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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 II: fixed dental prostheses

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Abstract

Objectives: The objective of this systematic review was to assess the 5-year survival rates and incidences of complications of all-ceramic fixed dental prostheses (FDPs) and to compare them with those of metal–ceramic FDPs.

Methods: An electronic MEDLINE and Dental Global Publication Research System search complemented by manual searching was conducted to identify prospective and retrospective cohort studies on all-ceramic and metal–ceramic reconstructions with a mean follow-up time of at least 3 years. Patients had to have been examined clinically at the follow-up visit. Assessment of the identified studies and data abstraction was performed independently by three reviewers. Failure rates were analyzed using standard and random-effects Poisson regression models to obtain summary estimates of 5-year survival proportions.

Results: The search provided 3473 titles for single crowns and FDPs and resulted in 100 abstracts for all-ceramic FDPs. Full-text analysis was performed for 39 articles, resulting in nine studies of ceramic FDPs that met the inclusion criteria. The data on survival and complication rates of metal–ceramic FDPs were obtained from a previous systematic review of Tan et al. (2004) and the updated version from the same authors (Pjetursson et al. 2007). In Poisson regression meta-analysis, the 5-year survival of metal–ceramic FDPs was significantly ($P<0.0001$) higher with 94.4% [95 confidence interval (CI): 91.1–96.5%] than the survival of all-ceramic FDPs, being 88.6% (95 CI: 78.3–94.2%). The frequencies of material fractures (framework and veneering material) were significantly ($P<0.0001$) higher for all-ceramic FDPs (6.5% and 13.6%) compared with those of metal–ceramic FDPs (1.6% and 2.9%). Other technical complications like loss of retention and biological complications like caries and loss of pulp vitality were similar for the two types of reconstructions over the 5-year observation period.

Conclusion: Based on the present systematic review of all-ceramic FDPs, significantly lower survival rates at 5 years were seen compared with metal–ceramic FDPs. The most frequent reason for failure of FDPs made out of glass-ceramics or glass-infiltrated ceramics was fracture of the reconstruction (framework and veneering ceramic). However, when zirconia was used as framework material, the reasons for failure were primarily biological and technical complications other than framework fracture.

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Changes in restorative treatment patterns and the introduction of new and improved restorative materials and techniques have greatly influenced the longevity and esthetic outcome of dental restorations (Hickel & Manhart 2001). Conventional fixed dental prostheses (FDPs) with a metallic framework exhibited good long-term clinical results as three meta-analyses were able to show (Creugers et al. 1994; Scurria et al. 1998; Tan et al. 2004). However, the gray metal framework made the imitation of natural esthetics difficult, especially in situations with limited space for the veneering material. Therefore, all-ceramic reconstructive materials were developed (McLean & Hughes 1965; Sadoun 1988).

The advantage of all-ceramic materials lies in their excellent conditions to obtain optimal esthetic treatment outcomes. However, due to their low mechanical stability, all-ceramic systems (feldspathic-, glass- and glass-reinforced ceramics) only seem suitable for single crowns (Sorensen et al. 1998a; Pospiech et al. 2000; Olsson et al. 2003; Zimmer et al. 2004). More recently, high-strength ceramics with mechanical characteristics superior to those of conventional ceramics have been developed for reconstructive dentistry. Zirconia is the most stable of these high-strength ceramics and has flexural strength and fracture toughness values of 900 MPa and 9 MPa m$^{1/2}$, respectively (Seghi et al. 1995; Lüthy 1996). These values are two times higher than those achieved by glass-ceramics and glass-infiltrated alumina (InCeram Alumina) (Olsson et al. 2003; Zimmer et al. 2004).

In recent years, an increasing interest in the replacement of missing teeth by use of FDPs with ceramic frameworks has been observed (Raigrodsky & Chiche 2002; Raigrodsky et al. 2002). However, only two studies have been available presenting 5-year results of all-ceramic FDPs (Vult von Steyern et al. 2001; Olsson et al. 2003). Both these studies analyzed InCeram Alumina FDPs. One reported a 10% failure after 5 years (Vult von Steyern et al. 2001) and the other one reported 12% failure after 6 years (Olsson et al. 2003).

For glass-ceramic and InCeram FDPs fracture of the ceramic framework occurring in the connector area was the most frequent reason for failure (Scurria et al. 1998). Studies using finite-element analysis demonstrated that during occlusal loading, the highest stress within FDPs was located at the gingival side of the connector area (Filser et al. 2001a, 2001b; Fischer et al. 2003). Under clinical function bending forces lead to tension in this region of FDPs. As ceramics are brittle, their resistance to tension is low, promoting cracks and subsequent fracture (Filser et al. 2001a, 2001b; Pospiech et al. 2003). When using traditional ceramics for FDP frameworks, the cross-section of the connector needs to be enlarged in order to increase he stability of the framework. However, this enlargement is not necessary for connectors of metal–ceramic FDPs and may lead to periodontal and esthetical disadvantages. In an effort to overcome these shortcomings and the associated high failure rates, ceramics like zirconia with higher bending strength and fracture toughness have been developed. In clinical studies with medium-term follow-up, promising success rates for zirconia frameworks in anterior and posterior areas have been observed (Tinschert et al. 2005; Raigrodsky et al. 2006; Sailer et al. 2007).

To be suitable for clinical applications, all-ceramic reconstructions need to achieve good long-term results, similar to those for metal–ceramic reconstructions.

The objectives of this review were:

(1) To obtain robust estimates of the long-term survival rates and of the incidences of biological and technical complications of all-ceramic FDPs over an observation period of at least 3 years.
(2) To compare the survival and complication rates of all-ceramic reconstructions with those of metal–ceramic reconstructions (gold standard).

Materials and methods

Search strategy and study selection

First, a MEDLINE (Ovid search form) search was performed from 1966 up to and including November 2006, searching for 'ceramics' AND 'crowns', 'dental porcelain' AND 'crowns', 'metals' AND 'crowns', 'metal–ceramics' AND 'crowns', 'ceramics' AND 'fixed partial dentures' (FPDs), 'dental porcelain' AND 'fixed partial dentures', 'metals' AND 'fixed partial dentures' and 'metal–ceramics' AND 'fixed partial dentures' limited to human studies. The second electronic search was performed using the Dental Global Publication Research System (Dental GPRS) using the same search terms from 1990 extending up to and including December 2005, searching for publications in the German and French languages.

The electronic search was complemented by manual searches of the bibliographies of all full-text articles and related reviews, selected from the electronic search. Moreover, manual searching was applied to the following journals for the years 2001–2006: Dental Materials, International Journal of Prosthodontics, Journal of Esthetic and Restorative Dentistry, Journal of Prosthetic Dentistry, Journal of Prosthodontics, Schweizer Monatsschrift für Zahnmedizin (Acta Medicinae Dentium Helvetica), International Journal of Computerized Dentistry and Quintessence International.

From this extensive search, it was obvious that there were no randomized-controlled clinical trials (RCTs) available comparing all-ceramic reconstructions with conventional metal–ceramic reconstructions.

Inclusion criteria

In the absence of RCTs, this systematic review was based on prospective or retrospective cohort studies. The additional inclusion criteria for study selection were as follows:

- the studies had a mean follow-up time of 3 years or more and
- studies that reported details on the characteristics of the reconstructions.

Studies where the included patients had not been examined clinically at the follow-up visit, i.e., publications based on patient records, questionnaires or interviews were excluded.

Selection of studies

Titles and abstracts of the searches were initially screened by three independent reviewers (I. S., C. H. and B. E. P.) for possible inclusion in the review. The full text of all studies of possible relevance was then obtained for independent assessment by the reviewers. Any disagreement regarding inclusion was resolved by discussion.

Figure 1 describes the process of identifying the 39 full-text articles on ceramic FDPs selected from an initial yield of 3473 titles.

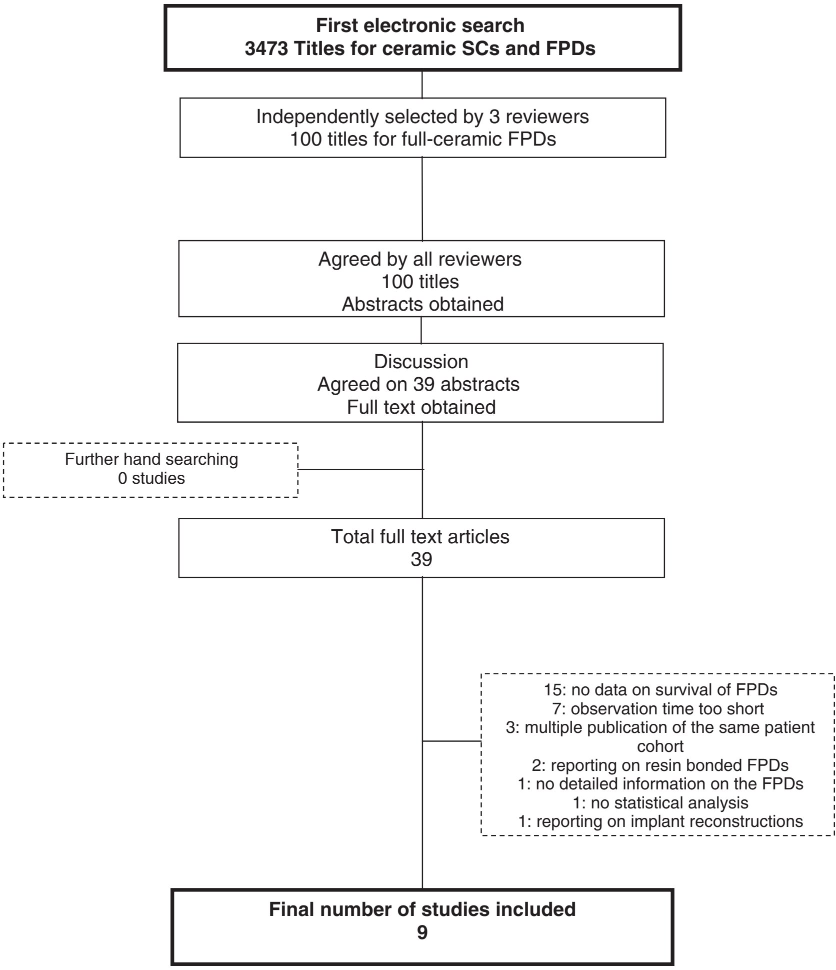

Fig. 1. Search strategy.

Excluded studies

Of the 39 full-text articles examined, 30 were excluded from the final analysis.

The main reasons for exclusion were: a mean observation period of <3 years, no detailed information on the type of reconstructions, multiple publications on the same patient cohorts, no detailed analysis of the data and case descriptions of failures without relevant information on the entire patient cohort.

Data extraction

Information on the survival proportions and of the biological and technical complications of the reconstructions was extracted from the nine included studies. The number of events and the corresponding total exposure time of the reconstructions were calculated.

Survival was defined as the FDP remaining *in situ* at the examination visit with or without modifications.

The analysis of the *biological complications* encompassed caries, loss of pulp vitality, abutment tooth fracture and periodontal disease progression.

Technical complications included fracture of the framework, fracture or chipping of the veneering ceramic, marginal gap/discoloration and loss of retention.

Data from the studies were extracted independently by three reviewers (I. S., C. H. and B. E. P.) using a data extraction form. Disagreement regarding data extraction was resolved by consensus.

The five studies reporting on survival and complication rates of metal–ceramic FDPs were obtained from another systematic review, based on the same inclusion/exclusion criteria and methodology (Tan et al. 2004) and its updated version (Pjetursson et al. 2007).

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 entire 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 (Kirkwood & Sterne 2003a).

Robust standard errors were calculated to obtain 95% confidence intervals (CIs) of the summary estimates of the event rates. To assess the 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, indicating heterogeneity, random-effects Poisson regression (with γ-distributed random effects) was used to obtain a summary estimate of the event rates. 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 (Kirkwood & Sterne 2003b). The 95% CIs 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 8.2.

Results

Study characteristics

A total of nine studies of all-ceramic FDPs, all but one prospective, were included in this review (Fig. 1). With the exception of Sorensen et al. (1998a, 1998b) and Vult von Steyern et al. (2001), all studies were published within the last 3 years (Table 1). Out of the systematic review from Tan et al. (2004) and the updated version (Pjetursson et al. 2007) five studies reporting on metal-ceramic FDPs could be located. Except one investigation published within the last 5 years (Reichen-Graden & Lang 1989) all of the studies were retrospective (Table 2).

From the nine studies reporting on the all-ceramic FDPs, two reported on FDPs made out of glass-ceramics (Wolfart et al. 2005; Marquardt & Strub 2006), four studies reported on glass-infiltrated ceramics (InCeram Alumina and Zirconia) (Sorensen et al. 1998a, 1998b; Vult von Steyern et al. 2001; Olsson et al. 2003; Suárez et al. 2004) and the remaining three studies reported on FDPs made with zirconia frameworks (Tinschert et al. 2005; Raigrodsky et al. 2006; Sailer et al. 2007) (Table 1).

The metal–ceramic FDPs were all porcelain-fused-to-metal (PFM) reconstructions (Reichen-Graden & Lang 1989; Näpänkangas et al. 2002; Walton 2002, 2003; Hochman et al. 2003; De Backer 2006) (Table 2).

The studies included patients between the age of 13 and 82. The proportion of patients who could not be followed for the complete study period was available for 11 of the studies and ranged from 0% to 40%.

FDP survival

The nine studies on all-ceramic FDPs provided data on the survival of a total of 343 FDPs after a mean follow-up time of 3.8 years (Table 3). Thirty-three FDPs were reported to be lost. In meta-analysis, the annual failure rate was estimated to be at 2.42 (95% CI: 1.2–4.89) translating into a 5-year survival rate for all-ceramic FDPs of 88.6% (95% CI: 78.3–94.2%) (Table 3).

For metal–ceramic FDPs, five studies provided data on a total of 1163 FDPs after a mean follow-up time of 8 years (Table 4), of which 121 were reported to be lost. The annual failure rate was estimated at 1.15 (95% CI: 0.71–1.87), translating into a 5-year survival rate for metal–ceramic FDPs of 94.4% (95% CI: 91.1–96.5%) (Table 4).

Compared with metal–ceramic FDPs, the annual failure rate of all-ceramic FDPs was 2.11 times higher (95% CI: 1.35–3.28; $P<0.001$) (Table 8).

Biological complications

Caries

In six studies reporting on 227 all-ceramic FDPs, information about the incidence of caries was given. For this complication, one study (Sailer et al. 2007) was a clear outlayer, reporting high rates of secondary caries. In the remaining five studies, no secondary caries was observed over the entire observation period. In random-effects Poisson model analysis, the estimated annual rate of secondary caries was 0.36, translating into a 5-year complication rate of 1.8% (95% CI: 0.2–16.9%) for all-ceramic FDPs (Table 5).

Information about loss of the entire reconstruction due to secondary caries was given in all nine studies. In only one study (Sailer et al. 2007) were all-ceramic FDPs reported to be lost. Six of the original 57 FDPs were lost in this investigation. In random-effects Poisson model analysis, the annual FDP failure rate due to secondary caries was 0.34%. The estimated rate of ceramic FDPs lost due to caries over a 5-year observation period was 1.7% (95% CI: 1.7–24.4%) (Table 5).

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

Study	Year of publication	Manufacturing procedure	Study design	No. of patients in study	Age range	Mean age	Setting	Drop-out (in %)
Sailer et al.	2007	Zirconia	Prospective	45	NR	48.3	University	40
Raigrodsky et al.	2006	Zirconia	Prospective	16	36–60	48	University	0
Tinschert et al.	2005	Zirconia	Prospective	46	NR	NR	University	0
Wolfart et al.	2005	Glass-ceramic	Prospective	29	25–68	47.8	University	17
Marquardt & Strub	2006	Glass-ceramic	Prospective	43	22–65	39.9	University	0
Suàrez et al.	2004	InCeram Zi	Prospective	16	23–50	NR	University	0
Olsson et al.	2003	InCeram Al	Retrospective	37	28–84	54	Private practice	16
Vult von Steyern et al.	2001	InCeram	Prospective	18	25–70	NR	University and Private practice	0
Sorensen et al.	1998a, 1998b	InCeram	Prospective	47	19–66	NR	University	2

NR, not reported; FPDs, fixed partial dentures.

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

Study	Year of publication	Material	Study design	No. of patients in the study	Age range	Mean age	Setting	Drop-out (in %)
De Backer	2006	PFM	Retrospective	456	18–82	41	Dental students	21
Hochman et al.	2003	PFM	Retrospective	30	NR	NR	Dental students	NR
Walton	2002/2003	PFM	Retrospective	357	13–74	NR	Single specialist	NR
Näpänkangas et al.	2002	PFM	Retrospective	132	39–82	56.8	Dental students	17
Reichen-Graden & Lang	1989	PFM	Retrospective	58	26–72	NR	Dental students	NR

NR, not reported; PFM, porcelain fused to metal; FPDs, fixed partial dentures.

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

Study	Year of publication	Total no. of FDPs	Mean follow-up time	No. of failure	Total FDPs exposure time	Estimated failure rate (per 100 FDP years)	Estimated survival after 5 years (in %)
Sailer et al.	2007	57	4.5	12	210	5.71	75.1
Raigrodsky et al.	2006	13	3	0	39	0	100
Tinschert et al.	2005	65	3.2	0	202	0	100
Wolfart et al.	2005	36	4	0	120	0	100
Marquardt & Strub	2006	31	4.2	6	129	4.65	79.3
Suárez et al.	2004	18	3	1	53	1.89	91
Olsson et al.	2003	42	6.3	5	266	1.88	91
Vult von Steyern et al.	2001	20	5	2	95	2.1	90
Sorensen et al.	1998a, 1998b	61	3	7	165	4.24	80.9
Total		343	3.8	33	1279		
Summary estimate (95% CI)*						2.42 (1.2–4.89)	88.6% (78.3–94.2%)

*Based on random-effects Poisson regression, test for heterogeneity $P = 0.005$.
CI, confidence interval; FDP, fixed dental prostheses.

Table 4. **Annual failure rates and survival of metal–ceramic FDPs**

Study	Year of publication	Total no. of FDPs	Mean follow-up time	No. of failure	Total FDPs exposure time	Estimated failure rate (per 100 FDP years)	Estimated survival after 5 years (in %)
De Backer et al.	2006	322	11.4	69	3671	1.88	91
Hochman et al.	2003	49	6.3	6	324	1.85	91.2
Walton	2002/2003	515	7.4	37	3363	1.1	94.6
Näpänkangas et al	2002	204	7.6	7	1478	0.47	97.7
Reichen-Graden & Lang	1989	73	6.4	2	465	0.43	97.9
Total		1163	8	121	9301		
Summary estimate (95% CI)*						1.15 (0.71–1.87)	94.4% (91.1–96.5%)

*Based on random-effects Poisson regression, test for heterogeneity $P = 0.0002$.
CI, confidence interval; FDP, fixed dental prostheses.

Conventional FDPs exhibited a rate of secondary caries after 5 years of 4.8% (95% CI: 2.3–9.9%) (Pjetursson et al. 2007). Moreover, compared with all-ceramic FDPs there was no significant difference in the rate of conventional FDPs lost due to caries. The estimated 5-year rate for loss of conventional FDPs due to caries was 1.6% (95% CI: 1.1–2.3%) (Pjetursson et al. 2007) (Table 7).

Loss of vitality

Loss of abutment vitality was reported in two studies of all-ceramic FDPs. Four out of 158 abutment teeth reported to be vital at the time of cementation presented with loss of pulp vitality over the observation period. The annual complication rate ranged between 0.74 and 1.37. In standard Poisson model analysis, the estimated rate of vital abutments that had lost pulp vitality over a 5-year observation period was 4.1% (95% CI: 2.8–5.9%) (Table 5).

The estimated rate of vitality loss of abutments supporting conventional FDPs was 6.1% (95% CI: 4.9–7.6%) (Pjetursson et al. 2007). No significant difference was found when the rate of loss of abutment vitality for ceramic FDPs was compared with those of conventional FDPs (Pjetursson et al. 2007) (Table 7).

Abutment tooth fracture

FDPs lost due to fracture of abutment teeth were reported in two of the nine studies on all-ceramic FDPs. The failure rate ranged between 0 and 1.89. In a standard Poisson model analysis, the estimated rate of FDP loss due to abutment tooth fracture over a 5-year period was 1.2% (95% CI: 0.3–4.6%) (Table 5). The estimated rate of conventional metal–ceramic FDPs lost due to abutment tooth fracture after 5 years was 1% (95% CI: 0.7–1.3%) (Pjetursson et al. 2007) (Table 7).

Periodontal disease

All nine studies on all-ceramic FDPs provided information on reconstructions lost due to recurrent periodontal disease during the observation period. In none of the studies were FDPs lost due to periodontitis. Hence, the failure rate was 0% (Table 5). The estimated rate of conventional metal-ceramic FDPs that were reported to be lost due to recurrent periodontitis was comparably low with 0.4% (95% CI: 0.2–0.7%) after 5 years (Pjetursson et al. 2007) (Table 7).

Technical complications

Material complications: framework fracture, veneer chipping or fracture

In random-effects Poisson model analysis, the estimated 5-year rate of all-ceramic FDPs lost due to fracture of the framework was 6.5% (95% CI: 3.9–13.8%) (Table 6). For glass-ceramic and InCeram FDPs, fracture of the framework was the main reason for loss. The annual failure rate due to framwork fracture ranged between 1.88 and 4.24 for these materials. Fracture of a zirconia framework, however, was a rare complication, only observed in one of the studies analyzing this new ceramic mate-

Table 5. **All-ceramic FDPs – biological complications**

Study	Year of publication	Total no. of vital abutments	Total abutment exposure time	Estimated rate of loss of vitality (per 100 abutment years)	Total no. of FDPs	Total FDP exposure time	Estimated rate of caries of FDPs (per 100 FDP years)	Estimated rate of FDPs lost due to caries (per 100 FDP years)	Estimated rate of FDPs lost due to periodontitis (per 100 FDP years)	Estimated rate of FDPs lost due to abutment tooth fracture (per 100 FDP years)
Sailer et al.	2007	NA	NA	NA	57	210	1.9	6	0	0.95
Raigrodsky et al.	2006	28	73	1.37	13	39	NA	0	0	0
Tinschert et al.	2005	130	404	0.74	65	202	0	0	0	0
Wolfart et al.	2005	NA	NA	NA	36	120	0	0	0	0
Marquardt & Strub	2006	NA	NA	NA	31	129	0	0	0	0
Suárez et al.	2004	NA	NA	NA	18	53	0	0	0	1.89
Olsson et al.	2003	NA	NA	NA	42	266	NA	0	0	0
Vult von Steyern et al.	2001	NA	NA	NA	20	95	0	0	0	0
Sorensen et al.	1998	NA	NA	NA	61	165	NA	0	0	0
Summary estimate event rates (95% CI)				0.84* (0.57–1.23)			0.36† (0.04–3.69)	0.34† (0.02–5.59)	0	0.23* (0.06–0.94)
Cumulative 5-year complication rates (95% CI)				4.1%* (2.8–5.9%)			1.8%† (0.2–16.9%)	1.7%† (1.7–24.4%)	0%	1.2%* (0.3–4.6%)

*Based on standard Poisson regression.
†Based on random-effects Poisson regression.
NA, not available; CI, confidence interval; FDP, fixed dental prostheses.

rial. The annual failure rate of zirconia framework fracture ranged between 0 and 0.48.

Compared with the other ceramics, zirconia exhibited the highest stability as a framework material. On the other hand, the most frequent technical problem of FDPs with zirconia frameworks was minor chipping or extended fracture of the veneering ceramic. The annual complication rate was as high as 1.98 (Tinschert et al. 2005), 2.86 (Sailer et al. 2007) and 12.2 (Raigrodsky et al. 2006), translating into a 5-year complication rate of 10%, 15% and 60%, respectively. This technical complication was not only observed with zirconia as framework material. Two studies analyzing glass-ceramic FDPs also reported on chipping of veneering ceramic. However, the estimated complication rates were lower and the annual complication rate ranged between 0.83 and 1.55. Chipping of the veneering ceramic was not reported in any of the studies evaluating InCeram FDPs.

In summary, the estimated rate of chipping of veneering ceramic of all-ceramic FDPs after 5 years was 13.6% (95% CI: 6.6–26.9%) (Table 6). The estimated rate of chipping of veneering ceramic of conventional metal–ceramic FDPs was significantly ($P<0.0001$) lower at 2.9% (95% CI: 1.2–6.8%;) after a 5-year observation period (Pjetursson et al. 2007) (Table 7).

One study on zirconia FDPs (Sailer et al. 2007) and one study on glass-ceramic FDPs (Marquardt & Strub 2006) reported on reconstructions that had to be remade due to extended fractures of the veneering ceramic. In standard Poisson model analysis, the estimated rate of all-ceramic FDPs lost due to fracture of veneering ceramic after 5 years was 6.5% (95% CI: 3–13.8%) (Table 6).

The estimated rate of veneer or framework fracture reported for conventional FDPs with metal framework and acrylic or ceramic veneering was only 1.6% (95% CI: 0.9–2.9%) after 5 years (Pjetursson et al. 2007) (Table 7).

Loss of retention

Five of the nine studies on all-ceramic FDPs addressed the issue of loss of retention (fracture of the luting cement). In two studies (Olsson et al. 2003; Tinschert et al. 2005) utilizing conventional cemen-

***Table 6.* All-ceramic FDPs – technical complications**

Study	Year of publication	Total no of FPDs	Total FPDs exposure time	Estimated rate of loss of retention (per 100 FPD years)	Estimated rate of FPDs lost due to framew. fracture (per 100 FPD years)	Estimated rate of FDPs lost due to ceramic fracture (per 100 FPD years)	Estimated rate of ceramic chipping (per 100 FPD years)	Estimated rate of marginal discoloration (per 100 FPD years)
Sailer et al.	2007	57	210	0.48	0.48	0.48	2.86	10
Raigrodsky et al.	2006	13	39	0	0	0	12.2	2.44
Tinschert et al.	2005	65	202	0.99	0	0	1.98	NA
Wolfart et al.	2005	36	120	NA	0	0	0.83	0
Marquardt & Strub	2006	31	129	0	2.33	0.77	1.55	0
Suárez et al.	2004	18	53	NA	0	0	NA	3.77
Olsson et al.	2003	42	266	0.38	1.88	0	NA	NA
Vult von Steyern et al.	2001	20	95	NA	2.11	0	NA	NA
Sorensen et al.	1998a, 1998b	61	165	NA	4.24	0	NA	NA
Summary estimate event rates (95% CI)				0.47* (0.24–0.94)	1.35† (0.61–2.98)	0.16* (0.04–0.56)	2.92† (1.36–6.28)	3.32† (0.82–13.44)
Cumulative 5-year complication rates (95% CI)				2.3%* (1.2–4.6%)	6.5%† (3–13.8%)	0.8%* (0.2–2.7%)	13.6%† (6.6–26.9%)	15.3%† (4–48.9%)

*Based on standard Poisson regression.
†Based on random-effects Poisson regression.
NA, not available; FPDs, fixed partial dentures; FDP, fixed dental prostheses; CI, confidence interval.

***Table 7.* Summary of complications of conventional and full-ceramic FPDs**

Complication	Total number of FPDs or abutments	Total exposure time	Summary estimate event rates (95% CI)	Cumulative 5-year complication rates (95% CI)	Total number of FPDs or abutments	Total exposure time	Summary estimate event rates (95% CI)	Cumulative 5-year complication rates (95% CI)	Significance
	Conventional FPDs				Full-ceramic FPDs				
Estimated rate of caries of abutments	2871	22,477	0.99† (0.47–2.09)	4.8%† (2.3–9.9%)	227	809	0.36%† (0.04–3.69)	1.8%† (0.2–16.9%)	NS
Estimated rate of FPDs lost due to caries	894	9733	0.32* (0.22–0.46)	1.6%* (1.1–2.3%)	343	1279	0.34%† (0.02–5.59)	1.7%† (1.7–24.4%)	NS
Estimated rate of FPDs lost due to periodontitis	1264	12,549	0.07* (0.04–0.14)	0.4%* (0.2–0.7%)	343	1279	0%	0%	NS
Estimated rate of loss of vitality	1072	9441	1.26* (1.01–1.57)	6.1%* (4.9–7.6%)	158	477	0.84%* (0.57–1.23)	4.1%* (2.8–5.9%)	NS
Estimated rate of FPDs lost due to abutment fracture	1071	11,052	0.2* (0.15–0.27)	1%* (0.7–1.3%)	343	1279	0.23* (0.06–0.94)	1.2%* (0.3–4.6%)	NS
Estimated rate of loss of retention	1204	10,627	0.66† (0.4–1.1)	3.3%† (2–5.3%)	208	846	0.47* (0.24–0.94)	2.3%* (1.2–4.6%)	NS
Estimated rate of veneer or framework fracture	1743	14,397	0.32† (0.18–0.58)	1.6%† (0.9–2.9%)	343	1279	1.35† (0.61–2.98)	6.5%† (3–13.8%)	$P<0.0001$
Estimated rate of ceramic clipping or fracture	841	2292	0.59† (0.25–1.41)	2.9%† (1.2–6.8%)	202	700	2.92† (0.36–6.28)	13.6%† (6.6–26.9%)	$P<0.0001$

*Based on random-effects Poisson regression.
†Based on multivariable random-effects Poisson regression.
CI, confidence interval; FDP, fixed dental prostheses; FPDs, fixed partial dentures.

tation, FDPs became loose. In another study one adhesively cemented reconstruction lost retention (Sailer et al. 2007). In one study, using conventional (Raigrodsky et al. 2006) and in another one using adhesive cementation (Marquardt & Strub 2006), no loss of retention was found. In summary, the standard Poisson model analysis gave an estimated rate of loss of retention of ceramic FDPs after 5 years of 2.3% (95% CI: 1.2–4.6%) (Table 6).

The estimated rate of loss of retention for conventional metal–ceramic FDPs after 5 years was comparable with 3.3% (95% CI: 2–5.3%) (Pjetursson et al. 2007) (Table 7).

Marginal discoloration

Marginal discoloration or occurrence of marginal gaps was evaluated in five of the nine studies (Table 6). The estimated annual complication rate ranged between 0 and 10. The highest rate of marginal discoloration was found in a study on zirconia FDPs. In this study, a prototype manufacturing procedure was used for the fabrication of the frameworks. The authors reported on difficulties with the accuracy of the frameworks (Sailer et al. 2007). Owing to this out-layer study, the estimated 5-year rate of ceramic FDPs exhibiting marginal gaps or discoloration was as high as 15.3% (95% CI: 4–48.9%) obtained with a random-effects Poisson model analysis (Table 6).

Discussion

In the absence of RCTs to compare all-ceramic and metal–ceramic reconstructions, a lower level of evidence, prospective and retrospective cohort studies, had to be included in this systematic review in order to summarize the available information about their survival rates. It may be argued that follow-up periods of only 3 years are too short to obtain reliable information on survival and complication rates. Owing to the fact that the use of all-ceramic materials for FDPs is a recent development, a mean follow-up period of at least 3 years was a necessary compromise. Information on the long-term survival of ceramic FDPs is still sca, while conventional metal–ceramic FDPs have been followed for decades. A limitation of this review is that the estimated annual failure rates of all-ceramic FDPs can only partly be extrapolated to follow-up times of conventional FDPs with metallic frameworks.

The failure rate of all-ceramic FDPs after 5 years was 11.4%. The corresponding figure for metal–ceramic FDPs was 5.6%, resulting in a 2.11-fold higher failure of all-ceramic FDPs.

The most frequent reason for failure of FDPs made out of InCeram was fracture of the reconstruction (framework and veneering ceramic) (Sorensen et al. 1998a, 1998b; Vult von Steyern et al. 2001; Olsson et al. 2003; Suárez et al 2004; Wolfart et al. 2005; Marquardt & Strub 2006). When zirconia was first introduced as a framework material, its excellent physical properties led to the assumption that it may be used successfully for the fabrication of all-ceramic reconstructions replacing molars and premolars (Filser et al. 2001a, 2001b). The results of clinical studies demonstrated its feasibility for this indication (Tinschert et al. 2005; Raigrodsky et al. 2006; Sailer et al. 2007). In only one of these three studies was a fracture of a single zirconia framework reported (Sailer et al. 2007). However, the overall survival rate of zirconia FDPs in the same study amounted only to 75.1% due to various biological and technical complications (Sailer et al. 2007). It may be concluded, that with this new high-strength ceramic framework material, the reasons for failure will not be the same as seen for other all-ceramic reconstructions. Owing to the increase in stability framework fracture is no longer the main complication.

With the exception of material fracture, no significant differences were found between all-ceramic and metal–ceramic FDPs regarding other technical and biological complications after 5 years of observation. This conclusion should, however, be interpreted with caution as the mean follow-up time of the conventional metal–ceramic FDPs was twice as long as the follow-up time for the all-ceramic FPDs (8 years compared with 3.8 years). The risk for biological and technical complications might increase with time.

The most frequent complication reported for both all-ceramic and conventional FDPs was loss of pulp vitality. During a 5-year observation period this complication was occurring in 4.1% of vital abutment teeth with all-ceramic and at 6.1% of teeth with metal–ceramic FDPs, respectively (Pjetursson et al. 2007). This may be due to the fact that the observed ceramic materials only served as core material. For all of them, a veneering coverage was necessary as for metallic frameworks. The preparation guidelines for all-ceramic FDPs resembled the ones for conventional FDPs regarding reduction of tooth substance and, hence, the risk for loss of pulp vitality was comparable (Sturzenegger et al. 2000; Goodachre et al. 2001).

Caries was found to be the second most frequent biological complication in both types of FDPs. However, only one study of all-ceramic FDPs reported on high rates of caries (Sailer et al. 2007). In this study, marginal gaps were frequently found, leading to secondary caries in more than 20% of the reconstructions. Compared with this, no caries was reported for glass-ceramic and InCeram FDPs, resulting in an average complication rate for caries of abutment teeth of 1.8% and for loss of FDP due to caries of 1.7% after 5 years of observation (Olsson et al. 2003; Zimmer et al. 2004; Vult von Steyern et al. 2005). This difference in marginal accuracy is probably due to the fact that a prototype manufacturing technique [direct ceramic machining (DCM)] was used in the study of zirconia FDPs (Sailer et al. 2007), whereas fully developed production systems were used in the other studies. Furthermore, adapted preparation designs for the abutment teeth had to be developed and new manufacturing methods were worked out for this first clinical investigation of zirconia as a framework material.

Caries was found in 4.8% of the abutment teeth of conventional metal–ceramic FDPs after 5 years. Again, as mentioned before, due to the different follow-up periods of the investigations, the complication rates should be compared with caution to the ones of all-ceramic FDPs.

The worst technical complication for all-ceramic FDPs, of course, was catastrophic fracture of the framework, yielding a loss of 6.5% of the all-ceramic FDPs during a 5-year observation period. Framework fracture was frequently found for glass-ceramic and InCeram FDPs. Only in two studies evaluating these ceramics were no fractures observed (Suárez et al. 2004; Wolfart et al. 2005). Moreover, fracture of a zirconia framework was reported exclusively in

***Table 8.* Summary of annual failure rates, relative failure rates and survival estimates for FDPs**

Type of FPDs	Total number of reconstructions	Total FPDs exposure time	Mean follow-up time	Estimated annual failure rate	5 year survival summary estimate (95% CI)	Relative failure rate	*P*-value
Metal–ceramic FPDs	1163	9301	8	1.15* (0.71–1.87)	94.4%* (91.1–96.5%)	1 (Ref.)	
All-ceramic FPDs	343	1279	3.8	2.42* (1.2–4.89)	88.6%* (78.3–94.2%)	2.11 (1.36–3.28)	$P<0.001$

*Based on random-effects Poisson regression.
FPDs, fixed partial dentures; FDP, fixed dental prostheses; CI, confidence interval.

one study, where a five-unit posterior framework broke due to an accident (Sailer et al. 2007). Compared with all-ceramic FDPs, material fracture (framework or veneering) was rarely seen by conventional FDPs (1.6%) (Tan et al. 2004; Pjetursson et al. 2007).

Interestingly, the most frequent technical complication reported for all-ceramic FDPs was marginal discoloration (15.3%), which was observed for InCeram and zirconia FDPs (Suárez et al. 2004; Raigrodsky et al. 2006; Sailer et al. 2007). In the two studies using a pressed glass-ceramic, no discoloration was found (Wolfart et al. 2005; Marquardt & Strub 2006). 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 (Sulaiman et al. 1997; Beschnidt & Strub 1999; Goldin et al. 2005). In the two studies reporting on marginal discoloration of zirconia FDPs, frameworks were produced by means of computer-guided systems (Raigrodsky et al. 2006; Sailer et al. 2007). The highest rate of gaps or discoloration was found in the study using a prototype CAM-system (Sailer et al. 2007). The possible explanations for the misfit of these frameworks were discussed previously.

Almost as frequent as marginal problems was chipping or fracture of the veneering ceramic. The rate for ceramic chipping was 13.6% after 5 years of observation. Chipping occurred in all studies of glass-ceramic and zirconia FDPs and unfortunately was not analyzed for InCeram FDPs. Conventional feldspathic veneering ceramics for metal–ceramic reconstructions yielded significantly ($P<0.0001$) lower fracture rates (2.9%).

The most frequent problems with the veneering ceramics were found in studies of zirconia FDPs (Tinschert et al. 2005; Raigrodsky et al. 2006; Sailer et al. 2007). The high incidence of chipping zirconia-veneering ceramics may be due to the fact that new materials had to be developed for this purpose. Specifically, new low-fusing ceramics with a thermal expansion coefficient compatible with zirconia (TEC $>11\times10^{-6}$/K) had to be developed and are still under development. Similar problems have previously been reported for low-fusing veneering ceramics developed for titanium frameworks. In a study comparing titanium and PFM FDPs, significantly more defects of the veneering were found at the titanium reconstructions. The results of three studies reporting on zirconia FDPs included in this review (Tinschert et al. 2005; Raigrodsky et al. 2006; Sailer et al. 2007) indicate that various veneering ceramics available for zirconia possess insufficient mechanical properties and that there is an urgent need for refined veneering ceramics. One disadvantage of CAD/CAM design and manufacture of frameworks may be that the uniform thickness of the virtually designed frameworks may not provide proper support to the veneering ceramic. The ideal proportions of the frameworks for sufficient support for the veneering material are virtually either difficult to achieve or even not possible.

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 the follow-up period after reconstruction. When interpreting the results, it must be kept in mind that the mean observation period was on average 8 years for metal–ceramic FDPs and only 3.8 years for all-ceramic FDPs. If the annual failure rates were higher in the years 5–10 than in the years 0–5, then the average annual failure rates would be automatically higher for those reconstruction types for which studies with a 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 (Table 8).

Comparing the results of the present systematic review with those obtained for conventional metal–ceramic FDPs (Pjetursson et al. 2007), a significantly higher failure rate was observed for all-ceramic FDPs.

In conclusion, if posterior teeth shall be replaced with an all-ceramic FDP, zirconia should be used as the framework material. However, the veneering ceramics for this high-strength framework material exhibit higher rates of chipping than the ones observed for metal frameworks. For clinical long-term success, the veneering materials, therefore, need to be refined. Shortcomings of the marginal accuracy of zirconia reconstructions will be overcome by further refinements of the computerized production technologies in future.

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