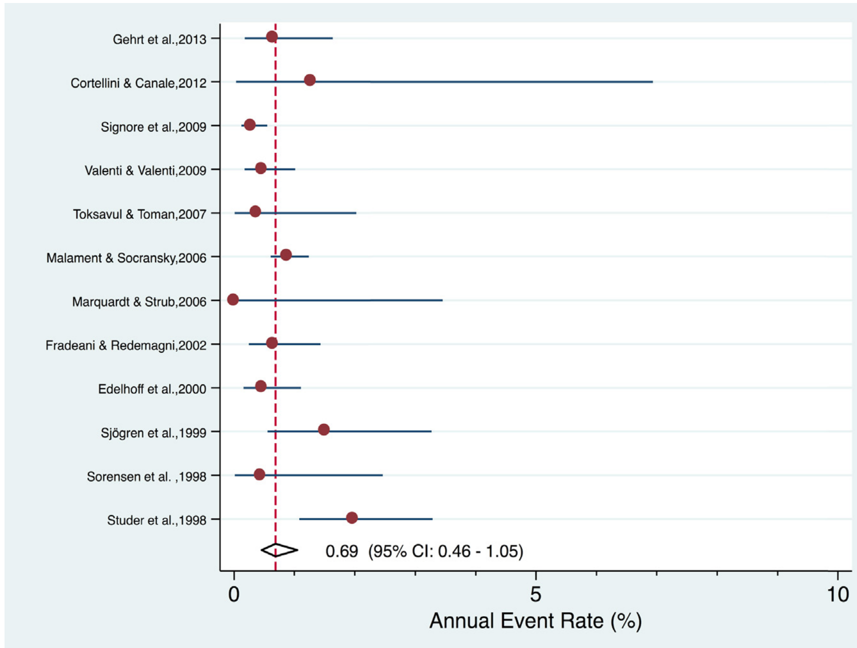

Fig. 4 – Annual failure rate of leucit or lithium-disilicate reinforced glass ceramic SCs.

3.2.2. *Biological complications*

Loss of abutment tooth vitality, abutment tooth fracture and secondary caries were the predominantly reported as biologic complications for SCs.

For metal-ceramic crowns loss of abutment tooth vitality was the most frequent biologic complication (5-year complication rate 1.8%; 95% CI 1.6–1.8%). This problem less frequently occurred for leucit or lithium-disilicate reinforced glass ceramic and glass-infiltrated alumina crowns ($p = .006$, $p < .0001$).

In addition, abutment tooth fracture was also predominantly found for metal-ceramic crowns (5-year complication rate 1.2%; 95% CI 0.7–2.0%). This complication occurred significantly less frequently for all-ceramics like leucit or lithium disilicate reinforced glass ceramics, glass infiltrated alumina or at zirconia-ceramics ($p = .009$, $p = .04$, $p = .02$).

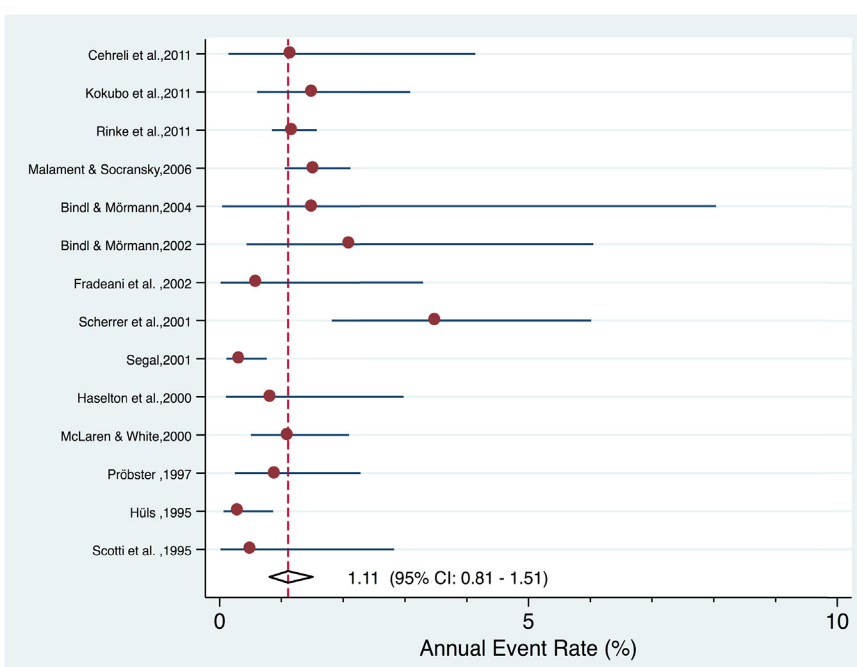

Fig. 5 – Annual failure rate of glass infiltrated alumina SCs.

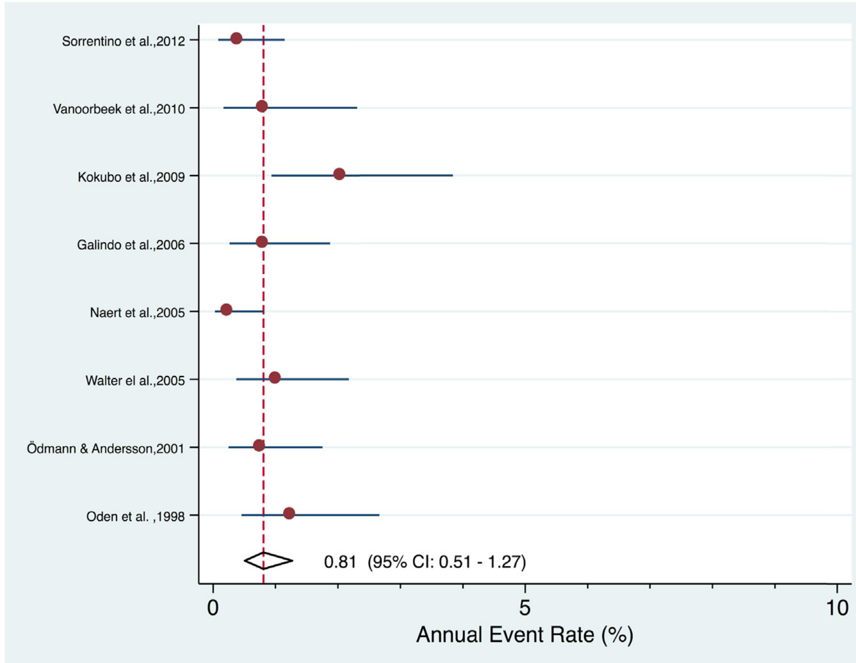

Fig. 6 – Annual failure rate of densely infiltrated alumina ceramic SCs.

Finally, secondary caries was reported for 1% of metal-ceramic crowns (95% CI 0.8–1.4%) after 5 years in function. Most all-ceramic crowns exhibited similar 5-year caries rates as metal-ceramic SCs. However, zirconia based crowns had significantly less secondary caries, and glass-infiltrated ceramic crowns had higher caries rates ($p = .04$, $p < .0001$) (Tables 6 and 7).

4. Discussion

The present systematic review showed that the 5-year survival rates of all-ceramic crowns made out of leucit or lithium-disilicate reinforced glass ceramics or the oxide ceramics alumina and zirconia exhibited similar survival rates as the gold standard, metal ceramic crowns. This was not the case,

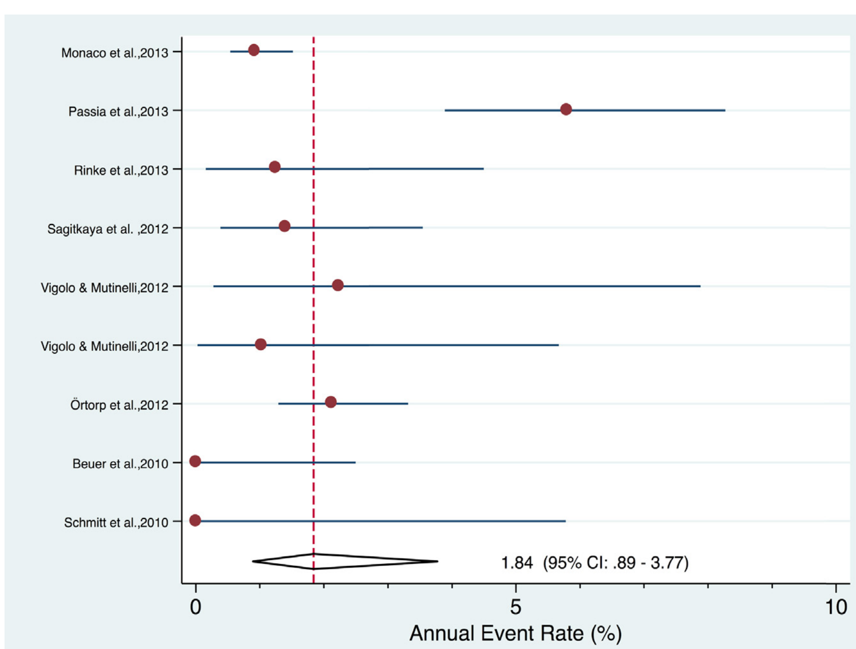

Fig. 7 – Annual failure rate of densely sintered zirconia ceramic SCs.

Table 4 – Summary of annual failure rates, relative failure rates and survival estimates for single crowns.

Type of SCs	Total number of reconstructions	Total crown exposure time	Mean crown follow-up time	Estimated annual failure rate*	5 year survival summary estimate* (95% CI)	Relative failure rate**	*p*-Value**
Metal-ceramic	4663	33,965	7.3	0.88 (0.63–1.22)	95.7% (94.1–96.9%)	1.00 (Ref.)	
Feldspathic/silica-based ceramic	2208	15,710	7.1	1.96 (1.44–2.67)	90.7% (87.5–93.1%)	2.23 (1.45–3.45)	$p < 0.001$
Leucit or lithium-disilicate reinforced glass ceramic	2689	12,231	4.5	0.69 (0.46–1.05)	96.6% (94.9–97.7%)	0.79 (0.47–1.32)	$p = 0.373$
Glass-infiltrated ceramic	2389	11,644	4.9	1.12 (0.83–1.51)	94.6% (92.7–96.0%)	1.27 (0.82–1.96)	$p = 0.276$
Densely sintered alumina	1099	4829	4.3	0.81 (0.51–1.27)	96.0% (93.8–97.5%)	0.92 (0.54–1.57)	$p = 0.761$
Densely sintered zirconia	1049	3918	3.7	1.84 (0.89–3.77)	91.2% (82.8–95.6%)	2.09 (0.99–4.45)	$p = 0.055$
Composite crowns	59	165	2.8	3.64 (1.35–7.75)	83.4% (67.9–93.5%)	4.14 (3.01–5.70)	$p < 0.001$

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

Table 5 – Annual failure rates and survival estimates of crowns placed anterior and posterior.

Type of crowns	Total number of crowns	Estimated annual failure rate*	5 year survival summary estimate* (95% CI)	Total number of crowns	Estimated annual failure rate*	5 year survival summary estimate* (95% CI)	*p*-Value**
	Anterior			Posterior			
Overall results	4517	0.77 (0.62–0.98)	96.2% (95.2–97.0%)	4948	1.59 (0.99–2.57)	92.3% (87.9–95.2%)	
Metal-ceramic	1215	0.69* (0.68–0.71)	96.6%* (96.5–96.7%)	1263	0.61 (0.41–0.93)	97.0% (95.5–98.0%)	$p = 0.564$
Feldspathic/silica-based ceramic	1432	1.10 (0.74–1.63)	94.6% (92.2–96.4%)	1847	2.61 (2.10–3.24)	87.8% (85.1–90.0%)	$p < 0.0001$
Reinforced glass ceramic	1019	0.50 (0.24–1.04)	97.5% (94.9–98.8%)	430	1.20 (0.55–2.61)	94.2% (87.8–97.3%)	$p = 0.098$
Glass-infiltrated ceramic	526	0.74 (0.58–0.94)	96.4% (95.4–97.2%)	672	1.22 (0.62–2.39)	94.1% (88.7–97.0%)	$p = 0.050$
Densely sintered alumina	133	0.67 (0.42–1.07)	96.7% (94.8–97.9%)	296	1.05 (0.69–1.61)	94.9% (92.3–96.6%)	$p = 0.135$
Densely sintered zirconia	192	0.29 (0.19–0.47)	98.5% (97.7–99.1%)	440	1.02 (0.68–1.54)	95.0% (92.6–96.7%)	$p < 0.0001$

* Based on robust Poisson regression.
** Based on multivariable robust Poisson regression.

Table 6 – Summary of annual complication rates, overall complication estimates and relative complication rates and or single crowns.

	Number of abutments or SCs	Estimated annual complication rates* (95% CI)	Cumulative 5 year complication rates* (95% CI)	Metal ceramic	Feldspathic/silica-based ceramic: Relative compl. rate**	p-Value**	Reinforced glass ceramic: Relative compl. rate**	p-Value**	Glass infiltrated alumina: Relative compl. rate**	p-Value**	Densely sintered alumina: Relative compl. rate**	p-Value**	Densely sintered zirconia: Relative compl. rate**	p-Value**
Caries on abutments	7730	0.20* (0.15–0.28)	1.0%* (0.7–1.4%)	1.00 (Ref.)	0.61 (0.35–1.09)	$p = 0.094$	0.52 (0.18–1.55)	$p = 0.243$	2.05 (1.39–3.04)	$p < 0.0001$	1.33 (0.46–3.85)	$p = 0.600$	0.45 (0.20–0.98)	$p = 0.045$
SCs lost due to caries	11,068	0.08* (0.03–0.19)	0.4%* (0.2–0.9%)	1.00 (Ref.)	0.62 (0.14–2.77)	$p = 0.534$	0.10 (0.01–0.99)	$p = 0.049$	0.53 (0.09–3.08)	$p = 0.477$	0.38 (0.07–2.01)	$p = 0.256$	0.27 (0.03–2.17)	$p = 0.217$
SCs lost due to abutment tooth fracture	11,153	0.18* (0.11–0.28)	0.9%* (0.6–1.4%)	1.00 (Ref.)	0.33 (0.18–0.62)	$p = 0.001$	0.20 (0.06–0.67)	$p = 0.009$	0.56 (0.19–1.61)	$p = 0.277$	0.43 (0.11–1.68)	$p = 0.223$	0.12 (0.02–0.75)	$p = 0.024$
Loss of abutment tooth vitality	2494	0.35* (0.29–0.43)	1.8%* (1.4–2.1%)	1.00 (Ref.)	2.22 (0.75–6.55)	$p = 0.149$	0.41 (0.21–0.77)	$p = 0.006$	0	$p < 0.0001$	n.a	n.a	n.a	n.a
Framework fracture	10,075	0.40* (0.20–0.82)	2.0%* (1.0–4.0%)	1.00 (Ref.)	274.95 (23.18–3261.79)	$p < 0.0001$	92.38 (8.24–1035.29)	$p < 0.0001$	82.95 (7.96–864.29)	$p < 0.0001$	93.79 (9.46–929.73)	$p < 0.0001$	17.20 (1.26–234.31)	$p = 0.033$
SCs lost due to ceramic fractures	9144	0.13* (0.07–0.24)	0.7%* (0.4–1.2%)	1.00 (Ref.)	1.27 (0.37–4.32)	$p = 0.699$	4.06 (1.99–8.28)	$p < 0.0001$	2.71 (1.13–6.49)	$p = 0.025$	4.00 (1.59–10.07)	$p = 0.003$	11.36 (6.09–21.18)	$p < 0.0001$
Ceramic chipping	5499	0.43* (0.29–0.62)	2.1%* (1.5–3.1%)	1.00 (Ref.)	0.46 (0.09–2.33)	$p = 0.349$	0.56 (0.25–1.24)	$p = 0.154$	0.69 (0.33–1.43)	$p = 0.316$	1.34 (0.56–3.17)	$p = 0.512$	1.19 (0.56–2.54)	$p = 0.650$
Loss of retention	7594	0.19* (0.11–0.34)	1.0%* (0.5–1.7%)	1.00 (Ref.)	0.94 (0.12–7.25)	$p = 0.954$	1.64 (0.62–4.33)	$p = 0.315$	1.06 (0.53–2.13)	$p = 0.861$	3.61 (0.92–14.27)	$p = 0.067$	7.85 (2.67–23.04)	$p < 0.0001$
Esthetic failures	5671	0.15* (0.08–0.30)	0.7%* (0.4–1.5%)	1.00 (Ref.)	0.85 (0.23–3.18)	$p = 0.811$	0	$p < 0.0001$	0.88 (0.23–3.29)	$p = 0.847$	6.73 (2.47–18.35)	$p < 0.0001$	0	$p < 0.0001$

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

Table 7 – Overview of biological and technical complications of different types of SCs.

Complication	Number of abutments or SCs	Estimated annual complication rates* (95% CI)	Cumulative 5 year complication rates* (95% CI)	Number of abutments or SCs	Estimated annual complication rates* (95% CI)	Cumulative 5 year complication rates* (95% CI)	Number of abutments or SCs	Estimated annual complication rates* (95% CI)	Cumulative 5 year complication rates* (95% CI)	Number of abutments or SCs	Estimated annual complication rates* (95% CI)	Cumulative 5 year complication rates* (95% CI)	Number of abutments or SCs	Estimated annual complication rates* (95% CI)	Cumulative 5 year complication rates* (95% CI)	Number of abutments or SCs	Estimated annual complication rates* (95% CI)	Cumulative 5 year complication rates* (95% CI)
	Metal ceramic SCs			Feldspathic/silica-based ceramic SCs			Leucit or lithium-disilicate reinforced glass ceramic SCs			Glass infiltrated ceramic SCs			Densely sintered alumina SCs			Densely sintered zirconia SCs		
Caries on abutments	2908	0.21 (0.15–0.29)	1.0% (0.8–1.4%)	890	0.13 (0.08–0.22)	0.6% (0.4–1.1%)	1685	0.11 (0.04–0.33)	0.5% (0.2–1.6%)	729	0.43 (0.33–0.56)	2.1% (1.6–2.8%)	592	0.28 (0.09–0.86)	1.4% (0.5–4.2%)	876	0.09 (0.04–0.2)	0.5% (0.2–1.0%)
SCs lost due to caries	4303	0.11 (0.03–0.34)	0.5% (0.2–1.7%)	1261	0.07 (0.02–0.20)	0.3% (0.1–1.0%)	1797	0.01 (0.001–0.09)	0.06% (0.007–0.4%)	1623	0.06 (0.01–0.24)	0.3% (0.07–1.2%)	1099	0.04 (0.01–0.15)	0.2% (0.006–0.08%)	926	0.03 (0.004–0.19)	0.1% (0.002–1.0%)
SCs lost due to abutment tooth fracture	5276	0.24 (0.15–90.40)	1.2% (0.7–2.0%)	1088	0.08 (0.05–0.12)	0.4% (0.3–0.6%)	1628	0.05 (0.02–0.15)	0.2% (0.1–0.8%)	1077	0.14 (0.05–0.36)	0.7% (0.3–1.8%)	1099	0.10 (0.03–0.41)	0.5% (0.1–2.0%)	926	0.03 (0.004–0.19)	0.1% (0.02–1.0%)
Loss of abutment tooth vitality	1684	0.34 (0.32–0.36)	1.7% (1.6–1.8%)	375	0.76 (0.21–2.71)	3.7% (1.0–12.7%)	395	0.14 (0.07–0.28)	0.7% (0.3–1.4%)	40	0	0%	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Marginal discoloration	345	0.36 (0.14–0.90)	1.8% (0.7–4.4%)	160	0.87 (0.24–3.11)	4.3% (1.2–14.4%)	975	0.46 (0.12–1.75)	2.3% (0.6–8.4%)	322	1.74 (0.45–6.65)	8.3% (2.2–28.3%)	370	0	0%	670	0.	0%
Framework fracture	3075	0.005 (0.0005–0.05)	0.03% (0.002–0.3%)	1261	1.40 (0.48–4.06)	6.7% (2.4–18.4%)	1952	0.47 (0.19–1.14)	2.3% (1.0–5.5%)	1703	0.42 (0.22–0.80)	2.1% (1.1–3.9%)	1099	0.48 (0.31–0.73)	2.4% (1.5–3.6%)	926	0.09 (0.02–0.35)	0.4% (0.1–1.7%)
SCs lost due to ceramic fractures	4457	0.06 (0.03–0.11)	0.3% (0.1–0.6%)	529	0.07 (0.002–3.03)	0.4% (0.01–14.1%)	1155	0.23 (0.15–0.36)	1.1% (0.7–1.8%)	1441	0.15 (0.10–0.24)	0.8% (0.5–1.2%)	577	0.23 (0.09–0.55)	1.1% (0.5–2.7%)	926	0.64 (0.47–0.88)	3.2% (2.3–4.3%)
Ceramic chipping	1146	0.53 (0.27–1.10)	2.6% (1.3–5.2%)	953	0.25 (0.05–1.26)	1.2% (0.2–6.0%)	1408	0.30 (0.19–0.48)	1.5% (0.9–2.4%)	594	0.37 (0.27–0.50)	1.8% (1.3–2.5%)	999	0.71 (0.40–1.29)	3.5% (2.0–6.2%)	340	0.64 (0.42–1.0)	3.1% (2.1–4.7%)
Loss of retention	2971	0.12 (0.07–0.21)	0.6% (0.4–1.0%)	823	0.12 (0.01–1.04)	0.6% (0.07–5.1%)	1583	0.20 (0.08–0.49)	1.0% (0.4–2.4%)	987	0.13 (0.08–0.22)	0.7% (0.4–1.1%)	757	0.45 (0.11–1.85)	2.2% (0.5–8.8%)	414	0.97 (0.34–2.81)	4.7% (1.7–13.1%)
Esthetic failures	2806	0.11 (0.08–0.15)	0.5% (0.4–0.8%)	563	0.09 (0.02–0.43)	0.5% (0.1–2.1%)	1006	0	0%	282	0.10 (0.02–0.41)	0.5% (0.1–2.0%)	757	0.74 (0.26–2.09)	3.6% (1.3–9.9%)	196	0	0%

n.a. stands for "not available".

* Based on robust Poisson regression.

however, for feldspathic/silica based ceramic SCs. Crowns made out of these rather weak ceramics exhibited significantly higher failure rates compared to metal-ceramic crowns.

The same observation was made when the outcomes of the crowns in anterior and posterior regions were compared. Metal-ceramic crowns and all-ceramic crowns out of leucit or lithium-disilicate reinforced glass ceramics or oxide ceramics performed similarly in anterior and posterior regions. However, weaker feldspathic/silica-based ceramics and glass-infiltrated alumina exhibited significantly lower survival rates in the posterior region than in the anterior.

Technically, catastrophic framework fracture was the main complication of the all-ceramics, this problem was most specifically found when weaker ceramic materials were used [12]. With respect to the non-catastrophic technical complications, chipping of the veneering ceramic was a main clinical issue both found at the metal-ceramic as well as at the all-ceramic crowns [13]. Another technical problem observed was loss of retention, which was most frequently reported for zirconia-based single crowns [14].

Biologically, all-ceramic single crowns seemed to perform better than the gold standard, metal-ceramic crowns. Significantly more loss of abutment tooth vitality and abutment tooth fracture was reported for metal-ceramic crowns. These biologic complications might impair the prognosis of the abutment tooth or even lead to its loss and a loss of the reconstruction. In comparison, these complications were rarely reported for the all-ceramic crowns.

At the time the previous systematic review was published by the same authors in 2007, limited scientific data was available in the literature on a number of materials. Still, the review already indicated favorable outcomes of all-ceramic single crowns made out of more recently developed reinforced ceramics and oxide ceramics [1]. The review, furthermore, displayed limitations of mechanically weaker all ceramic crowns. The gold standard metal-ceramics, interestingly, was not well documented [1].

In the present review, 14 new studies on metal-ceramics were available as well as a high number of new studies evaluating all-ceramic crowns. The results of the present review, hence, may be considered more robust with more impact for the daily clinical practice.

In the present review it was shown that all-ceramic crowns made of leucit or lithium-disilicate reinforced glass ceramics or alumina based oxide ceramics can be recommended as an alternative treatment option to the gold standard metal-ceramics for SCs in anterior and posterior regions. The less stable feldspathic/silica glass ceramics can only be recommended in the anterior region.

The review also indicated that zirconia based single crowns performed less well in the clinics, despite the enhanced mechanical stability of this oxide ceramic. Failure due to extensive fracture of the veneering ceramic and loss of retention were frequently found technical problems for this type of ceramic crowns, occurring more often than at the other types of all-ceramics. Chipping of the veneering ceramic and loss of retention were technical complications also reported for multiple-unit zirconia based FDPs [15–17], occurring significantly more often at the zirconia-based FDPs than at metal-ceramics [18]. The more recent clinical studies showed that despite all developments and efforts for the improvement of the veneering procedures of zirconia frameworks, the problem of chipping of the zirconia veneering ceramic has not been eliminated yet [19,20]. Consequently, zirconia-based single crowns should not be considered as the primary treatment option for now, and patients need to be thoroughly informed about current limitations.

Another factor influencing the choice of the material for single crowns in daily clinical practice is the biologic outcome of the reconstructions. The present review indicated, that the biological outcomes of all-ceramic crowns were significantly better than the ones of metal-ceramics. Less invasive abutment tooth preparation for the highly esthetic all-ceramic FDPs may be assumed as reason for the observed differences [21,22].

Considering the current trend toward less invasive dental rehabilitation, the biological differences between materials may be considered as one of the key decisive factors for the choice of ceramics as reconstructive material for single crowns today [21,22]. Future research should focus on this topic and also further elucidate the reasons for the biologic differences between all-ceramic and metal-ceramic reconstructions.

5. Conclusion

All-ceramic single crowns exhibit similar survival rates as metal-ceramic single crowns after a mean observation period of at least 3 years. However, this is solely true for SCs are made out of leucit or lithium-disilicate reinforced glass ceramics or oxide ceramics. Those materials perform similarly well in anterior and posterior regions. Crowns made out of densely sintered zirconia, however, cannot be recommended as primary treatment option, due to an increased risk of chipping of the veneering ceramic and loss of retention. These limitations must first be overcome by further refinements of the production technology. Finally, the mechanically weaker ceramics like the feldspathic or silica glass-ceramics can only be recommended in anterior regions with low functional load.

Conflict of interest

The authors do report to have no conflict of interest.

Newly included further literature, as given in Tables

[1] Pjetursson BE, Sailer I, Zwahlen M, Hammerle CH. A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part I: Single crowns. Clinical oral implants research, 2007;18 Suppl. 3:73–85.

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List of excluded full-text articles and the reason for exclusion

[1] Mansour YF, Al-Omiri MK, Khader YS, Al-Wahadni A. (2008) Clinical performance of IPS-Empress 2 ceramic crowns inserted by general dental practitioners. *The Journal of Contemporary Dental Practice.* 9(4):9–16. Exclusion criteria: mean follow-up time < 3 years.

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Exclusion criteria: multiple publication of the same patient cohort.

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Exclusion criteria: data not specified between implant and tooth abutments, single crowns and bridges.

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