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Review

All-ceramic or metal-ceramic tooth-supported fixed dental prostheses (FDPs)? A systematic review of the survival and complication rates. Part II: Multiple-unit FDPs☆

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ABSTRACT

Objective. To assess the 5-year survival of metal-ceramic and all-ceramic tooth-supported fixed dental prostheses (FDPs) and to describe the incidence of biological, technical and esthetic complications.

Methods. Medline (PubMed), Embase and Cochrane Central Register of Controlled Trials (CENTRAL) searches (2006–2013) were performed for clinical studies focusing on tooth-supported FDPs with a mean follow-up of at least 3 years. This was complemented by an additional hand search and the inclusion of 10 studies from a previous systematic review [1]. Survival and complication rates were analyzed using robust Poisson's regression models to obtain summary estimates of 5-year proportions.

Results. Forty studies reporting on 1796 metal-ceramic and 1110 all-ceramic FDPs fulfilled the inclusion criteria. Meta-analysis of the included studies indicated an estimated 5-year survival rate of metal-ceramic FDPs of 94.4% (95% CI: 91.2–96.5%). The estimated survival rate of reinforced glass ceramic FDPs was 89.1% (95% CI: 80.4–94.0%), the survival rate of glass-infiltrated alumina FDPs was 86.2% (95% CI: 69.3–94.2%) and the survival rate of densely sintered zirconia FDPs was 90.4% (95% CI: 84.8–94.0%) in 5 years of function. Even though the survival rate of all-ceramic FDPs was lower than for metal-ceramic FDPs, the differences did not reach statistical significance except for the glass-infiltrated alumina FDPs ($p = 0.05$). A significantly higher incidence of caries in abutment teeth was observed for densely sintered zirconia FDPs compared to metal-ceramic FDPs. Significantly more framework fractures were reported for reinforced glass ceramic FDPs (8.0%) and glass-infiltrated alumina FDPs

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(12.9%) compared to metal-ceramic FDPs (0.6%) and densely sintered zirconia FDPs (1.9%) in 5 years in function. However, the incidence of ceramic fractures and loss of retention was significantly ($p = 0.018$ and 0.028 respectively) higher for densely sintered zirconia FDPs compared to all other types of FDPs.

Conclusions. Survival rates of all types of all-ceramic FDPs were lower than those reported for metal-ceramic FDPs. The incidence of framework fractures was significantly higher for reinforced glass ceramic FDPs and infiltrated glass ceramic FDPs, and the incidence for ceramic fractures and loss of retention was significantly higher for densely sintered zirconia FDPs compared to metal-ceramic FDPs.

Contents

1. Introduction

Socio-economic factors, better prophylaxis and oral hygiene regimens with patients included in regular recall programs have led to an increased number of teeth and to a shift from fully to more partially edentulous patients over the past decades [2]. This resulted in more single and multiple tooth gaps that can be restored with fixed tooth- or implant-supported reconstructions. In order to support the decision-making process for either one option, evidence-based clinical data are needed reporting on survival and complication rates for both types of reconstructions. Whereas for implant-supported reconstructions, systematic reviews provide very recent evidence comparing metal- and all-ceramic reconstructions [3,4], a systematic pooling of newer clinical data on tooth-supported reconstructions is limited to all-ceramic reconstructions [5].

Traditionally, metal-based reconstructions for fixed dental prostheses (FDPs) were considered as the gold standard [6]. Alloys, mainly gold-based, were fully or partially veneered with feldspathic ceramics. The evolution in material science led to the introduction of new framework materials (ceramics) and partially a change in clinical concepts (e.g. monolithic rather than veneered framework materials) [7–10]. Ceramics as part of reconstructive materials fulfill the need for esthetics. However, low-strength materials such as feldspathic-based ceramics and (reinforced) glass-ceramic materials appear to be more suitable for single crowns than for FDPs [7,11]. In order to overcome the limited material properties, high-strength ceramics were introduced in dentistry. Zirconia as the most stable of these materials is available for CAD/CAM technology and offers a higher flexural strength (900–1400 MPa) and a higher fracture toughness (5–10 MPa $m^{1/2}$) [12,13]. Zirconia is mainly used as a framework material for single crowns and FDPs [14–16]. Zirconia used as framework material appears to withstand the clinical forces during chewing and regular function and fracture rates are low and comparable to metal-based FDPs [17]. However, in contrast to metal-based FDPs, a higher rate of technical complications (major chippings) was reported [18,19]. The adhesion between zirconia and veneering ceramics is reported to be the critical issue for this observation [20].

In a systematic review, analyzing the survival and complications rates of all-ceramic and metal-ceramic reconstructions, an imbalance in terms of the number of studies for all-ceramic and metal-based FDPs was observed [1]. Clinical studies on newer materials such as zirconia, lithium disilicate reinforced glass ceramics and glass-infiltrated alumina (In-Ceram Alumina) or glass-infiltrated alumina-zirconia (Inceram-Zirconia) were available, but only few of them provided longer term data. Since that time, the evidence increased and clinical data are available for a number of all-ceramic materials for FDPs. The aim of the present systematic review was therefore,

(i) 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;
(ii) to assess the 3-year survival rate of tooth-supported fixed dental prostheses (FDPs) and to describe the rate of biological, technical and esthetic complications;

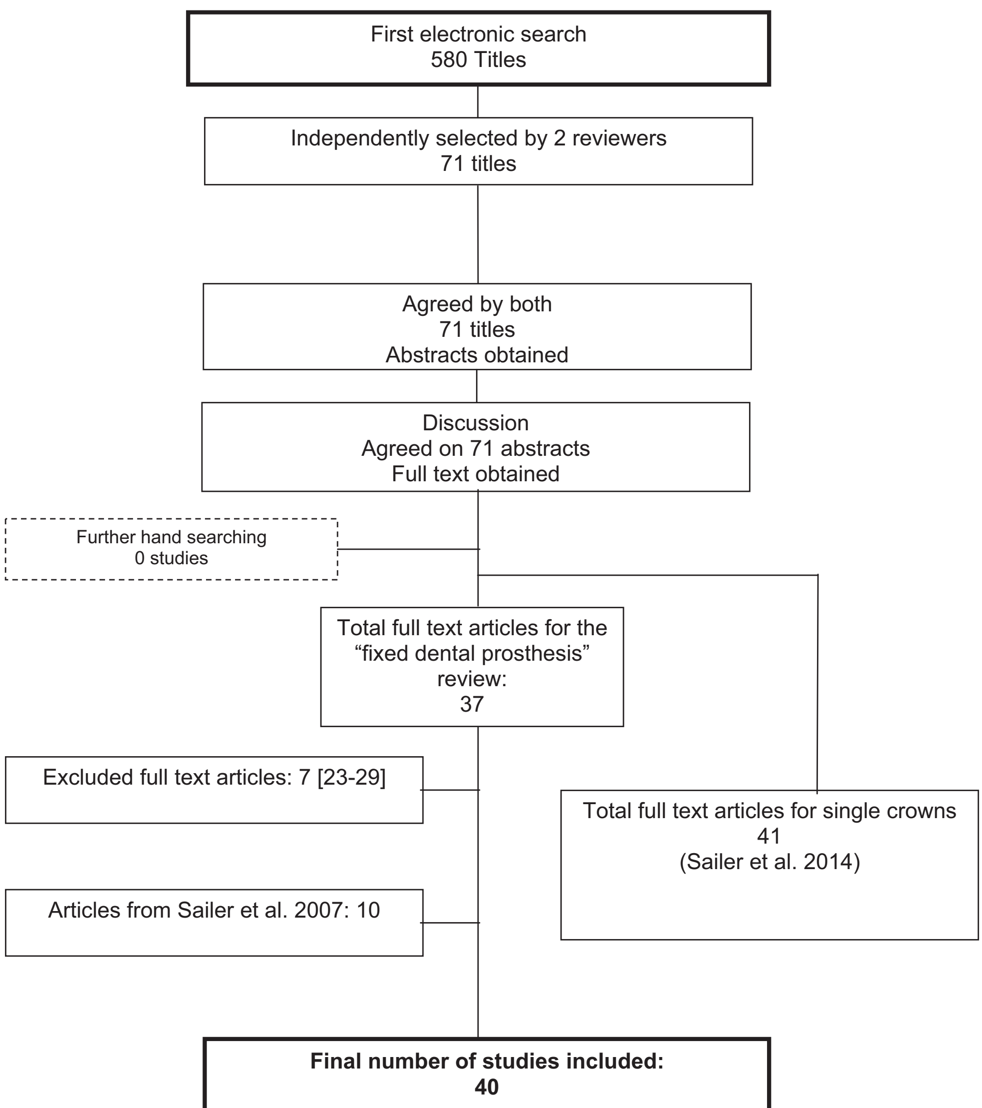

Fig. 1 – Search strategy.

(iii) to compare the survival and complication rates of metal-based FDPs and all-ceramic FDPs.

2. Materials and methods

2.1. Search strategy

This systematic review was designed as an update to a previously prepared publication with the same objectives [1]. For that purpose, Medline (PubMed), Embase and Cochrane Central Register of Controlled Trials (CENTRAL) searches were performed for clinical studies, including articles published from December 1st, 2006 up to December 31, 2013 in the Dental literature. The search was limited to the English language (Fig. 1).

2.2. 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?"

2.3. PICO

The PICO for the present systematic review was defined as follows:

P Population: subjects with anterior and/or posterior fixed tooth-supported FDPs
I Intervention: all-ceramic FDP
C Comparison: metal-ceramic FDP
O Outcome: clinical survival and technical, biological and esthetic complication rates

2.4. Search terms

The following four searches and search terms were applied:

Population and intervention
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]
comparison
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]
outcome
Survival[Mesh] OR survival rate[Mesh] OR survival analysis[Mesh] OR dental restoration failure[Mesh] OR prosthesis failure[Mesh] OR treatment failure[Mesh].

The search combination in the builder was "population AND intervention AND comparison AND outcome".

An additional hand search was performed identifying relevant studies by screening the reference list of all included publications.

2.5. Inclusion criteria

Clinical publications were considered if all of the following criteria were suitable: (i) human trials with a minimum amount of 10 patients with FDPs, (ii) mean follow-up of at least 3 years in function, (iii) randomized controlled trials (RCT), controlled clinical trials (CCT), prospective case series, cohort studies, retrospective studies, (iv) patients needed to be examined clinically, and (v) reported details of materials characteristics, methods and results.

2.6. Exclusion criteria

Studies not meeting all inclusion criteria were excluded from the review. Publications dealing with the following topics were also excluded: in vitro and preclinical studies, studies with a follow-up of less than 3 years, reports based on questionnaires, interviews and charts.

2.7. Selection of studies

Two authors (IS, NAM) independently screened the titles derived from the searches based on the inclusion criteria. Disagreements were resolved by discussion. Following this, abstracts of all titles agreed on by both authors were obtained, and screened for meeting the inclusion criteria. If no abstract was available in the database, the abstract of the printed article was used. Based on the selection of abstracts, articles were then obtained in full text. If title and abstract did not provide sufficient information regarding the inclusion criteria, the full report was obtained as well. Again, disagreements were resolved by discussion.

The final selection based on inclusion/exclusion criteria was made for the full text articles. For this purpose Materials and Methods, Results and Discussion of these studies were screened. This step was again carried out by 2 readers (IS, NAM) and double-checked. Any questions that came up during the screening were discussed to aim for consensus. In addition, 15 publications from the previous systematic review [1] were included in the analyses.

2.8. Data extraction and method of analysis

All included articles were independently screened and data extracted using data extraction tables by two reviewers (DTH, BPJ). Any disagreements were resolved by discussion to aim for consensus. In addition, data of the included publications of the previously published review [1] were extracted as well.

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

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

Study	Year of publication	Framework material	Study design	No. of patients in study	Age range	Mean age	Setting	Drop-out (in percent)
Sola-Ruiz et al.	2013	Lithium disilicate reinforced glass ceramic	Prosp.	19	n.r.	49	University	0%
Rinke et al.	2013	Zirconia	Prosp.	75	26–76	49.4	University	19%
Raigrodski et al.	2012	Zirconia	Prosp.	16	36–60	48	University	6%
Peleaz et al.	2012	Zirconia	RCT	37	23–65	n.r.	University	0%
Sagitkaya et al.	2012	Zirconia	Prosp.	28	n.r.	38	University	0%
Kern et al.	2012	Lithium disilicate reinforced glass ceramic	Prosp.	28	n.r.	47.5	University	7%
Lops et al.	2012	Zirconia	Prosp.	28	n.r.	46.2	University	14%
Sax et al.	2011	Zirconia	Prosp.	45	n.r.	48.3	University	53%
Sorrentino et al.	2011	Zirconia	Prosp.	37	21–68	45.3	University	0%
Makarouna et al.	2011	Lithium disilicate reinforced glass ceramic	RCT	19	n.r.	47	University	26%
Schmitt et al.	2011	Zirconia	Prosp.	15	29–73	50.1	University	0%
Christensen and Ploeger	2010	Zirconia and glass-infiltrated alumina	RCT	259	16–89	50	Private practice multi-center	4%
Beuer et al.	2010	Zirconia	Prosp.	38	27–71	50.9	University	0%
Roediger et al.	2010	Zirconia	Prosp.	75	26–76	49.4	University	11%
Wolfart et al.	2009	Lithium disilicate reinforced glass ceramic	Prosp.	29	25–68	47.9	Multi-Center	7%
Eschbach et al.	2009	Glass-infiltrated alumina-zirconia	Prosp.	58	n.r.	46.8	University	3%
Sailer et al.	2009	Zirconia	RCT	59	n.r.	54.4	University	5%
Wolfart et al.	2009	Zirconia	Prosp.	48	23–75	55	University	4%
Beuer et al.	2009	Zirconia	Prosp.	19	27–71	50.9	University	0%
Edelhoff et al.	2008	Zirconia	Prosp.	18	n.r.	n.r.	University	6%
Molin and Karlsson	2008	Zirconia	Prosp.	18	40–84	59	Specialists and private practice	0%
Tinschert et al.	2008	Zirconia	Prosp.	46	20–58	n.r.	University	13%
Esquivel et al.	2008	Lithium disilicate reinforced glass ceramic	Prosp.	21	30–62	n.r.	University	0%
Wolfart et al.	2005	Lithium disilicate reinforced glass ceramic	Prosp.	29	25–68	47.8	University	17%
Marquart and Strub	2005	Lithium disilicate reinforced glass ceramic	Prosp.	43	22–65	39.9	University	0%
Suàrez et al.	2004	Glass-infiltrated alumina-zirconia	Prosp.	16	23–50	n.r.	University	0%
Olsson et al.	2003	Glass-infiltrated alumina	Retrosp.	37	28–84	54	Private practice	16%
Vult von Steyern et al.	2001	Glass-infiltrated alumina	Prosp.	18	25–70	n.r.	University and private practice	0%
Sorensen et al.	1998	Glass-infiltrated alumina	Prosp.	47	19–66	n.r.	University	2%

n.r., “not reported”; RCT, randomized controlled clinical trial.

(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.

2.9. *Statistical analysis*

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 [21].

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, $S(T) = \exp(-T \times \text{event rate})$, by assuming constant event rates [22]. 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.

3. Results

3.1. *Study characteristics*

A total of 40 studies fulfilled the inclusion criteria of the present systematic review. Seven studies were excluded for

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

Study	Year of publication	Framework material	Study design	No. of patients in study	Age range	Mean age	Setting	Drop-out (in percent)
Svanborg et al.	2013	Co-Cr	Retrosp.	149	39–90	66.8	Private practice	16%
Peleaz et al.	2012	Co-Cr	RCT	37	23–65	n.r.	University	0%
Wolleb et al.	2012	Gold metal	Retrosp.	52	34–84	61	University students	14%
Heschl et al.	2013	Gold metal	Retrosp.	96	21–64	50.3	University	71%
Makarouna et al.	2011	Gold metal	RCT	18	n.r.	47	University	56%
Brägger et al.	2011	Gold metal	Retrosp.	84	36–84	62	University	n.r.
Christensen et al.	2010	Gold metal	RCT	259	16–89	50	Private practice multi-center	4
Boeckler et al.	2010	Titanium	Prosp.	23	27–69	55.3	University	17%
Sailer et al.	2009	Gold metal	RCT	59	n.r.	54.4	University	18%
De Backer et al.	2008	Gold metal	Retrosp.	270	n.r.	n.r.	University Students	19%
Eliasson et al.	2007	Co-Cr	Retrosp.	45	n.r.	n.r.	University	7%
Hochman et al.	2003	Gold metal	Retrosp.	30	n.r.	n.r.	University Students	n.r.
Walton	2002	Gold metal	Retrosp.	357	13–74	n.r.	Single specialist	n.r.
Napankangas et al.	2002	Gold metal	Retrosp.	132	39–82	56 .8	University Students	17%
Reichen-Graden and Lang	1989	Gold metal	Retrosp.	58	26–72	n.r.	University Students	n.r.

n.r., "not reported"; Co-Cr, cobalt-chromium; RCT, randomized controlled clinical trial.

various reasons, ranging from multiple publications on the same patient cohort to insufficiently reported data on FDPs [23–29]. 28 studies, published between 1998 and 2013, on all-ceramic FDPs and 15 studies, published between 1989 and 2013, on metal ceramic FDPs, were included in this review (Tables 1 and 2). The median year of publications for all-ceramic FDPs was 2009 and for metal-ceramic FDPs 2010. For all-ceramic FDPs, the majority or 28 studies had a prospective design and only one had a retrospective design. In contrast, for metal-ceramic FDPs the majority of the included studies or 10 were retrospective and the remaining 5 studies were prospective. Four of the included studies (Peleaz et al., 2012, Makarouna, 2011, Christensen, 2010 and Sailer et al., 2009) were randomized controlled clinical trails comparing different types of all-ceramic FDPs with metal-ceramic FDPs. The included studies on all-ceramic FDPs reported on reconstructions made out of reinforced glass ceramics, glass-infiltrated alumina (InCeram Alumina), glass-infiltrated alumina-zirconia (InCeram Zirconia), and densely sintered zirconia (Table 1). The studies of metal-ceramic FDPs reported on reconstructions having framework out of gold metal, cobalt chromium or titanium (Table 2).

The majority of the included studies, or 35 out of 40 were conducted in university settings. The remaining studies were executed in specialist clinics or private practices (Tables 1 and 2).

The 29 studies using all-ceramic materials included 1225 patients, where as the 15 studies on metal-ceramic FDPs included 1669 patients. The age of the patients ranged between 16 and 90 years at the time of treatment. The proportion of patients who could not be followed-up for the complete study period was available for 90% of the studies and ranged from 0% to 71%. The mean drop-out rate of patients was 8% for studies reporting on all-ceramic FDPs and 19% for studies on metal-ceramic FDPs (Tables 1 and 2).

3.2. *FDP survival*

For metal-ceramic FDPs, 15 studies provided data on 1796 FDPs after a mean follow-up time of 7.0 years. Out of these, 145 FDPs were reported to be lost. The annual failure rate was estimated at 1.15% (95% CI: 0.72–1.84%) (Fig. 2), translating into a 5-year survival rate for metal-ceramic FDPs of 94.4% (95% CI: 91.2–96.5%) (Table 3).

The results for all-ceramic FDPs was divided split into reconstructions based on reinforced glass ceramic, glass-infiltrated alumina (InCeram Alumina and InCeram Zirconia) and densely sintered zirconia. For reinforced glass ceramic FDPs, 7 studies provided data on 208 FDPs. After a mean follow-up time of 6.0 years, 29 FDPs were reported to be lost. The annual failure rate was estimated at 2.31% (95% CI: 1.23–4.35%) (Fig. 3) translating into a 5-year survival rate for reinforced glass ceramic FDPs of 89.1% (95% CI: 80.4–94.0%) (Table 3). For glass-infiltrated alumina FDPs, 6 studies provided data on 229 FDPs. After a mean follow-up time of 4.1 years, 28 FDPs were reported to be lost. The annual failure rate was estimated at 2.97% (95% CI: 1.20–7.35%) (Fig. 4) translating into a 5-year survival rate for glass-infiltrated alumina FDPs of 86.2% (95% CI: 69.3–94.2%) (Table 3). For densely sintered zirconia FDPs, 16 studies provided data on 673 FDPs from which 62 FDPs were reported to be lost after a mean follow-up time of 4.5 years. The annual failure rate was estimated at 2.02% (95% CI: 1.24–3.31%) (Fig. 5) translating into a 5-year survival rate for densely sintered zirconia FDPs of 90.4% (95% CI: 84.8–94.0%) (Table 3).

At the 5-year follow-up, the annual failure rates of different types of FDPs ranged from 1.15% to 2.97% and the 5-year survival ranged from 86.2% to 94.4%. Investigating formally the relative failure rates of different types of FDPs, using metal-ceramic FDPs as reference, all-ceramic FDPs showed higher annual failure rates. Moreover, for glass-infiltrated alumina FDPs this difference reached statistical significance ($p = 0.052$) (Table 4).

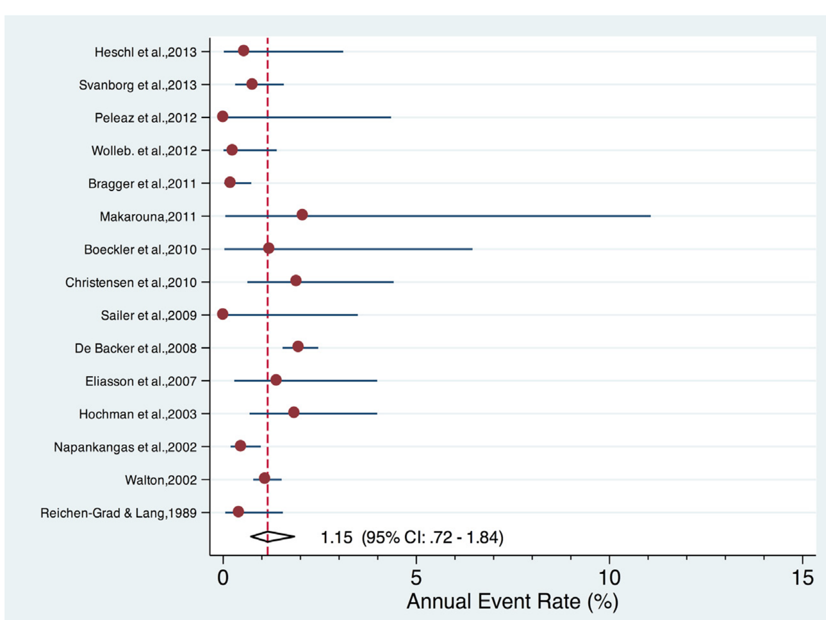

Fig. 2 – Annual failure rate of metal-ceramic FDPs.

Table 3 – Annual failure rates and survival of metal-ceramic and all-ceramic FDPs.

Study	Year of publication	Total no. of FDPs	Mean follow-up time	No. of failure	Total FDPs exposure time	Estimated annual failure rate* (per 100 FDP years)	Estimated survival after 5 years[a] (in percent)
Metal ceramic							
Svanborg et al.	2013	201	4.6	7	915	0.77	96.2%
Peleaz et al.	2012	20	4.2	0	83	0	100%
Wolleb et al.	2012	76	5.3	1	400	0.25	98.8%
Heschl et al.	2013	28	6.3	1	177	0.56	97.2%
Makarouna	2011	19	2.5	1	48	2.08	90.1%
Brägger et al.	2011	82	12.1	2	992	0.20	99.0%
Christensen and Ploeger	2010	87	3.0	5	261	1.92	90.9%
Boeckler et al.	2010	31	2.7	1	84	1.19	94.2%
Sailer et al.	2009	38	2.7	0	104	0	100%
De Backer et al.	2008	322	11.4	72	3675	1.96	90.7%
Eliasson et al.	2007	51	4.3	3	217	1.38	93.3%
Hochman et al.	2003	49	6.3	6	324	1.85	91.2%
Walton	2002	515	7.4	37	3363	1.10	94.6%
Napankangas et al.	2002	204	7.6	7	1478	0.47	97.7%
Reichen-Grad and Lang	1989	73	6.4	2	465	0.43	97.9%
Total		1796	7.0	145	12,586		
Summary estimate (95% CI)[a]						1.15 (0.72–1.84)	94.4% (91.2–96.5%)
Reinforced glass ceramic							
Sola-Ruiz et al.	2013	21	10.0	6	210	2.86	86.7%
Kern et al.	2012	36	10.1	4	363	1.10	94.6%
Makarouna	2011	18	4.7	6	84	7.14	70.0%
Wolfart et al.	2009	36	6.9	2	247	0.81	96.0%
Esquivel et al.	2008	30	3.3	5	100	5.00	77.9%
Wolfart et al.	2005	36	4.0	0	120	0	100%
Marquart et al.	2005	31	4.2	6	129	4.65	79.3%
Total		208	6.0	29	1253		
Summary estimate (95% CI) [a]						2.31 (1.23–4.35)	89.1% (80.4–94.0%)
Glass infiltrated alumina							
Christensen and Ploeger	2010	23	3.0	11	69	15.9	45.1%
Eschbach et al.	2009	65	4.5	2	295	0.68	96.7%
Suarez et al.	2004	18	3.0	1	53	1.89	91.0%
Olsson et al.	2003	42	6.3	5	266	1.88	91.0%
van Steyern et al.	2001	20	5.0	2	95	2.11	90.0%
Soerensen et al.	1998	61	3.0	7	165	4.24	80.9%
Total		229	4.1	28	943		
Summary estimate (95% CI) [a]						2.97 (1.20–7.35)	86.2% (69.3–94.2%)
Densely sintered zirconia							
Rinke et al.	2013	99	6.3	19	627	3.03	85.9%
Raigrodski et al.	2012	20	4.7	0	94	0	100%

Table 3 – (*Continued*)

Study	Year of publication	Total no. of FDPs	Mean follow-up time	No. of failure	Total FDPs exposure time	Estimated annual failure rate* (per 100 FDP years)	Estimated survival after 5 years[a] (in percent)
Peleaz	2012	20	4.2	1	83	1.20	94.2%
Lops et al.	2012	28	6.5	2	182	1.10	94.7%
Sax et al.	2011	57	7.6	15	433	3.46	84.1%
Sorrentino et al.	2011	48	5.0	0	240	0	100%
Schmitt et al.	2011	15	4.0	0	60	0	100%
Christensen and Ploeger	2010	80	3.0	14	240	5.83	74.7%
Beuer et al.	2010	18	2.9	1	53	1.89	91.0%
Roediger et al.	2010	99	4.2	7	413	1.69	91.9%
Sailer et al.	2009	38	3.2	0	121	0	100%
Wolfart et al.	2009	24	4.0	1	97	1.03	95.0%
Beuer et al.	2009	21	2.5	2	53	3.77	82.8%
Edelhoff et al.	2008	22	3.1	0	69	0	100%
Molin and Karlsson	2008	19	5.0	0	95	0	100%
Tinschert et al.	2008	65	3.1	0	202	0	100%
Total		673	4.5	62	3062		
Summary estimate (95% CI) [a]						2.02 (1.24–3.31)	90.4% (84.8–94.0%)
Overall results		2906	6.1	264	17,844		
Summary estimate (95% CI)[a]						1.48 (1.11–1.97)	92.9% (90.6–94.6%)

[a] Based on robust Poisson regression.

Table 4 – Summary of annual failure rates, relative failure rates and survival estimates for FDPs with metal-ceramic FDPs as reference.

Type of FDPs	Total number of FDPs	Total FDPs exposure time	Mean FDPs follow-up time	Estimated annual failure rate*	5-Year survival summary estimate* (95% CI)	Relative failure rate**	*p*-Value**
Metal-ceramic	1796	12,586	7.0	1.15 (0.72–1.84)	94.4% (91.2–96.5%)	1.00 (Ref.)	
Reinforced glass ceramic	208	1253	6.0	2.31 (1.23–4.35)	89.1% (80.4–94.0%)	2.01 (0.95–4.25)	0.068
Glass-infiltrated alumina	229	943	4.1	2.97 (1.20–7.35)	86.2% (69.3–94.2%)	2.58 (0.99–6.69)	0.052
Densely sintered zirconia	673	3062	4.5	2.02 (1.24–3.31)	90.4% (84.8–94.0%)	1.76 (0.90–3.41)	0.096

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

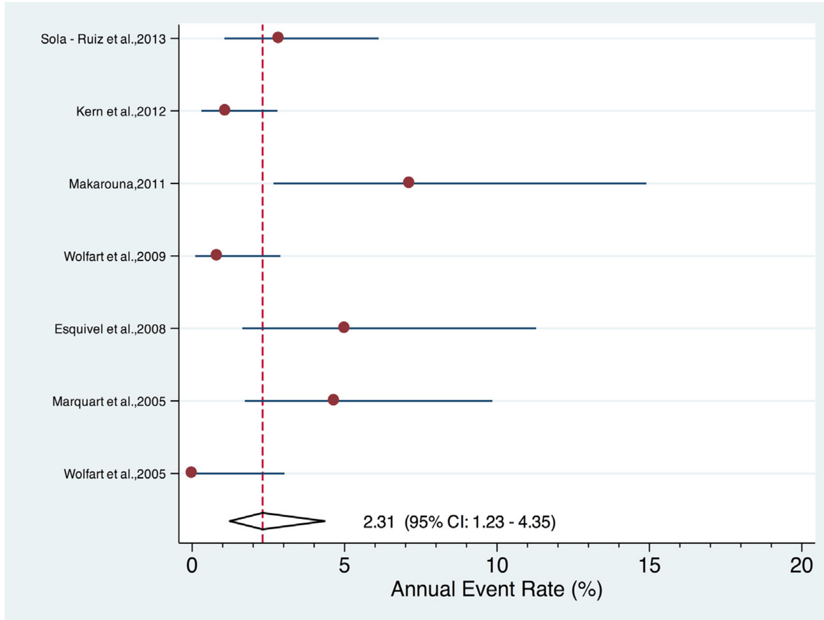

Fig. 3 – Annual failure rate of reinforced glass ceramic FDPs.

3.3. *Biological complications*

3.3.1. *Secondary caries*

Eighteen studies reported on the incidence of secondary caries on the abutment level. From 3351 FDP abutments included in those studies, 52 abutments developed secondary caries. The overall annual complication rate was 0.29%, translating into a 5-year complication rate of 1.4% (Table 5). For different types of FDPs the annual rate of secondary caries ranged from 0.11% to 0.65%. The lowest annual complication rate 0.11% was reported for reinforced glass ceramic FDPs and the highest complication rate 0.65% was reported for densely sintered zirconia FDPs. Investigating the relative complication rates of different types of FDPs, using metal-ceramic FDPs as reference, densely sintered zirconia FDPs experienced significantly higher rate of secondary caries ($p = 0.001$) (Table 6).

Information about loss of the entire reconstruction due to secondary caries was given in 38 studies. From 2145 FDPs included in these studies 55 were lost due to secondary caries. The overall annual failure rate was 0.43%, translating into a 5-year failure rate of 2.1% (Table 5). For different types of FDPs the annual rate of failures due to caries ranged from 0.09% to 0.54%. The lowest annual failure rate 0.09% was reported for reinforced glass ceramic FDPs and the highest failure rates

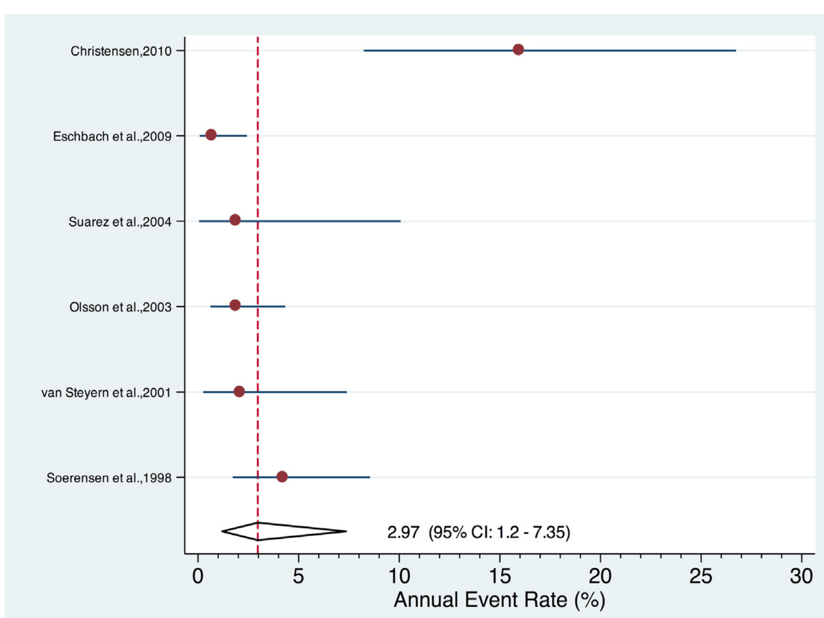

Fig. 4 – Annual failure rate of glass-infiltrated alumina FDPs.

Table 5 – Overview of biological and technical complications of different types of FDPs.

Complication	Number of abutments or FDPs	Estimated annual complication rates (95% CI)	Cumulative 5-year complication rates (95% CI)	Number of abutments or FDPs	Estimated annual complication rates (95% CI)	Cumulative 5-year complication rates (95% CI)	Number of abutments or FDPs	Estimated annual complication rates (95% CI)	Cumulative 5-year complication rates (95% CI)
	Overall results – all FDPs			Metal ceramic FDPs			Reinforced glass ceramic FDPs		
Caries on abutments	3351	0.29* (0.14–2.94)	1.4%* (0.7–2.9%)	2497	0.24* (0.10–0.57)	1.2%* (0.5–2.8%)	199	0.11* (0.01–0.94)	0.5%* (0.06–4.6%)
FDPs lost due to caries	2145	0.43* (0.21–0.88)	2.1%* (1.1–4.3%)	1053	0.54* (0.24–1.22)	2.7%* (1.2–5.9%)	190	0.09* (0.01–0.76)	0.4%* (0.05–3.7%)
FDPs lost due to periodontal disease	2096	0.23* (0.10–0.54)	1.2%* (0.5–2.7%)	1004	0.06* (0.03–0.11)	0.3%* (0.1–0.6%)	190	0.60* (0.10–3.52)	2.9%* (0.5–16.1%)
FDPs lost due to abutment tooth fracture	2107	0.17* (0.12–0.25)	0.9%* (0.6–1.3%)	1053	0.19* (0.11–0.30)	0.9%* (0.6–1.5%)	190	0.09* (0.02–0.44)	0.4%* (0.1–2.2%)
Loss of abutment tooth vitality	243	0.44* (0.11–1.80)	2.2%* (0.5–8.6%)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Marginal discolorations	253	3.91* (1.46–10.46)	17.7%* (7.0–40.7%)	20	4.82* (1.33–11.88)	21.4%* (6.4–44.8%)	118	0.72.* (0.23–2.19)	3.5%* (1.2–10.4%)
Framework fracture	2640	0.45* (0.25–0.82)	2.2%* (1.2–4.0%)	1530	0.12* (0.04–0.40)	0.6%* (0.2–2.0%)	208	1.68* (0.84–3.33)	8.0%* (4.1–15.3%)
Ceramic fractures	2129	1.56* (0.85–2.86)	7.5%* (4.2–13.3%)	1305	1.03* (0.42–2.56)	5.0%* (2.1–12.0%)	187	1.34* (0.99–1.82)	6.5%* (4.8–8.7%)
Ceramic chipping	1659	2.71.* (1.52–4.83)	12.7%* (7.3–21.4%)	781	1.79* (0.81–3.96)	8.6%* (4.0–18.0%)	213	1.07* (0.48–2.36)	5.2%* (2.4–11.1%)
Loss of retention	1702	0.64* (0.35–1.16)	3.1%* (1.7–5.6%)	955	0.42* (0.16–1.09)	2.1%* (0.8–5.3%)	142	0.58* (0.35–0.97)	2.9%* (1.7–4.7%)

Complication	Number of abutments or FDPs	Estimated annual complication rates (95% CI)	Cumulative 5-year complication rates (95% CI)	Number of abutments or FDPs	Estimated annual complication rates (95% CI)	Cumulative 5-year complication rates (95% CI)
	Glass-infiltrated alumina FDPs			Densely sintered zirconia FDPs		
Caries on abutments	168	0.41* (0.22–0.74)	2.0%* (1.1–3.6%)	487	0.65* (0.27–1.56)	3.2%* (1.3–7.5%)
FDPs lost due to caries	229	0.11* (0.02–0.56)	0.5%* (0.1–2.8%)	673	0.39* (0.20–0.77)	1.9%* (1.0–3.8%)
FDPs lost due to periodontal disease	229	1.59* (0.62–4.08)	7.6%* (3.1–18.4%)	673	0.10* (0.03–0.30)	0.5%* (0.2–1.5%)
FDPs lost due to abutment tooth fracture	229	0.11* (0.01–1.02)	0.5%* (0.05–5.0%)	635	0.21* (0.11–0.38)	1.0%* (0.6–1.9%)
Loss of abutment tooth vitality	n.a.	n.a.	n.a.	243	0.44* (0.11–1.80)	2.2%* (0.5–8.6%)
Marginal discolorations	18	3.77* (0.46–12.98)	17.2%* (2.3–47.7%)	97	6.72* (3.30–13.68)	28.5%* (15.2–49.5%)
Framework fracture	229	2.76* (1.01–7.52)	12.9%* (4.9–31.3%)	673	0.39* (0.24–0.65)	1.9%* (1.2–3.2%)
Ceramic fractures	65	1.36* (0.37–3.44)	6.6%* (1.8–15.8%)	572	3.14* (2.37–4.17)	14.5%* (11.2–18.8%)
Ceramic chipping	90	7.55* (1.09–52.24)	31.4%* (5.3–92.7%)	575	4.33* (1.93–9.72)	19.5%* (9.2–38.5%)
Loss of retention	107	0.53* (0.31–0.93)	2.6%* (1.5–4.5%)	498	1.28* (0.83–1.97)	6.2%* (4.1–9.4%)

n.a., "not available".
* Based on robust Poisson regression.

Table 6 – Relative complication rates for different types of FDPs.

Type of complications	Metal ceramic FDPs	Reinforced glass ceramic FDPs		Glass-infiltrated alumina FDPs		Densely sintered zirconia FDPs	
		Relative compl. rate*	p-Value*	Relative compl. rate*	p-Value*	Relative compl. rate*	p-Value*
Caries on abutments	1.00 (Ref.)	0.45 (0.06–3.29)	0.432	1.73 (0.53–5.63)	0.366	2.75 (1.50–5.07)	0.001
FDPs lost due to caries	1.00 (Ref.)	0.16 (0.02–1.37)	0.095	0.19 (0.03–1.10)	0.064	0.72 (0.26–2.01)	0.535
FDPs lost due to periodontal disease	1.00 (Ref.)	10.8 (1.82–64.31)	0.009	28.80 (9.45–87.74)	<0.0001	1.77 (0.49–6.44)	0.384
FDPs lost due to abutment tooth fracture	1.00 (Ref.)	0.46 (0.09–2.26)	0.341	0.57 (0.07–4.92)	0.612	1.11 (0.52–2.38)	0.784
Marginal discolorations	1.00 (Ref.)	0.14 (0.05–0.42)	<0.0001	0.78 (0.78–0.78)	<0.0001	1.39 (0.75–2.58)	0.289
Framework fracture	1.00 (Ref.)	13.81 (3.65–52.28)	<0.0001	22.72 (5.13–100.69)	<0.0001	3.23 (0.91–11.42)	0.069
Ceramic fractures (Chipping and fractures)	1.00 (Ref.)	1.30 (0.52–3.28)	0.578	1.31 (0.54–3.18)	0.544	3.05 (1.21–7.69)	0.018
Ceramic chipping	1.00 (Ref.)	0.60 (0.21–1.72)	0.338	4.21 (0.71–24.92)	0.113	2.42 (0.81–7.25)	0.115
Loss of retention	1.00 (Ref.)	1.40 (0.50–3.88)	0.523	1.28 (0.48–3.47)	0.621	3.07 (1.12–8.37)	0.028

* Based on multivariable robust Poisson regression including all types of FDPs with metal ceramic FDPs as reference.

0.39% and 0.54% for densely sintered zirconia FDPs and metal-ceramic FDPs, respectively. The difference between different types of FDPs did not reach statistical significance ($p = 0.064$, 0.095 & 0.535) (Table 6).

3.3.2. *Loss of vitality*

Loss of abutment vitality was reported in three studies. All of them reporting on densely sintered zirconia FDPs. Four out of 243 abutment teeth, reported to be vital at the time of cementation, presented loss of pulp vitality during the observation period. The annual complication rate was 0.44%, translating into a 5-year complication rate of 2.2% (Table 5).

3.3.3. *Abutment tooth fracture*

The incidence of FDPs lost due to fracture of abutment teeth was reported in 36 studies evaluating 2107 FDPs, out of which 22 were lost. The overall annual failure rate was 0.17%, translating into a 5-year failure rate of 0.9% (Table 5). For different types of FDPs the annual failure rates due to abutment tooth fractures ranged from 0.09% to 0.21%. The difference between different types of FDPs did not reach statistical significance ($p = 0.341$, 0.612 & 0.784) (Table 6).

3.3.4. *Periodontal disease*

The incidence of FDPs lost due to recurrent periodontal disease, was reported in 37 studies evaluating 2096 FDPs, out of which 29 were lost. The overall annual failure rate was 0.23%, translating into a 5-year failure rate of 1.2% (Table 5). For different types of FDPs, the annual failure rates due to recurrent periodontal diseases ranged from 0.06% to 1.59%. The highest annual failure rate was reported for reinforced glass ceramic FDPs 0.60% and glass-infiltrated alumina FDPs 1.59%, translating into a 5 years failure rates of 2.9% and 7.6%, respectively (Table 5). Investigating the relative complication rates of different types of FDPs, using metal-ceramic FDPs as reference, significantly more glass-infiltrated alumina FDPs and reinforced glass ceramic FDPs were lost due to recurrent periodontal diseases ($p < 0.0001$ & 0.009).

3.4. **Technical complications**

3.4.1. *Material complications: framework fracture, ceramic chipping or ceramic fracture*

The incidence of framework fracture was reported in 43 out of the 44 studies included in the present systematic review. From 2640 FDPs that were evaluated, 72 were known to be lost due to framework fractures. The overall annual failure rate was 0.45%, translating into a 5-year failure rate of 2.2% (Table 5). For different types of FDPs, the annual failure rates of framework fractures ranged from 0.12% to 2.76%. The highest annual failure rate was reported for reinforced glass ceramic FDPs (1.68%) and glass-infiltrated alumina FDPs (2.76%), translating into a 5-year failure rates of 8.0% and 12.9%, respectively (Table 5). Investigating the relative complication rates of different types of FDPs, using metal-ceramic FDPs as reference, significantly more glass-infiltrated alumina FDPs and reinforced glass ceramic FDPs were lost due to framework fractures ($p < 0.0001$). Compared to the other ceramics, densely sintered zirconia exhibited the highest stability as framework material with an estimated 5-year failure rate of 1.9% (Table 5).

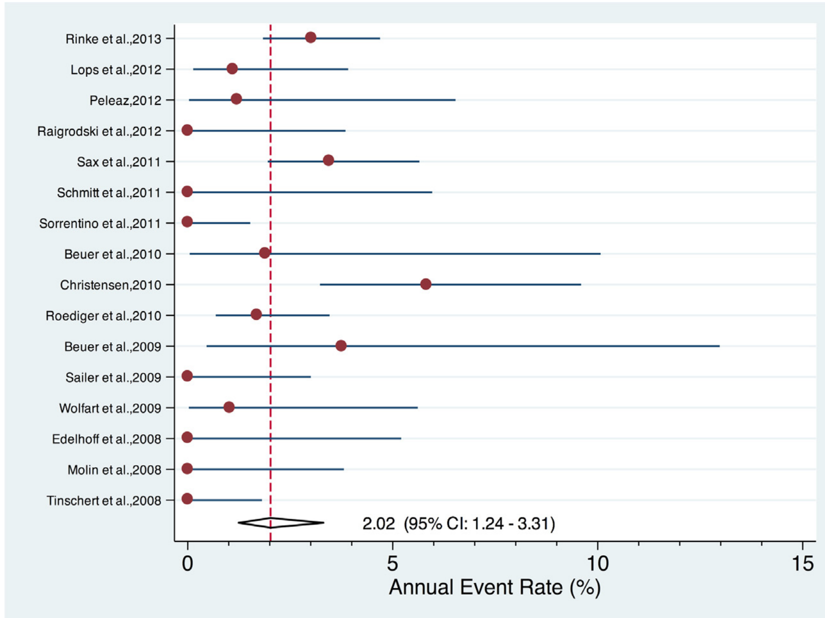

Fig. 5 – Annual failure rate of densely sintered zirconia FDPs.

The incidence, however, of fractures of the ceramic veneering that needed repair or replacement was highest for densely sintered zirconia FDPs with an annual complication rate of 3.14%, translating into a 5-year complication rate of 14.5%. This difference reached statistical significance ($p = 0.018$) (Table 6). For other types of FDPs the annual rate of ceramic fractures ranged from 1.03% to 1.36%, translating into a 5-year complication rate of 5.0–6.5% (Table 6). The incidence of ceramic chipping that could be solved with polishing was reported in 32 studies including 1659 FDPs. The overall annual complication rate was 2.71%, translating into a 5-year complication rate of 12.7% (Table 5). For different types of FDPs, the annual complication rates ranged from 1.07% to 7.55%. Ceramic chipping was the most frequent technical complication reported, but the difference in ceramic chipping between different types of FDPs did not reach statistical significance ($p = 0.338$, 0.113 & 0.115).

3.4.2. *Loss of retention*

Loss of retention or fracture of the luting cement was analyzed in 25 studies reporting on 1702 FDPs. The overall annual complication rate was 0.64%, translating into a 5-year failure rate of 3.1% (Table 5). Densely sintered zirconia FDPs experienced statistically significantly ($p = 0.028$) (Table 6) more retention loss than the other types of FDPs with an annual complication rate of 1.28% and a 5-year complication rate of 6.2%. For other types of FDPs the annual complication rates ranged from 0.42% to 0.58%, translating into a 5-year failure rates of 2.1–2.9% (Table 5).

3.4.3. *Marginal discoloration*

Marginal discoloration or the occurrence of marginal gaps was evaluated in 9 studies reporting on 253 FDPs. The overall annual complication rate was 3.91%, translating into a 5-year complication rate of 17.7% (Table 5). The lowest incidence of marginal discoloration was seen for reinforced glass ceramic with annual complication rate of 0.72% or a 5-year complication rate of 3.5%. For the other three types of FDPs, the annual rates of marginal discoloration ranged between 3.77% and 6.72% with the highest incidence reported for densely sintered zirconia FDPs, representing a 5-year complication rate of 28.5% (Table 5).

4. Discussion

Systematic reviews have been used extensively in medicine for the last two decades to summarize the cumulative information on the optimal treatment for clinically relevant questions and to support the clinicians in the decision-making process for different treatment options. This research method has slowly found its way into dental research. Systematic reviews have mainly been used to analyze and summarize results from randomized controlled clinical trials (RCTs) [30]. In the absence of RCTs with adequate statistical power to compare head-to-head metal-ceramic and all-ceramic fixed dental prosthesis (FDPs) prospective and retrospective cohort studies and case series with stringent inclusion criteria were included in this systematic review in order to summarize the available information about survival and complication rates of metal-ceramic and all-ceramic FDPs after a observation period of at least 3 years. Even with follow-up periods of at least 3 years, some clinicians may argue that such a period is still too short to obtain reliable information on survival and complication rates of fixed reconstructions. Due to the fact that the use of all-ceramic FDPs is relatively recent, a mean follow-up period of 3 years or more was a necessary compromise.

However it was interesting to see that the median year of publication was 2010 for metal-ceramic FDPs compared with 2009 for all-ceramic FDPs. In a systematic review on the same topic published in the year 2007 by the same authors, only five studies on metal-ceramic FDPs fulfilled the inclusion criteria's and only one of them was published before the year 2000 [1]. This must be considered peculiar as metal-ceramic FDPs have been considered the golden standard in reconstructive dentistry over decades. A positive shift has to be noticed, as 15 studies reporting on metal-ceramic could be included in the present systematic review.

Survival was defined as FDP remaining in situ with or without modifications and success was defined as the FDPs remaining in situ free of all complications over the entire observation period. From the Forrest plots of study specific failure rates, it is evident that these vary widely among the various studies. This may be attributable to the patient cohort observed, the design and extent of the FDPs, the maintenance care provided and the experience and clinical set-up of the clinicians.

After an observation period of 3 years, the lowest failure rate were observed for metal-ceramic FDPs (5.6%) compared with a failure rates of 9.6% for densely sintered zirconia ceramic FDPs, 10.9% for reinforced glass ceramic FDPs and 13.8% for glass-infiltrated alumina FDPs. Due to the different composition of different ceramic materials it was decided not to pull, different types of all-ceramic FDPs, into one group in the meta-analysis as was done in the previous review on the same topic. Four of the included studies randomized the patients according to material utilized. Three of them reported more failure of all-ceramic FDPs compared with metal-ceramic FDPs [19,31,32]. The last one reported no failures in either group [17].

The most frequent reason for failure of reinforced glass ceramic FDPs and glass-infiltrated alumina FDPs over the 3 years observation period was fracture of the reconstruction framework, reported for 8.0% and 17.2% of the reconstructions respectively. This technical failure was frequently related to using reinforced glass ceramic FDPs and glass-infiltrated alumina FDPs in the posterior area and where the diameter of the connectors was reduced below $4\,\text{mm} \times 4\,\text{mm}$ [33]. It has also been argued that all-ceramic FDPs suffer more often from parafunctional habits and malocclusion leading to framework fractures [34]. The framework fracture failure rate was rarer for metal-ceramic FDPs (0.6%) and densely sintered zirconia ceramic FDPs (1.9%). One aspect to consider for all-ceramic FDPs might be the length of the reconstruction. Studies demonstrated a higher rate of framework fractures with an increasing FDP length [35,36].

The most frequent technical complication was chipping of the veneering ceramic with an overall complication rate of 12.7% after 3-year observation period. The incidence of this complication ranged from 6.6% to 31.4% depending on the material type and was most frequently seen by glass-infiltrated alumina FDPs and densely sintered zirconia FDPs. Ceramic chippings for metal-ceramic FDPs appear to occur more frequently during the first year in function. The rate of chippings may then slightly decrease [23]. The high incidence of chipping by densely sintered zirconia FDPs, may be due to the fact that the first generation of zirconia FDPs was made before special low-fusing ceramics with a thermal expansion coefficient compatible with zirconia had been developed. Another reason for this might be the difficulty of getting correct uniform thickness of the virtually designed frameworks, which may not provide proper support to the veneering ceramic.

Marginal discoloration was, with the exception of reinforced glass ceramic FDPs (3.5%), a frequent technical complication reported for all-ceramic FDPs and metal-ceramic FDPs, ranging from 17.2% to 28.5%. The drawback of this analysis was that it is based on very few observations for metal-ceramic and glass-infiltrated alumina FDPs representing in a very wide confidence interval. In the two studies using a pressed glass-ceramic no discoloration was found [37,38]. This can partly be explained by the manufacturing procedures of the frameworks. The high precision of the manufacturing technique of pressable glass-ceramics has been documented in several investigations [39–41]. Among the studies reporting on marginal discoloration of densely sintered zirconia ceramic FDPs, there was a clear outlier using a prototype CAM-system reporting the highest rate of gaps or discoloration [36]. A possible explanation could be the misfit of these prototype frameworks. In a RCT comparing metal-ceramic and densely sintered zirconia FDPs [17], the fit of the frameworks was analyzed prior to the insertion of the reconstruction [42]. It was demonstrated that milled zirconia frameworks exhibited larger internal gaps than those constructed using conventional metal-ceramic techniques. This larger misfit of CAD/CAM reconstruction can explain a rather high rate of marginal discoloration.

With the exception of caries on abutment level by densely sintered zirconia ceramic FDPs (3.2%) and FDPs lost due to periodontal disease by glass-infiltrated alumina FDPs (7.6%) was the incidence of biological complications such as caries on abutment level, FDPs lost due to caries, FDPs lost due to periodontal disease, FDPs lost due to abutment tooth fracture and loss of abutment tooth vitality relative rare, ranging from 0.3% to 2.9% (Table 5).

When densely sintered zirconia was first introduced as framework material, its excellent physical properties led to the assumption that it may successfully be used to replace the conventional metal-ceramic FDP. The zirconia has been proven to be a strong framework material with low incidence of framework fracture. Specially if not used for long edentulous spans (3 teeth or more) and criteria's for connector dimension are respected. One the other hand, there are still issues with fit and framework design. The present systematic review has demonstrated that problems such as discolorations, secondary caries and loss of retentions, that can be directly related to semi optimal fit are more frequent by densely sintered zirconia FDPs compared with metal-ceramic FDPs and other types of all-ceramic FDPs. Moreover, high incidence of ceramic fractures and chipping is another issue that has taken into account utilizing densely sintered zirconia FDPs.

In this review stringent study inclusion criteria were used. Only studies with a clinical follow-up examination of at least 3 years were included to avoid the potential inaccuracies in event description in studies that based their analysis on patient self-reports. Clearly, a limitation of the present review is the assumption of a constant annual event rate throughout follow-up time after reconstruction. Interpreting the results it must be kept in mind that the mean observation period was on average 7.0 years for metal-ceramic FDPs, and only

4.7 years for all-ceramic FDPs. If the annual failure rates were higher in the years 5–10 than in the years 0–5, then average annual failure rates would be automatically higher for those reconstruction types for which studies with longer follow-up were available. To reduce the impact of such a bias, the results of the present analysis were restricted to estimating the 5-year survival. Another limitation of this review is that it was mainly based on studies that were conducted in an institutional environment, such as university or specialized implant clinics. Therefore, the long-term outcomes observed, cannot be generalized to dental services provided in private practice.

5. Conclusion

Metal-ceramic FDPs had lower failure rates then all-ceramic FDPs after a mean observation period of at least 3 years. Framework fractures were frequently reported for reinforced glass ceramic and glass-infiltrated alumina FDPs. Densely sintered zirconia was significantly more stable as framework material, but misfit lead to complications such as discolorations, secondary caries and loss of retention. Moreover, ceramic fractures and chipping of ceramics were frequent. In the future, further refinements in the production of all-ceramic reconstructions are indicated.

Conflict of interest

The authors do report to have no conflict of interest.

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