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

Key words: all-ceramic, biological complications, complication rates, failures, fixed dental prostheses, fixed partial dentures, longitudinal, success, survival, systematic review, technical complications

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.

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 (feldspatic-, 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 the 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.


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.
Full text obtained

Further hand searching
0 studies

Abstracts obtained

Independently selected by 3 reviewers
100 titles for full-ceramic FPDs

Agreed by all reviewers
100 titles
Abstracts obtained

Discussion
Agreed on 59 abstracts
Full text obtained

Total full text articles
9

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 was 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 \( \gamma \)-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 \( S(T) = \exp(-T \times \text{event rate}) \), 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 5 years [Table 1]. Out of the systematic review from Tan et al. [2004] and the updated version [Pietursson 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; Suarez 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; Nåpänkangas 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%. The annual failure rate was estimated at 1.15 (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 the survival of a total of 1,163 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 2.43 (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].

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 outlier, 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 FDPs

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

NR, not reported; FPDs, fixed partial dentures.

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

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

NR, not reported; PFM, porcelain fused to metal; FPDs, fixed partial dentures.
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 1.6% (95% CI: 1.1–2.3%) (Pjetursson et al. 2007) (Table 7).

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 annual complication rate ranged between 0.74 and 1.37. 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 framework 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 3. Annual failure rates and survival of all-ceramic FDPs

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

*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

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

*Based on random-effects Poisson regression, test for heterogeneity $P = 0.0002$.

CI, confidence interval; FDP, fixed dental prostheses.
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 (Rai-grodsky 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 annual 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 lower at 2.9% (95% CI: 1.6–4.8%) after a 5-year observation period (Raigrodsky et al. 2006) [Table 6]. One study on zirconia FDPs (Sailer et al. 2007) reported on chipping of veneering ceramic. However, in any of the studies evaluating InCeram FDPs, the estimated rate of chipping of veneering ceramic was 6.5% (95% CI: 3.5–11.1%) [Table 5]. The estimated rate of chipping of veneering ceramic of all-ceramic FDPs was 1.8% (95% CI: 0.2–16.9%) [Table 5]. The estimated rate of FDPs lost due to caries of FDPs was 1.7% (95% CI: 1.7–24.4%) [Table 5]. The estimated rate of FDPs lost due to periodontitis was 0% [Table 5]. The estimated rate of FDPs lost due to abutment tooth fracture was 1.2% (95% CI: 0.3–4.6%) [Table 5]. The estimated rate of loss of retention due to abutment tooth fracture (per 100 FDP years) was 0.23 (95% CI: 0.06–0.94) [Table 5].

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 cementation, the estimated rate of loss of retention was only 1.6% (95% CI: 0.9–2.9%) after 5 years (Tinschert et al. 2007) [Table 6]. The estimated rate of loss of retention due to extended fractures of the luting cement was only 1.6% (95% CI: 0.9–2.9%) after 5 years (Tinschert et al. 2007) [Table 6]. The estimated rate of loss of retention due to extended fractures of the luting cement was only 1.6% (95% CI: 0.9–2.9%) after 5 years (Tinschert et al. 2007) [Table 6].

Table 5. All-ceramic FDPs – biological complications

<table>
<thead>
<tr>
<th>Study</th>
<th>Year of publication</th>
<th>Total no. of vital abutments</th>
<th>Total abutment exposure time (per 100 abutment years)</th>
<th>Estimated rate of loss of vitality (per 100 abutment years)</th>
<th>Total no. of FDPs</th>
<th>Total FDP exposure time (per 100 FDP years)</th>
<th>Estimated rate of caries of FDPs (per 100 FDP years)</th>
<th>Estimated rate of FDPs lost due to caries (per 100 FDP years)</th>
<th>Estimated rate of FDPs lost due to periodontitis (per 100 FDP years)</th>
<th>Estimated rate of FDPs lost due to abutment tooth fracture (per 100 FDP years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sailer et al. 2007</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>57</td>
<td>210</td>
<td>1.9</td>
<td>6</td>
<td>0</td>
<td>0.95</td>
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<td>73</td>
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<td>13</td>
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<td>NA</td>
<td>0.74</td>
<td>0</td>
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</tr>
<tr>
<td>Tinschert et al. 2005</td>
<td>130</td>
<td>404</td>
<td>0.74</td>
<td>65</td>
<td>202</td>
<td>0</td>
<td>0.74</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>Wolfart et al. 2005</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>36</td>
<td>120</td>
<td>0.74</td>
<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>Marquardt &amp; Strub 2006</td>
<td>31</td>
<td>129</td>
<td>0.74</td>
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<td>129</td>
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<td>0.74</td>
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<td>NA</td>
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<td>53</td>
<td>0.74</td>
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<td>NA</td>
<td>NA</td>
<td>42</td>
<td>266</td>
<td>0.74</td>
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<td>Suárez et al. 2001</td>
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<td>NA</td>
<td>NA</td>
<td>20</td>
<td>95</td>
<td>0.74</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Wolfart et al. 1998</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>61</td>
<td>165</td>
<td>0.74</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Summary estimate event rates (95% CI)

<table>
<thead>
<tr>
<th>Study</th>
<th>Year of publication</th>
<th>Total no. of vital abutments</th>
<th>Total abutment exposure time (per 100 abutment years)</th>
<th>Estimated rate of loss of vitality (per 100 abutment years)</th>
<th>Total no. of FDPs</th>
<th>Total FDP exposure time (per 100 FDP years)</th>
<th>Estimated rate of caries of FDPs (per 100 FDP years)</th>
<th>Estimated rate of FDPs lost due to caries (per 100 FDP years)</th>
<th>Estimated rate of FDPs lost due to periodontitis (per 100 FDP years)</th>
<th>Estimated rate of FDPs lost due to abutment tooth fracture (per 100 FDP years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sailer et al. 2007</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>57</td>
<td>210</td>
<td>1.9</td>
<td>6</td>
<td>0</td>
<td>0.95</td>
</tr>
<tr>
<td>Raigrodsky et al. 2006</td>
<td>28</td>
<td>73</td>
<td>1.37</td>
<td>13</td>
<td>39</td>
<td>NA</td>
<td>0.74</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tinschert et al. 2005</td>
<td>130</td>
<td>404</td>
<td>0.74</td>
<td>65</td>
<td>202</td>
<td>0</td>
<td>0.74</td>
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<tr>
<td>Wolfart et al. 2005</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>36</td>
<td>120</td>
<td>0.74</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Marquardt &amp; Strub 2006</td>
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<td>129</td>
<td>0.74</td>
<td>31</td>
<td>129</td>
<td>0</td>
<td>0.74</td>
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<td>Suárez et al. 2004</td>
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<td>18</td>
<td>53</td>
<td>0.74</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Sailer et al. 2003</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<td>42</td>
<td>266</td>
<td>0.74</td>
<td>0</td>
<td>0</td>
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<td>NA</td>
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<td>95</td>
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<tr>
<td>Wolfart et al. 1998</td>
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<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>61</td>
<td>165</td>
<td>0.74</td>
<td>0</td>
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</tr>
</tbody>
</table>

Summary estimate event rates (95% CI)

Based on standard Poisson regression.

Based on random-effects Poisson regression.

NA, not available; CI, confidence interval; FDP, fixed dental prostheses.
Table 6. All-ceramic FDPs – technical complications

<table>
<thead>
<tr>
<th>Study</th>
<th>Year of publication</th>
<th>Total no of FPDs</th>
<th>Total FPDs exposure time</th>
<th>Estimated rate of loss of retention (per 100 FPD years)</th>
<th>Estimated rate of FPDs lost due to framework fracture (per 100 FPD years)</th>
<th>Estimated rate of FPDs lost due to ceramic fracture (per 100 FPD years)</th>
<th>Estimated rate of ceramic chipping (per 100 FPD years)</th>
<th>Estimated rate of marginal discoloration (per 100 FPD years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sailer et al.</td>
<td>2007</td>
<td>57</td>
<td>210</td>
<td>0.48</td>
<td>0.48</td>
<td>0.48</td>
<td>2.86</td>
<td>10</td>
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<tr>
<td>Raigrodsky et al.</td>
<td>2006</td>
<td>13</td>
<td>39</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12.2</td>
<td>2.44</td>
</tr>
<tr>
<td>Tischert et al.</td>
<td>2005</td>
<td>65</td>
<td>202</td>
<td>0.99</td>
<td>0</td>
<td>0</td>
<td>1.98</td>
<td>NA</td>
</tr>
<tr>
<td>Wolfart et al.</td>
<td>2005</td>
<td>36</td>
<td>120</td>
<td>NA</td>
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<td>0</td>
<td>0.83</td>
<td>0</td>
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<tr>
<td>Marquardt &amp; Strub</td>
<td>2006</td>
<td>31</td>
<td>129</td>
<td>0</td>
<td>2.33</td>
<td>0.77</td>
<td>1.55</td>
<td>0</td>
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<td>Suárez et al.</td>
<td>2004</td>
<td>18</td>
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<td>42</td>
<td>266</td>
<td>0.38</td>
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<td>2001</td>
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<tr>
<td>Sorensen et al.</td>
<td>1998a, 1998b</td>
<td>61</td>
<td>165</td>
<td>NA</td>
<td>4.24</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Summary estimate</td>
<td></td>
<td></td>
<td></td>
<td>0.47* (0.24–0.94)</td>
<td>1.35† (0.61–2.98)</td>
<td>0.16* (0.04–0.56)</td>
<td>2.92† (1.36–6.28)</td>
<td>3.32† (0.82–13.44)</td>
</tr>
</tbody>
</table>

*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

<table>
<thead>
<tr>
<th>Complication</th>
<th>Total number of FPDs or abutments</th>
<th>Total exposure time</th>
<th>Summary estimate event rates (95% CI)</th>
<th>Cumulative 5-year complication rates (95% CI)</th>
<th>Total number of FPDs or abutments</th>
<th>Total exposure time</th>
<th>Summary estimate event rates (95% CI)</th>
<th>Cumulative 5-year complication rates (95% CI)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional FPDs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Full-ceramic FPDs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated rate of caries of abutments</td>
<td>2871</td>
<td>22,477</td>
<td>0.99† (0.47–2.09)</td>
<td>4.8%† (2.3–9.9%)</td>
<td>227</td>
<td>809</td>
<td>0.36%† (0.04–3.69)</td>
<td>1.8%† (0.2–16.9%)</td>
<td>NS</td>
</tr>
<tr>
<td>Estimated rate of FPDs lost due to caries</td>
<td>894</td>
<td>9733</td>
<td>0.32* (0.22–0.46)</td>
<td>1.6%* (1.1–2.3%)</td>
<td>343</td>
<td>1279</td>
<td>0.34%† (0.02–5.59)</td>
<td>1.7%† (1.7–24.4%)</td>
<td>NS</td>
</tr>
<tr>
<td>Estimated rate of FPDs lost due to periodontitis</td>
<td>1264</td>
<td>12,549</td>
<td>0.07* (0.04–0.14)</td>
<td>0.4%* (0.2–0.7%)</td>
<td>343</td>
<td>1279</td>
<td>0%</td>
<td>0%</td>
<td>NS</td>
</tr>
<tr>
<td>Estimated rate of loss of vitality</td>
<td>1072</td>
<td>9441</td>
<td>1.26* (1.01–1.57)</td>
<td>6.1%* (4.9–7.6%)</td>
<td>158</td>
<td>477</td>
<td>0.84%* (0.57–1.23)</td>
<td>4.1%* (2.8–5.9%)</td>
<td>NS</td>
</tr>
<tr>
<td>Estimated rate of FPDs lost due to abutment fracture</td>
<td>1071</td>
<td>11,052</td>
<td>0.2* (0.15–0.27)</td>
<td>1%* (0.7–1.3%)</td>
<td>343</td>
<td>1279</td>
<td>0.23* (0.06–0.94)</td>
<td>1.2%* (0.3–4.6%)</td>
<td>NS</td>
</tr>
<tr>
<td>Estimated rate of loss of retention</td>
<td>1204</td>
<td>10,627</td>
<td>0.66† (0.4–1.1)</td>
<td>3.3%† (2.5–3.9%)</td>
<td>208</td>
<td>846</td>
<td>0.47* (0.24–0.94)</td>
<td>2.3%† (1.2–4.6%)</td>
<td>NS</td>
</tr>
<tr>
<td>Estimated rate of veneer or framework fracture</td>
<td>1743</td>
<td>14,397</td>
<td>0.32† (0.18–0.58)</td>
<td>1.6%† (0.9–2.9%)</td>
<td>343</td>
<td>1279</td>
<td>1.35† (0.61–2.98)</td>
<td>6.5%† (3–13.8%)</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>Estimated rate of ceramic clipping or fracture</td>
<td>841</td>
<td>2292</td>
<td>0.59† (0.25–1.41)</td>
<td>2.9%† (1.2–6.8%)</td>
<td>202</td>
<td>700</td>
<td>2.92† (0.36–6.28)</td>
<td>13.6%† (6.6–26.9%)</td>
<td>P&lt;0.0001</td>
</tr>
</tbody>
</table>

*Based on standard Poisson regression.
†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 & Strub 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 13.3% [95% CI: 4.4–48.9%] 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 scarce, 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 3.6%, resulting in a 3.21-fold higher failure rate of all-ceramic FDPs. 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; Goodacre 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; Wollart et al. 2005]. Moreover, fracture of a zirconia framework was reported exclusively in
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 \( (\text{TEC} > 11 \times 10^{-6}/\text{K}) \) 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.

References


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


Sailer et al. Systematic review of all-ceramic FDPs


