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Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs)

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Abstract

Objectives: The objective of this systematic review was to assess and compare the 5- and 10-year survival of different types of tooth-supported and implant-supported fixed dental prosthesis (FDPs) and single crowns (SCs) and to describe the incidence of biological and technical complications.

Methods: Three electronic searches complemented by manual searching were conducted to identify prospective and retrospective cohort studies on FDPs and SCs with a mean follow-up time of at least 5 years. Patients had to have been examined clinically at the follow-up visit. Failure and complication rates were analyzed using random-effects *Poisson's* regression models to obtain summary estimates of 5- and 10-year survival proportions.

Results: Meta-analysis of the included studies indicated an estimated 5-year survival of conventional tooth-supported FDPs of 93.8%, cantilever FDPs of 91.4%, solely implant-supported FDPs of 95.2%, combined tooth-implant-supported FDPs of 95.5% and implant-supported SCs of 94.5%. Moreover, after 10 years of function the estimated survival decreased to 89.2% for conventional FDPs, to 80.3% for cantilever FDPs, to 86.7% for implant-supported FDPs, to 77.8% for combined tooth-implant-supported FDPs and to 89.4% for implant-supported SCs. Despite high survival rates, 38.7% the patients with implant-supported FDPs had some complications after the 5-year observation period. This is compared with 15.7% for conventional FDPs and 20.6% for cantilever FDPs, respectively. For conventional tooth-supported FDPs, the most frequent complications were biological complications like caries and loss of pulp vitality. Compared with tooth-supported FDPs, the incidence of technical complications was significantly higher for the implant-supported reconstructions.The most frequent technical complications were fractures of the veneer material (ceramic fractures or chipping), abutment or screw loosening and loss of retention.

Conclusion: On the basis of the results of the present systematic review, planning of prosthetic rehabilitations should preferentially include conventional end abutment tooth-supported FDPs, solely implant-supported FDPs or implant-supported SCs. Only for reasons of anatomical structures or patient-centered preferences and as a second option should cantilever tooth-supported FDPs or FDPs supported by combination of implants and teeth be chosen.

There is an open question whether or not the practice of evidence-based treatment planning is posible in prosthetic dentistry. Ideally, treatment decisions should be based on well-performed systematic reviews of the available evidence and, if

possible, on formal quantitative evidence synthesis and meta-analysis (Egger & Smith 1997; Egger et al. 2001a, 2001c).

Reviewing the literature involves grading of the available and published studies. Often, such gradings are based on study design. Usually randomized studies are rated higher than observational studies (Grades of Recommendation 2004). Furthermore, the quality of studies and trials is of crucial importance: if the 'raw material' is flawed, then the findings of reviews of this material may also be compromised (Egger & Smith 1997; Egger et al. 2001a). The trials and studies included in systematic reviews and meta-analyses should ideally be of high methodological quality and free of bias. As a conseqence, the differences in study outcomes observed between patients can confidently be attributed to the intervention under investigation. If there are no studies on the highest level of evidence (randomized controlled clinical trials), the systematic review has to be based on the highest level of evidence available (Egger et al. 2001b; Glasziou et al. 2004) and point out which additional research should be conducted to strengthen the evidence base.

The studies in the dental literature reporting on tooth-supported and implant-supported fixed dental prosthesis (FDPs) are mostly observational studies and single-center case cohorts. The systematic reviews conducted so far (Pjetursson et al. 2004a, 2004b; Tan et al. 2004) indicate that the observed survival of FDPs after 10 years ranged between 85% and 95%. To strengthen the evidence base, more studies should report on the long-term outcomes of reconstructions already inserted. A few key options should be tested in comparative randomized controlled clinical trials. Such trials would best be conducted in a multi-center setting with long enough follow-up and sample sizes that allow estimating relevant differences. For example, to detect with a 80% power and at the significance level of 5%, a clinically relevant difference of an annual rate of loss of reconstructions of 1% vs. 2%, a two-arm study would need to randomize in 1 year approximately 1060 patients and to follow them for at least 4 years resulting in a total study time of 5 years. With a longer follow-up of about 10 years it would be sufficient to randomize 500 patients. For a scenario comparing the annual rate of loss of reconstructions of 0.5% vs. 2.5%, the 5- or 10-year follow-up study would need to randomize 260 or 130 patients, respectively.

There are no studies on the highest level of evidence (RCTs) available in the dental literature comparing tooth-supported and implant-supported FDPs. In addition, only few studies have reported on the longevity of reconstructions on implants with same details. Therefore, a series of systematic reviews, based on consistent inclusion and exclusion criteria, has summarized the available information on survival and success rates and the incidence of biological and technical complications of conventional FDPs, cantilever FDPs, combined tooth-implant-supported FDPs and solely implant-supported FDPs and implant-supported SCs (Lang et al. 2004; Pjetursson et al. 2004a, 2004b; Tan et al. 2004; Jung et al. 2007).

The aim of this systematic review is to extend these reviews to analyze and compare the survival and success rates by different designs of tooth and implant-supported fixed reconstructions and to assess the incidence of biological and technical complications.

Material and methods

Search strategy and study selection

Three MEDLINE (PubMED) searches were performed for articles published in the Dental Literature. The first one covered the time period 1966 – April 2004 and searched for articles reporting on conventional tooth-supported end-abutment FDPs and cantilever tooth-supported FDPs published in the English language by searching for 'fixed partial dentures OR bridges,' and 'partial edentulism' (Pjetursson et al. 2004b; Tan et al. 2004). The second search covered the same time interval and was conducted for English-language articles reporting on solely implant-supported FDPs and combined tooth-implant-supported FDPs using the search terms 'fixed partial dentures OR bridges,' 'partial edentulism,' 'implants and fixed partial dentures OR bridges,' 'implants' and 'complications,' 'implants' and 'failures,' 'implants' and 'longitudinal' (Lang et al. 2004; Pjetursson et al. 2004a). The third literature search, for MEDLINE from 1966 up to and including July 2006, was conducted for English- and German-language articles in Dental Journals using the following search terms (modified from Berglundh et al. 2002) and limited to human trials: 'implants' and 'survival,' 'implants' and 'survival rate,' 'implants' and 'survival analysis,' 'implants' and 'cohort studies,' 'implants' and 'case–control studies,' 'implants' and 'controlled clinical trials,' 'implants' and 'randomized controlled clinical trials,' 'implants' and 'complications,' 'implants' and 'clinical,' 'implants' and 'longitudinal,' 'implants' and 'prospective,' 'implants' and 'retrospective.' Additional search strategies included the terms 'single-tooth,' 'failure,' 'peri-implantitis,' 'fracture,' 'complication,' 'technical complication,' 'biological complication,' 'screw loosening' and 'maintenance (Jung et al. 2007).'

All three searches were complemented by manual searches of the bibliographies of all full-text articles and related reviews, selected from the electronic search. Furthermore, manual searching was applied to relevant journals in the field of interest.

Preparing this systematic review, all three original searches were updated and extended up to and including September 2006.

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 that:

- the studies had a mean follow-up time of 5 years or more,
- the included patients had been examined clinically at the follow-up visit, i.e., publications based on patient records only, on questionnaires or interviews were excluded,
- the studies reported details on the characteristics of the suprastructures,
- publications that combined findings of both FDP and single crowns (SCs) described at least 2/3 of the reconstruction as FDPs.

Selection of studies

Titles and abstracts of the searches were always screened by at least two indepen-

dent reviewers for possible inclusion in the reviews. The full text of all studies of possible relevance was then obtained for independent assessment by the reviewers. Any disagreement was resolved by discussion.

In the first original search, identifying studies reporting on conventional and cantilever FDPs the electronic search initial yielded 3568 titles from which 211 abstracts were obtained and finally 76 full-text articles were evaluated. From the full-text articles, 26 fulfilled all inclusion criteria. The extended search up to September 2006 found two additional papers for inclusion. In the second original search identifying studies reporting on solely implant-supported and combined tooth-implant-supported FDPs, the electronic search gave 3844 titles from which 560 abstracts and finally 176 full-text articles were selected. After evaluating full-text articles, 28 fulfilled the inclusion criteria. The extended search found additional three papers for inclusion. The third electronic search for studies reporting on implant-supported SC resulted in 2560 titles from which 356 abstracts and finally 76 full-text articles were selected. After comparing the full-text articles with the inclusion criteria, 26 were included.

Excluded studies

The main reasons for exclusion were a mean observation period yielding <5 years, when no data were available with respect to the reconstruction, or if no distinction was made between the type of reconstructions or between totally and partially edentulous patients. Furthermore, publications based on questionnaires or interviews without clinical examinations, multiple publications on the same patient cohorts and case descriptions of failures without relevant information on the entire patient cohort were excluded.

Data extraction

Data were extracted independently by at least two reviewers using a data extraction form. Disagreement regarding data extraction was resolved by consensus.

Information on the survival and success proportions of the reconstructions and of biological and technical complications were retrieved. Survival was defined as the reconstruction remaining *in situ* at the follow-up examination visit irrespective of its condition. Success was defined as the reconstruction that remained unchanged and did not require any intervention during the entire observation period.

Biological complications for tooth-supported reconstructions covered dental caries, loss of pulp vitality and periodontal disease progression. Biological complications for implant and combined tooth-implant-supported reconstructions were characterized by a biological process affecting the supporting tissues. Soft tissue complications, periimplantitis, bone loss exceeding 2 mm, intrusion of abutment teeth and esthetic complications were included in this category.

Technical complications for tooth-supported reconstructions encompassed fractures of the luting cement (loss of retention), abutment tooth fractures and fractures or deformations of the framework or veneers. Technical complications for implant and combined tooth-implant-supported reconstructions denoted mechanical damage of implants, implant components and/or the suprastructures. Among these, fractures of the implants, fracture of screws or abutments, fractures of the luting cement (loss of retention), fractures or deformations of the framework or veneers, loss of the screw access hole restoration and screw or abutment loosening were included.

For all these categories, number of events were extracted and the corresponding total exposure time of the reconstructions was calculated.

Statistical analysis

Failure and complication rates were calculated by dividing the number of events (failures or complications) in the numerator by the total exposure time of the reconstruction 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 reconstructions that could be followed for the entire observation time.
(2) Exposure time up to a failure of the reconstructions that were lost due to failure during the observation time.
(3) Exposure time up to the end of observation time for reconstructions that did not complete the observation period due to reasons such as death, change of address, refusal to participate in the follow-up, non-response, chronic illnesses, missed appointments and work commitments.

For each study, event rates for reconstructions were calculated by dividing the total number of events by the total reconstruction exposure time in years. For further analysis, the total number of events was considered to be Poisson distributed for a given sum of implant exposure years, and Poisson's regression with a logarithmic link-function and total exposure time per study as an offset variable were used (Kirkwood & Sterne, 2003a, 2003b).

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, indicating heterogeneity, random-effects Poisson's regression (with γ-distributed random-effects) was used to obtain a summary estimate of the event rates. Five- and 10-year survivals were calculated through the relationship between event rate and survival function S, $S(T) = \exp(-T * \text{event rate})$, by assuming constant event rates (Kirkwood & Sterne, 2003a, 2003b). The 95% confidence intervals for the survivals were calculated by using the 95% confidence limits of the event rates. Multivariable random-effect Poisson's regression was used to investigate formally whether event rates varied by types of reconstruction or material used. All analyses were performed using Stata®, version 8.2.

Results

Study characteristics

The year of publication for the 85 studies included in this series of systematic reviews ranged from 1968 up to 2006. The earliest articles were the studies reporting on cantilever FDPs with no article published after the year 2000 and material extending back to 1970 (median year of publication was 1991). For conventional

Table 1. **Characteristics of included studies**

Type of reconstruction	Year of publications		Number of publications	Study design		Follow-up time	
	Range	Median		Prospective	Retrospective	Range	Mean
Conventional FDPs	1968–2006	1995	21	2	19	1–25	7.1
Cantilever FDPs	1970–2000	1991	13	3	10	2–23	7.1
Implant-supported FDPs	1989–2002	2001	24	19	5	0–16	6.3
Tooth-implant-supported FDPs	1989–2002	2000	14	9	5	1–19	6.1
Implant-supported SCs	1996–2006	2002	26	21	5	1–13	5.4

FDP, fixed dental prosthesis; SCs, single crowns.

Table 2. **Material and type of retention**

Type of reconstruction	Number of reconstructions	Material				Retention		
		Metal ceramic (%)	Gold resin (%)	All ceramic (%)	Not reported (%)	Cemented (%)	Screw retained (%)	Not reported (%)
Conventional FDPs	3548	6	54	0	40	–	–	–
Cantilever FDPs	816	17	45	0	38	–	–	–
Implant-supported FDPs	1336	52	33	0	15	5	43	52
Tooth-implant-supported FDPs	538	32	19	0	49	3	52	45
Implant-supported SCs	1530	40	4	9	47	39	5	56

FDP, fixed dental prosthesis; SCs, single crowns.

tooth-supported FDPs, the earliest studies dated back 35 years and the median year of publication was 1995 (Table 1). The studies reporting on implant and tooth-implant-supported reconstructions were more recent and almost exclusively published within the past 10 years. The most recent articles reported on implant-supported SCs with 2002 as a median year of publication (Table 1).

The majority, or 23 out of 28, of the studies on conventional and cantilever tooth-supported FDPs were retrospective. On the other hand, the majority of studies on implant-supported reconstructions (42 out of 57) were prospective in nature. The highest proportion (81%) of prospective studies was found for the implant-supported SCs (Table 1). To evaluate the influence of study design, 10 prospective studies and five retrospective studies reporting on survival of implants, supporting FDPs, were analyzed separately. For the prospective studies, based on 1576 implants, the summary estimate of the survival was 95.6% (95% CI: 93.3–97.2%) and for the retrospective studies, based on 1973 implants, the summary estimate of the survival was 95% (95% CI: 93–96.4%). Formally investigating the difference in event rates in a Poisson regression analysis confirmed the absence of a study design effect ($P = 0.64$) for this material (Pjetursson et al. 2004a).

From the 21 studies reporting on conventional FDPs, 11 reported on bridge design. The relative distribution of FDPs in these reports was 6% metal-ceramic, 54% gold-acrylic, while for the remainder 40%, the bridge design was not reported. For cantilever FDPs, 17% of the FDPs were metal-ceramic, 45% were gold-acrylic and for 38% of the material, bridge design was not reported (Table 2). For implant-supported FDPs, 52% of the FDPs were metal-ceramic, 33% were gold-acrylic and for 15%, the bridge design was not reported. The corresponding figures for tooth-implant-supported FDPs were 32%, 19% and 49%. For implant-supported SCs, 15 out of the 26 studies reported on the material used. Fourty percent of the SCs were metal-ceramic, 4% were gold-acrylic and 9% were all-ceramic (Table 2). About half of the studies, reporting on implant-supported reconstructions, described the type of retention utilized. For the solely implant and combined tooth-implant-supported FDPs, the majority of the reconstructions were screw retained. On the other hand, the majority of the SCs were cemented (Table 2).

Survival

Survival was defined as the reconstruction remaining *in situ* with or without modification over the observation period.

Conventional FDPs

Fifteen studies provided data on the survival of conventional FDPs (Table 3). The reports were divided into two groups: The first group with a total of 2088 FDPs and a mean follow-up time of 5.7 years and the second group with a total of 1218 FDPs and a mean follow-up time of 11.9 years.

In the former group, 273 out of 2088 FDPs and in the second group 190 out of 1218 FDPs were lost. In meta-analysis, the annual failure rate (Table 3) was estimated at 1.28 per 100 FDP years for the former and 1.14 for the latter group, translating into a 5-year survival of conventional FDPs of 93.8% and a 10-year survival of 89.2% (Table 3).

The studies were also divided according to the material utilized: A group of five studies with a total of 1163 metal-ceramic FDPs and a group of six studies with a total of 1756 gold-acrylic FDPs. The group with metal-ceramic FDPs demostrated a higher 10-year survival of 89.1% (95% CI: 82.9–93.2%) compared with survival of 86.3% (95% CI: 72.6–93.5%) for the gold-acrylic FDPs. This difference, however, did not reach statistical significance ($P = 0.6$).

Cantilever FDPs

Twelve studies provided data on the survival of cantilever FDPs (Table 4). The reports were, like for the conventional FDPs,

Table 3. **Annual failure rate and survival of conventional FDPs**

Study	Year of publication	Total number of FDPs	Mean follow-up time	Number of failures	Total FDP exposure time	Estimated failure rate (per 100 FDP years)	Estimated survival after 5 years (%)	Estimated survival after 10 years (%)
5-year follow-up								
Hochman et al.	2003	49	6.3	6	324	1.85	91.2	
Walton	2003	515	7.4	37	3363	1.1	94.6	
Napankangas 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	
Gustavsen & Silness	1986	114	6	3	676	0.44	97.8	
Roberts	1970	1045	5.1	217	5132	4.23	80.9	
Ericsson & Markén	1968	88	6.4	1	560	0.18	95.1	
Total summary estimate (95% CI)*		2088	5.7	273	11,998	1.28 (0.64–2.59)	93.8 (87.9–96.9%)	
10-year follow-up								
De Backer et al.	2006	322	11.4	69	3671	1.88		82.9
Petersson et al.	2006	103	20–23	20	n.a.†	n.a.		n.a.
Sundh & Ödman	1997	163	16–18	35	2532	1.38		87.1
Yi et al.	1995	43	14.7	0	632	0		100
Palmqvist & Swartz	1993	103	18–23	24	n.a.†	n.a.		n.a.
Hochman et al.	1992	138	4–17	9	n.a.†	n.a.		n.a.
Valderhaug	1991	108	15	26	1263	2.06		81.4
Karlsson	1986	238	10	7	2348	0.3		97.1
Total summary estimate (95% CI)*		1218	11.9‡	190	10,446	1.14 (0.48–2.73)		89.2 (76.1–95.3%)

*Based on random-effects Poisson's regression, test for heterogeneity $P < 0.05$.
†Total exposure time could not be estimated.
‡Based on the five studies where total exposure time could be estimated.
n.a., not available; FDP, fixed dental prosthesis.

Table 4. **Annual failure rate and survival of cantilever FDPs**

Study	Year of publication	Total number of FDPs	Mean follow-up time	Number of failures	Total FDP exposure time	Estimated failure rate (per 100 FDP years)	Estimated survival after 5 years (%)	Estimated survival after 10 years (%)
5-year follow-up								
Decock et al.	1996	168	6	20	782	2.56	88	
Laurell et al.	1991	36	8.4	1	300	0.33	98.3	
Budtz-Jörgensen & Isidor	1990	41	5	2	196	1.02	95	
Reichen-Graden & Lang	1989	21	6.2	1	130	0.77	96.2	
Hochman et al.	1987	29	5–10	0	n.a.†	n.a.	n.a.	
Roberts	1970	137	5.1	14	704	1.99	90.5	
Total summary estimate (95% CI)*		432	5.2‡	31	2112	1.8 (1.15–2.82)	91.4 (86.9–94.4%)	
10-year follow-up								
Hämmerle et al.	2000	115	10	18	1035	1.74		84
Sundh & Ödman	1997	31	18	10	488	2.05		81.5
Carlson & Yontchev	1996	12	9.5	4	105	3.81		68.3
Palmquist & Swartz	1993	34	18–23	8	n.a.†	n.a.		n.a.
Öwall et al.	1991	11	18	5	147	3.4		71.2
Karlsson	1989	36	14	12	454	2.64		76.8
Total summary estimate (95% CI)*		239	10.9‡	57	2229	2.2 (1.7–2.84)		80.3 (75.2–84.4%)

*Based on standard Poisson's regression, test for heterogeneity $P = 0.11$ and 0.45.
†Total exposure time could not be estimated.
‡Based on the studies where total exposure time could be estimated.
n.a., not available; FDP, fixed dental prosthesis.

divided into two groups: The first group with a total of 432 FDPs and a mean follow-up time of 5.2 years and the second group with a total of 239 FDPs and a mean follow-up time of 10.9 years.

In the former group, 31 out of 432 FDPs and in the second group 57 out of 239 FDPs were lost. In meta-analysis, the annual failure rate (Table 4) was estimated at 1.8 per 100 FDP years for the former and 2.2 for the latter group, translating into a 5-year survival of cantilever FDPs of 91.4% and a 10-year survival of 80.3% (Table 4).

Two of the studies tested the limit of the ability of the tooth-supportive tissues to

cope with occlusal load. These evaluated 10- or 12-unit FDPs in the mandible with two to three cantilever units bilaterally, supported by only two canines (Öwall et al. 1991; Carlson & Yontchev 1996). If these extreme reconstructions were excluded from the analysis, the 10-year survival of cantilever FDPs went up to 81.7% (95% CI: 77.2–85.3%).

The studies were also divided according to the veneer material utilized: A group of two studies with a total of 136 FDPs with ceramics as a veneer material and a group of four studies with a total of 211 FDPs with acrylic veneers were available for analysis. There was no significant difference between the two groups. The metal ceramic FDPs had a survival after 10 years of 85% (95% CI: 81.4–87.9%), compared with a survival of 84.9% (95% CI: 75.1–91.1%) for the gold-acrylic FDPs.

Implant-supported FDPs

Twenty studies provided data on the survival of solely implant-supported FDPs (Table 5). The reports were again divided into two groups: The first group with a total of 1384 FDPs and a mean follow-up time of 5 years, and the second group with a total of 219 FDPs and a mean follow-up time of 10 years.

In the former group 67 out of 1384 FDPs and in the second group 27 out of 219 FDPs were lost. In meta-analysis, the annual failure rate (Table 5) was estimated at 0.99 per 100 FDP years for the former and 1.43 for the latter group, translating into a 5-year survival of implant-supported FDPs of 95.2% and a 10-year survival of 86.7% (Table 5).

The studies in the 5-years observation group were also divided according to the veneer material utilized: A group of 13 studies with a total of 927 FDPs with ceramic as then veneer material and a group of four studies with a total of 450 FDPs with acrylic veneers. The group with the metal-ceramic FDPs showed a significantly higher ($P = 0.005$) survival after 5 years of 96.7% (95% CI: 95.4–97.7%), compared with a survival of 90.4% (95% CI: 79.9–95.6%) for the gold-acrylic FDPs.

Combined tooth-implant-supported FDPs

Ten studies provided data on the survival of combined tooth-implant-supported FDPs (Table 6). The reports were divided into two groups: The first group with a total of 199 FDPs and a mean follow-up time of 5 years and the second group with only 72 FDPs and a mean follow-up time of 10 years.

In the former group nine out of 199 FDPs and in the second group 14 out of 72 FDPs were lost. In meta-analysis, the annual failure rate (Table 6) was estimated at 0.92 per 100 FDP years for the former and 2.51 for the latter group, translating into a 5-year survival of implant-supported FDPs of 95.5% and a 10-year survival of 77.8% (Table 5).

Implant-supported SC

Twenty-six out 465 SCs were lost, and the study specific 5-year survival varied between 89.6% and 100%. Ten (45%) out of the 26 SCs were lost while the supporting implants were lost, but in the remaining 16 cases (55%), only the recon-

Table 5. **Annual failure rate and survival of implant-supported FDPs**

Study	Year of publication	Total number of FDPs	Mean follow-up time	Number of failures	Total FDPs exposure time	Estimated failure rate (per 100 FDP years)	Estimated survival after 5 years (%)	Estimated survival after 10 years (%)
5-year follow-up								
Degidi & Piattelli	2005	9	7	1	56	1.79	91.5	
Becker	2004	51	5.1	0	261	0	100	
Wennström et al.	2004	56	5	3	269	1.12	94.6	
Preiskel & Tsolka	2004	78	6.6	2	519	0.39	98.1	
Andersson et al.	2003	36	5	1	164	0.61	97	
Jemt et al.	2002	63	5	3	295	1.02	95	
Naert et al.	2002	409	5.5	15	2049	0.73	96.4	
Gotfredsen & Karlsson	2001	52	5	2	236	0.85	95.9	
Brägger et al.	2001	40	5	1	198	0.51	97.5	
Mengel et al.	2001	7	5	0	33	0	100	
Behneke et al.	2000	68	5.4	1	372	0.27	98.7	
Hosny et al.	2000	18	6.5	0	117	0	100	
Örtrop & Jemt	1999	68	5	3	323	0.93	95.5	
Wennerberg & Jemt	1999	133	5	2	608	0.33	98.4	
Wyatt & Zarb	1998	97	5.4	16	498	3.21	85.2	
Olsson et al.	1995	23	5	4	102	3.92	82.2	
Lekholm et al.	1994	197	5	13	889	1.46	92.9	
Total summary estimate (95% CI)†		1384	5	67	6989	0.99 (0.64–1.52)	95.2 (92.7–96.8%)	
10-year follow-up								
Brägger et al.	2005	33	10	2	320	0.63		93.9
Lekholm et al.	1999	163	10	21	1378	1.52		85.9
Gunne et al.	1999	23	10	4	191	2.09		81.1
Total summary estimate (95% CI)*		219	10	27	1889	1.43 (1.08–1.89)		86.7 (82.8–89.8%)

*Based on standard Poisson's regression, test for heterogeneity $P = 0.035$.
†Based on random-effects Poisson's regression, test for heterogeneity $P < 0.0001$.
FDP, fixed dental prosthesis.

Table 6. **Annual failure rate and survival of combined tooth-implant-supported FDPs**

Study	Year of publication	Total number of FDPs	Mean follow-up time	Number of failures	Total FDPs exposure time	Estimated failure rate (per 100 FDP years)	Estimated survival after 5 years (%)	Estimated survival after 10 years (%)
5-year follow-up								
Nickenig et al.	2006	84	5	2	397	0.5	97.5	
Brägger et al.	2001	18	5	1	88	1.14	94.5	
Kindberg et al.	2001	41	5	3	201	1.49	92.8	
Hosny et al.	2000	18	6.5	0	117	0	100	
Olsson et al.	1995	23	5	2	100	2	90.5	
Koth et al.	1988	15	5	1	73	1.37	93.4	
Total summary estimate (95% CI)*		199	5	9	976	0.92 (0.5–1.7)	95.5 (91.9–97.5%)	
10-year follow-up								
Brägger et al.	2005	22	10	7	198	3.54		70.2
Gunne et al.	1999	23	10	3	186	1.61		85.1
Steflik et al.	1995	15	10	3	133	2.26		79.8
Jemt et al.	1989	12	n.a.	1	n.a.†	n.a.		n.a.
Total summary estimate (95% CI)*		72	10‡	14	517	2.51 (1.54–4.1)		77.8 (66.4–85.7%)

*Based on standard Poisson's regression, test for heterogeneity $P = 0.54$ and 0.48.
†Total exposure time could not be estimated.
‡Based on the three studies where total exposure time could be estimated.
n.a., not available; FDP, fixed dental prosthesis.

Table 7. **Annual failure rate and survival of implant-supported SCs**

Study	Year of publication	Total number of SCs	Mean follow-up time	Number of failures	Total SCs exposure time	Estimated failure rate (per 100 SC years)	Estimated survival after 5 years (%)	Estimated survival after 10 years (%)
5-year follow-up								
Wennström et al.	2005	44	5	1	208	0.48	97.6	
Bernard et al.	2004	32	5	0	158	0	100	
Gotfredsen	2004	20	5	1	98	1.02	95	
Andersen et al.	2002	8	5	0	40	0	100	
Haas et al.	2002	75	5.5	4	382	1.05	94.9	
Meriske-Stern et al.	2001	26	6.5	2	169	1.18	94.3	
Palmer et al.	2000	15	5	1	66	1.52	92.7	
Thilander et al.	1999	15	8	1	120	0.83	95.9	
Polizzi et al.	1999	30	5.3	2	154	1.3	93.7	
Andersson et al.	1998a	38	5	1	179	0.56	97.2	
Andersson et al.	1998b	65	5	4	295	1.36	93.4	
Scheller et al.	1998	97	5	9	411	2.19	89.6	
Total summary estimate (95% CI)*		465	5	26	2280	1.14 (0.76–1.7)	94.5 (91.8–96.3%)	
10-year follow-up								
Brägger et al.	2005	69	10	7	623	1.12		89.4
Total summary estimate (95% CI)		69	10	7	623	1.12 (0.45–2.32)		89.4 (79.3–95.6%)

*Based on standard Poisson's regression, test for heterogeneity $P = 0.72$.
SCs, single crowns.

structions failed. In meta-analysis, the annual failure rate (Table 7) was estimated at 1.14 per 100 SC years translating into a 5-year survival of implant-supported SCs of 94.5%.

Only one study (Brägger et al. 2005) was identified that reported on the 10-year survival of implant-supported SCs. For this study, the estimated annual failure was 1.12 per 100 SC years, translating into a 10-year survival of 89.4%.

The studies were also divided according to the material utilized: A group of seven studies with a total of 236 metal-ceramic crowns and a group of two studies with a total of 162 all-ceramic crowns. The group with metal-ceramic crowns showed a significantly higher ($P = 0.005$) survival rate. The stratified summary estimates of the survival after 5 years were 95.4% (95% CI: 93.6–96.7%) for the metal-ceramic crowns and 91.2% (95% CI: 86.8–94.2%) for the all-ceramic crowns, respectively.

Comparison of survival rates

After 5-year follow-up, the annual failure rates of different types of reconstructions ranged from 0.92 to 1.8 and the 5-year survival ranged from 91.4% to 95.5%. Investigating the relative failure rates of different types of reconstructions, using implant-supported SCs as reference, both

Table 8. **Summary of annual failure rates, relative failure rates and 5-year survival estimates**

Type of reconstructions	Total number of reconstructions	Total exposure time	Mean follow-up time	Estimated annual failure rate	5-year survival summary estimate (95% CI) (%)	Relative failure rate‡	*P*-value
Conventional FDPs	2088	11,998	5.7	1.28† (0.64–2.59)	93.8† (87.9–96.9%)	1.57 (0.96–2.58)	$P=0.073$
Cantilever FDPs	432	2112	5.2	1.8* (1.15–2.82)	91.4* (86.9–94.4%)	2.15 (1.19–3.89)	$P=0.011$
Implant-supported FDPs	1384	6880	5	0.99† (0.64–1.52)	95.2 (92.7–96.8%)	0.77 (0.45–1.3)	$P=0.327$
Tooth-implant-supported FDPs	199	976	5	0.92* (0.5–1.7)	95.5* (91.9–97.5%)	0.99 (0.44–2.25)	$P=0.989$
Implant-supported SCs	465	2280	5	1.14* (0.76–1.7)	94.5* (91.8–96.3%)	1 (Ref.)	

*Based on standard Poisson's regression.
†Based on random-effects Poisson's regression.
‡Based on multivariable random-effects Poisson's regression including all types of FDPs.
FDP, fixed dental prosthesis; SCs, single crowns.

Table 9. **Summary of annual failure rates, relative failure rates and 5-year survival estimates for different types of metal-ceramic reconstructions**

Type of reconstructions	Total number of reconstructions	Total exposure time	Mean follow-up time	Estimated annual failure rate	5-year survival summary estimate (95% CI) (%)	Relative failure rate‡	*P*-value
Conventional FDPs	1163	9301	8	1.15† (0.71–1.87)	94.4† (91.1–96.5%)	1.86 (1.02–3.39)	$P=0.041$
Cantilever FDPs	304	1947	6.4	2* (1.44–2.79)	90.5* (87–93.1%)	2.01 (1.09–3.7)	$P=0.026$
Implant-supported FDPs	948	5014	5.3	0.66* (0.52–0.83)	96.8* (95.9–97.4%)	0.89 (0.45–1.75)	$P=0.741$
Tooth-implant-supported FDPs	124	712	5.7	1.37† (0.35–5.32)	93.4† (76.6–98.2%)	1.35 (0.59–3.15)	$P=0.475$
Implant-supported SCs	259	1636	6.3	0.92* (0.66–1.27)	95.5* (93.9–96.7%)	1 (Ref.)	

*Based on standard Poisson's regression.
†Based on random-effects Poisson's regression.
‡Based on multivariable random-effects Poisson's regression including all types of FDPs.
FDP, fixed dental prosthesis; SCs, single crowns.

conventional and cantilever tooth-supported FDPs showed higher failure rates. Moreover, for the cantilever FDPs this difference reached statistical significance ($P=0.011$) (Table 8).

When the studies reporting solely on metal-ceramic reconstructions, excluding gold-resin and all-ceramic reconstruction, were analyzed separately, the lowest annual failure rate was seen for implant-supported FDP (0.66) followed by implant-supported SCs (0.92). Investigating formally, the relative failure rates of metal-ceramic reconstructions, using again implant-supported SCs as reference, both cantilever (2) and conventional FDPs (1.15) had significantly higher annual failure rates ($P=0.026$ and 0.041) (Table 9).

Analyzing the studies with 10-years follow-up time, the annual failure rates ranged from 1.12 to 2.51, and the 10-year survival ranged from 77.8% to 89.4%. After a 10-years observation period, the lowest annual failure rates were seen for implant-supported SCs (1.12) and in the conventional FDPs (1.14). Cantilever FDPs and combined tooth-implant FDPs had significantly higher annual failure rates of 2.20 and 2.51 ($P=0.043$ and 0.045), respectively. Nevertheless, it must be kept in mind that the results for combined tooth-implant-supported FDPs and implant-supported SCs after 10-years follow-up are based on a small number of observations, with 60 and 69 reconstructions, respectively (Table 10).

One single clinic, the Department of Periodontology and Fixed Prosthodontics, University of Berne, Switzerland, published data on all five different types of reconstructions (Table 11). With the exception of conventional FDPs (6.4 years), all the other groups of reconstructions had a mean follow-up time of 10 years. The results from this center were similar to the results obtained in the meta-analysis of the prosthetic dental literature. The highest survival was for conventional FDPs (95.8%), followed by implant-supported FDPs (93.9%) and implant-supported SCs (89.4%). Lower survivals were reported for cantilever FDPs (84%) and combined tooth-implant-supported FDPs (70.2%) (Table 11).

Success

Success was defined as an FDP that remained unchanged and *free of all* complications over the entire observation period. Hence, such a reconstruction did not require any intervention during the observation period.

Conventional FDPs

Four studies (Libby et al. 1979; Reichen-Graden & Lang 1989; Fayyad & al-Rafee 1996a, 1996b; Walton 2003) provided information on FDPs that remained intact over the observation period (Table 12). The estimated study-specific annual complication rates ranged from 1.34 to 7.07 per 100 FDP years. In meta-analysis, the annual complication rate was estimated 3.41 at 100 FDP years translating into a 5-year complication rate of conventional FDPs of 15.7% (95% CI: 8.5–27.7%) (Table 12). One study (Fayyad & al-Rafee 1996a, 1996b) reporting on patients treated at a University clinic and by a private dentist in Saudi Arabia represents an outlier with a

Table 10. **Summary of annual failure rates, relative failure rates and 10-year survival estimates**

Type of reconstructions	Total number of reconstructions	Total exposure time	Mean follow-up time	Estimated annual failure rate	10-year survival summary estimate (95% CI) (%)	Relative failure rate‡	*P*-value
Conventional FDPs	1218	10,446	11.9	1.14† (0.48–2.73)	89.2† (76.1–95.3%)	1.37 (0.63–2.99)	$P=0.418$
Cantilever FDPs	239	2229	10.9	2.2* (1.7–2.84)	80.3* (75.2–84.4%)	2.28 (1.03–5.09)	$P=0.043$
Implant-supported FDPs	219	1889	10	1.43* (1.08–1.89)	86.7* (82.8–89.8%)	1.47 (0.62–3.5)	$P=0.761$
Tooth-implant-supported FDPs	72	517	10	2.51* (1.54–4.1)	77.8* (66.4–85.7%)	2.6 (1.02–6.62)	$P=0.045$
Implant-supported SCs	69	623	10	1.12 (0.45–2.32)	89.4 (79.3–95.6%)	1 (Ref.)	

*Based on standard Poisson's regression.
†Based on random-effects Poisson's regression.
‡Based on multivariable random-effects Poisson's regression including all types of FDPs.
FDP, fixed dental prosthesis; SCs, single crowns.

Table 11. **Annual failure rate and 10-year survival of reconstructions made at the Department for Periodontology and Fixed Prosthodontics, University of Berne, Switzerland**

Type of reconstructions	Year of publication	Total number of reconstructions	Mean follow-up time	Number of failures	Total exposure time	Estimated failure rate (per 100 years)	Estimated survival after 10 years (%)
Conventional FDPs	1989	73	6.4	2	465	0.48	95.8
Cantilever FDPs	2000	115	10	18	1035	1.74	84
Implant-supported FDPs	2005	33	10	2	320	0.63	93.9
Tooth-implant-supported FDPs	2005	22	10	7	198	3.54	70.2
Implant-supported SCs	2005	69	10	7	623	1.12	89.4

FDP, fixed dental prosthesis; SCs, single crowns.

Table 12. **Complication rates and success of conventional FDPs**

Study	Year of publication	Total number of FDPs	Mean follow-up time	Number of complications	Total FDPs exposure time	Estimated complication rate (per 100 FDP years)	Estimated success after 5 years (%)
Walton	2002	515	7.4	45	3363	1.34	93.5
Libby et al.	1997	89	8.4	13	759	1.71	91.8
Fayyad & Al-Rafee	1996	156	5.1	56	792	7.07	70.2
Reichen-Graden & Lang	1989	73	6.4	17	465	3.66	83.3
Total summary estimate (95% CI)*		833		131	5379	3.41 (1.79–6.49)	84.3 (72.3–91.5%)

*Based on random-effects Poisson's regression, test for heterogeneity $P<0.00001$.
FDP, fixed dental prosthesis.

substantial higher FDP complication rate than all other studies.

Cantilever FDPs

Three studies (Budtz-Jørgensen & Isidor 1990; Carlson & Yontchev 1996; Decock et al. 1996) reported how many patients were free of any complications and for two studies (Reichen-Graden & Lang 1989; Hämmerle et al. 2000) this information could be extracted from the original database (Table 13).

In meta-analysis, the annual complication rate was estimated at 4.62 per 100 FDP years translating into a 5-year complication rate of cantilever FDPs of 20.6% (95% CI: 16.2–26.1%) (Table 13).

Implant-supported FDPs

Only three (Örtorp & Jemt 1999; Wennerberg & Jemt 1999; Jemt et al. 2002) out of the 24 studies reported how many patients were free of complications. For one study (Brägger et al. 2001), this information could be extracted from the original database (Table 14).

These four studies included 266 patients with a mean follow-up time of 5 years, and 122 patients had some kind of complications over the observation period (in total 253 complications). In meta-analysis, the annual complication rate was estimated at 9.78 per 100 FDP years (95% CI: 8.07–11.9) translating into a 5-year complication rate of implant-supported FDPs of 38.7% (95% CI: 33.2–44.7%) (Table 14).

Comparing the success proportion of conventional tooth-supported and solely implant-supported FDPs, the tooth-supported FDPs had a significantly ($P=0.008$) higher 5-year success proportion of 84.3% compared with 61.3% for the implant-supported FDPs. Hence, patients with implant-supported FDPs were

Table 13. **Complication rates and success of cantilever FDPs**

Study	Year of publication	Total number of FDPs	Mean follow-up time	Number of complications	Total FDPs exposure time	Estimated complication rate (per 100 FDP years)	Estimated success after 5 years (%)
Hämmerle et al.	2000	115	10	39	1035	3.77	82.8
Decock et al.	1996	168	6	41	741	5.53	75.8
Carlson & Yontchev	1996	12	9.5	10	105	9.52	62.1
Palmquist & Swartz	1993	34	18–23	17	n.a.	n.a.	n.a.
Budtz-Jörgensen & Isidor	1990	41	5	8	196	4.08	81.5
Reichen-Graden & Lang	1989	21	6.2	4	130	3.08	85.7
Total summary estimate (95% CI)*		391		119	2207	4.62 (3.54–6.04)	79.4 (73.9–83.8%)

*Based on standard Poisson's regression, test for heterogeneity $P = 0.06$.
n.a., not available; FDP, fixed dental prosthesis.

Table 14. **Complication rates and success of implant-supported FDPs**

Study	Year of publication	Total number of patients	Mean follow-up time	Number of complications	Total patients exposure time	Estimated complication rate (per 100 patients years)	Estimated success after 5 years (%)
Jemt et al.	2002	42	5	22	195	11.28	56.9
Brägger et al.	2001	33	5	7	163	4.29	80.7
Örtrop & Jemt	1999	58	5	30	281	10.68	58.6
Wennerberg & Jemt	1999	133	5	63	608	10.36	59.6
Total summary estimate (95% CI)*		266		122	1247	9.78 (8.07–11.86)	61.3 (55.3–66.8%)

*Based on standard Poisson's regression, test for heterogeneity $P = 0.12$.
FDP, fixed dental prosthesis.

at a higher risk of having complications, than patients with tooth-supported conventional FDPs.

Biological complications

Tooth-supported reconstructions

The most frequent biological complication by tooth-supported reconstructions was loss of abutment vitality. One hundred ninety-six out of 1227 abutment teeth considered vital at the time of cementation presented with a loss of pulp vitality over the observation period. The annual complication rates were 1.26 for conventional and 3.95 for cantilever FDPs translating into 5-year rates of loss of abutment vitality of 6.1% for conventional FDPs and a significantly ($P = 0.017$) higher complication rate of 17.9% for cantilever FDPs (Table 15). When the two studies (Öwall et al. 1991; Carlson & Yontchev 1996) reporting on 12-unit FDPs in the mandible supported by two canines were excluded from the analysis, the 5-year rate of loss of abutment vitality for cantilever FDPs decreased to 5.4% (95% CI: 2.8–9.2%).

One study (Bergenholtz & Nyman 1984), specifically addressing loss of vitality in patients reconstructed after successful therapy for advanced periodontitis, reported the highest 5-year rate for loss of abutment vitality of 8.2% (95% CI: 5.9–11.1%). Significantly higher loss of vitality was observed in abutments, when compared with non-prepared control teeth.

The second most common biological complication was dental caries. Caries rates were reported at the surface, abutment and at the FDP levels. Only one study (Karlsson 1986) addressed dental caries on a surface level and found 8.1% of all surfaces being decayed within 10 years. From 3176 abutments analyzed, 290 abutments developed decay over the observation period. The annual complication rates were 0.99 for conventional and 0.95 for cantilever FDPs giving 5-year rates of dental decay at abutment teeth of 4.8% for conventional FDPs and 4.7% for cantilever FDPs (Table 15). Several studies reported the number of FDPs lost due to caries. From 1439 FDPs examined, 27 were lost due to dental caries. The annual failure rates were 0.32 for conventional and 0.31 for cantilever FDPs, respectively, translating into 5-year rates of FDPs lost because of dental caries of 1.6% for conventional FDPs and 1.5% for cantilever FDPs (Table 15).

The third biological complication was the loss of the reconstruction due to recurrent periodontitis. From 1693 FDPs analyzed, only nine FDPs were lost due to periodontitis. The annual failure rates were 0.07 for conventional and 0.1 for cantilever FDPs translating into 5-year rates of loss of FDPs due to periodontitis of 0.4% for conventional FDPs and 0.5% for cantilever FDPs (Table 15).

One study (Fayyad & al-Rafee 1996a, 1996b), however, reported recurrent periodontitis to affect abutments of 12.8% of the FDPs after only 5.1 years. As the information provided did not differentiate between periodontitis reported as a complication or periodontitis leading to the loss of the FDP, the study was excluded from the analysis.

Implant-supported reconstructions

Peri-implant mucosal lesions were reported to in various ways by the different authors. Several studies provided information on soft tissue complications and periimplantitis, while other studies reported signs of inflammation (pain, redness, swelling and

Table 15. **Summary of complications by tooth-supported reconstructions**

Complication	Conventional FDPs				Cantilever FDPs				*P*-value‡
	Total number of FDPs or Abutments	Total exposure time	Summary estimate event rates (95% CI)	Cumulative 5-year complication rates (95% CI) (%)	Total number of FDPs or Abutments	Total exposure time	Summary estimate event rates (95% CI)	Cumulative 5-year complication rates (95% CI)	
Estimated rate of caries of abutments	2871	22,477	0.99† (0.47–2.09)	4.8† (2.3–9.9%)	305	2621	0.95* (0.65–1.39)	4.7%* (3.2–6.8%)	$P = 0.709$
Estimated rate of FDPs lost due to caries	894	9733	0.32* (0.22–0.46)	1.6* (1.1–2.3%)	545	3549	0.31* (0.1–0.92)	1.5%* (0.5–4.5%)	$P = 0.961$
Estimated rate of FDPs lost due to periodontitis	1264	12,549	0.07* (0.04–0.14)	0.4* (0.2–0.7%)	429	3109	0.1* (0.03–0.31)	0.5%* (0.2–1.5%)	$P = 0.12$
Estimated rate of loss of vitality	1072	9441	1.26* (1.01–1.57)	6.1* (4.9–7.6%)	155	1412	3.95† (1.49–10.47)	17.9%† (7.2–40.8%)	$P = 0.017$
Estimated rate of FDPs lost due to abutment fracture	1071	11,052	0.2* (0.15–0.27)	1* (0.7–1.3%)	340	2509	0.24* (0.06–1.03)	1.2%* (0.3–5%)	$P = 0.791$
Estimated rate of loss of retention	1204	10,627	0.66† (0.4–1.10)	3.3† (2–5.3%)	597	3891	1.75† (0.92–3.34)	8.4%† (4.5–15.4%)	$P = 0.019$
Estimated rate of veneer or framework fracture	1743	14,397	0.32† (0.18–0.58)	1.6† (0.9–2.9%)	544	3591	0.61† (0.34–1.1)	3%† (1.7–5.3%)	$P = 0.153$
Estimated rate of ceramic cipping or fracture	841	2292	0.59† (0.25–1.41)	2.9† (1.2–6.8%)	304	1947	0.72* (0.38–1.35)	3.5%* (1.9–6.5%)	$P = 0.765$

*Based on standard Poisson's regression.
†Based on random-effects Poisson's regression.
‡Comparing conventional and cantilever FDPs.
FDP, fixed dental prosthesis.

bleeding) or 'soft tissue complications,' defined as fistula, gingivitis or hyperplasia.

In a random-effects Poisson-model analysis, the annual complication rates were 1.79 for implant-supported FDPs, 1.44 for combined tooth-implant-supported FDPs and 2.03 for implant-supported SCs, translating into 5-year rates of soft tissue complications of 8.6% for implant-supported FDPs, 7% for combined tooth-implant-supported FDPs and 9.7% for implant-supported SCs (Table 16).

For combined tooth-implant-supported FDPs, five studies reported on intrusion of abutment teeth. After a 5-year observation period, intrusion was detected in 5.2% of the abutment teeth (Table 16).

Nine studies reported on survival of tooth and implant abutments in combined tooth–implant FDPs. After an observation period of 5 years, 3.2% of the abutment teeth and 3.4% of the functionally loaded implants were lost. At 10 years, this information was available only from two studies (Gunne et al. 1999; Brägger et al. 2005). The corresponding proportions were 10.6% for the abutment teeth compared with 15.6% for the implants, respectively. The reasons reported for loss of abutment teeth were tooth fractures, caries, endodontic complications and periodontitis. Loss of retention was frequently associated with tooth fractures or caries.

For implant-supported SCs, 10 studies evaluated changes in marginal bone height, evaluated on radiographs, over the observation period. In Poisson model analysis, the cumulative rate of implants having bone loss exceeding 2 mm after 5 years was 6.3% (Table 16).

Multivariable Poisson regression was used to investigate formally whether incidence of soft tissue complications and incidence of bone loss >2 mm varied between cemented and screw-retained crowns. No significant difference ($P = 0.42$ and $P = 0.84$) was detected regarding influence of crown design on these biological complications.

Six studies on SCs reported on the esthetic outcome of the treatment. The esthetic appearance was evaluated either by dental professionals or by the patient himself. In a meta-analysis, the cumulative rate of crowns having unacceptable or semi-optimal esthetic appearance was 8.7% (Table 16).

Table 16. Summary of complications by implant-supported reconstructions

Complication	Implant-supported FDPs			Combined tooth-implant-supported FDPs			Implant-supported single crowns		
	Number of implants or reconstructions	Summary estimate event rates (95% CI)	Cumulative 5-year complication rates (95% CI) (%)	Number of implants or reconstructs	Summary estimate event rates (95% CI)	Cumulative 5-year complication rates (95% CI) (%)	Number of implants or reconstructions	Summary estimate event rates (95% CI)	Cumulative 5-year complication rates (95% CI) (%)
Estimated rate of soft tissue complications	751	1.79* (1.05–3.03)	8.6* (5.1–14.1%)	184	1.44* (0.35–5.96)	7* (1.7–25.8%)	267	2.03* (1.05–3.95)	9.7* (5.1–17.9%)
Estimated rate of bone loss >2 mm		n.a.	n.a.		n.a.	n.a.	509	1.31* (0.61–2.79)	6.3* (3–13%)
Estimated rate of esthetic complications		n.a.	n.a.		n.a.	n.a.	418	1.82* (0.64–5.12)	8.7* (3.2–22.6%)
Estimated rate of abutment tooth intrusion		n.a.	n.a.	506	1.07* (0.4–2.87)	5.2* (2–13.3%)		n.a.	n.a.
Estimated rate of implant fracture	2559	0.11* (0.05–0.23)	0.5* (0.3–1.1%)	530	0.2* (0.08–0.34)	0.8* (0.4–1.7%)	1312	0.03* (0.006–0.13)	0.14* (0.03–0.64%)
Estimated rate of abutment or screw fracture	2590	0.3† (0.16–0.57)	1.5† (0.8–2.8%)	511	0.11* (0.06–0.22)	0.6* (0.3–1.1%)	510	0.07* (0.018–0.28)	0.35* (0.09–1.4%)
Estimated rate of loose abutments or screws	2453	1.15† (0.76–1.74)	5.6† (3.7–8.3%)	296	1.44* (0.95–2.17)	6.9* (4.7–10.3%)	752	2.72† (1.17–6.3)	12.7† (5.7–27%)
Estimated rate of lost access hole restorations	169	1.77	8.9		n.a.	n.a.		n.a.	n.a.
Estimated rate of loss of retention	93	1.18* (0.6–2.34)	5.7* (3–11%)	286	1.53* (1.09–2.13)	7.3* (5.3–10.1%)	374	1.13† (0.44–2.91)	5.5† (2.2–13.5%)
Estimated rate of veneer fracture	948	2.53† (1.6–4.02)	11.9† (7.7–18.2%)	125	1.51* (0.98–2.3)	7.2* (4.8–10.9%)	508	0.92† (0.48–1.75)	4.5† (2.4–8.4%)
Estimated rate of ceramic cipping or fracture	521	1.84† (1.03–3.27)	8.8† (5–15.1%)	125	1.51* (0.98–2.3)	7.2* (4.8–10.9%)	402	0.71† (0.34–1.46)	3.5† (1.7–7%)
Estimated rate of framework fracture	623	0.13* (0.06–0.32)	0.7* (0.3–1.6%)	120	0.33* (0.12–0.91)	1.6* (0.6–4.4%)	348	0.61† (0.22–1.73)	3† (1.1–8.3%)

*Based on standard Poisson's regression.
†Based on random-effects Poisson's regression.
n.a., not available; FDP, fixed dental prosthesis.

Technical complications

Tooth-supported reconstructions

The most frequent technical complication by tooth-supported reconstructions was loss of retention (fracture of the luting cement). From 1801 FDPs analyzed, this complication occurred in 121 reconstructions. The annual complication rates were 0.66 for conventional FDPs. However, for cantilever FDPs it was significantly ($P = 0.019$) higher (1.75). This translates into 5-year rates of loss of retention of 3.3% for conventional FDPs and 8.4% for cantilever FDPs (Table 15). Two studies (Karlsson 1986), (Gustavsen & Silness 1986) reported high incidence of loss of retention. This correlated to the increased incidence of caries reported in one of the two studies (Karlsson 1986).

The highest annual complication rate (5.7) was reported for the 12-unit FDPs in the mandible supported by two canines only.

The second most common technical complication was fracture of materials. These included fractures of the framework, the veneers or the core build-ups. Fifty-nine out of 2287 FDPs examined experienced some kind of material fractures. The annual failure rates were 0.32 for conventional and 0.61 for cantilever FDPs translating into 5-year rates of material fractures of 1.6% for conventional FDPs and 3% for cantilever FDPs (Table 15). When ceramic fracture or ceramic cipping were analyzed separately, the 5-year complication rates for conventional FDPs increased to 2.9%, and for cantilever FDPs the incidence went up to 3.5% (Table 15).

Fracture of abutment teeth was reported on the abutment and the FDP levels. For cantilever FDPs the annual failure rate of abutment tooth fracture was 0.30 translating into 5-year rates of abutment tooth fractures of 2.9% (95% CI: 1.7–5%). The incidence of fractures of an abutment tooth leading to the loss of the whole FDPs was reported for 1411 FDPs. The annual failure rates were 0.2 for conventional and 0.24 for cantilever FDPs translating into 5-year rates of FDPs lost due to abutment tooth fracture of 1% for conventional FDPs and 1.2% for cantilever FDPs (Table 15).

Implant-supported reconstructions

The most common technical complication by implant-supported reconstructions was

the fracture of a veneer material (acryl, ceramic and composite). In a Poisson' model analysis, the annual complication rates were 2.53 for implant-supported FDPs, 1.51 for combined tooth-implant-supported FDPs and 0.92 for implant-supported SCs, translating into 5-year rates of veneer fractures of 11.9% for implant-supported FDPs, 7.2% for combined tooth-implant-supported FDPs and 4.5% for implant-supported SCs (Table 16). When gold-resin reconstructions where excluded and ceramic fractures or chippings analyzed separately for metal-ceramic reconstructions, the 5-year complication rates for implant-supported FDPs decreased to 8.8% and for implant-supported SCs the 5-year rate of fractures went down to 3.5% (Table 16).

Comparing the rate of ceramic fracture or ceramic chipping of conventional tooth-supported FDPs and solely implant-supported FDPs, the tooth-supported FDPs had a significantly ($P = 0.042$) lower 5-year risk of ceramic fracture or chipping of 2.9% compared with 8.8% for the implant-supported FDPs.

With the exception of implant-supported SCs, fracture of the framework of the reconstruction is a rare complication. The annual complication rates were 0.13 for implant-supported FDPs and 0.33 for combined tooth-implant-supported FDPs translating into 5-year rates of framework fracture of 0.7% and 1.6%, respectively. For implant-supported SCs the fracture of the crown framework (coping) was reported in seven studies, and its annual complication rate was 0.61 translating into a 5-year rate of framework fracture of 3%. This technical complication was significantly higher ($P = 0.016$) in studies reporting on all-ceramic crowns.

The second most common technical complication was abutment or occlusal screw loosening. In a Poisson's model analysis, the annual complication rates were 1.15 for implant-supported FDPs, 1.44 for combined tooth-implant-supported FDPs and 2.72 for implant-supported SCs, translating into 5-year rates of abutment or occlusal screw loosening of 5.6% for implant-supported FDPs, 6.9% for combined tooth-implant-supported FDPs and 12.7% for implant-supported SCs (Table 16). In this respect, one study (Henry et al. 1996) reporting on the first generation of SCs on Brånemark implants was a clear outlier. If this study is excluded from the analysis, the cumulative incidence of screw loosening decreases to 5.8% (95% CI: 2.9–11.5%).

Loss of the screw-access hole restoration was reported only in one study (Örtorp & Jemt 1999). This occurred in 8.2% of the anchors.

Another technical complication was the loss of retention (fracture of the luting cement). From 753 FDPs analyzed, this complication occurred by 45 of the reconstructions. The annual complication rates were 1.18 for implant-supported FDPs, 1.53 for combined tooth-implant-supported FDPs and 1.13 for implant-supported SCs, translating into 5-year rates of loss of retention of 5.7% for implant-supported FDPs, 7.3% for combined tooth-implant-supported FDPs and 5.5% for implant-supported SCs (Table 16). Two studies, reporting on the same cohort of patients (Brägger et al. 2001, 2005), evaluated loss of retention. The cumulative incidence was 2.9% after 5 years, but increased to 16% after 10 years.

Fractures of components, such as implants, abutments and occlusal screws, were rare complications. Out of 3611 implants analyzed, 21 abutments and occlusal screws fractured. The annual complication rates were 0.3 for implant-supported FDPs, 0.11 for combined tooth-implant-supported FDPs and 0.07 for implant-supported SCs, translating into 5-year rates of abutment and occlusal screw fractures of 1.5% for implant-supported FDPs, 0.6% for combined tooth-implant-supported FDPs and 0.35% for implant-supported SCs (Table 16).

Out of 4401 implants analyzed, 21 fractured. The annual failure rates were 0.11 for implant-supported FDPs, 0.2 for combined tooth-implant-supported FDPs and 0.03 for implant-supported SCs, giving 5-year rates of implant fracture of 0.5% for implant-supported FDPs, 0.8% for combined tooth-implant-supported FDPs and 0.14% for implant-supported SCs (Table 16).

Discussion

In the absence of RCTs that would compare head-to-head the five different designs of FDPs, prospective and retrospective cohort studies with stringent inclusion criteria were included in this systematic review to summarize the available information about survival and complication rates of tooth-supported and implant-supported FDPs after a period of at least 5 years. Even with follow-up periods of at least 5 years, some clinicians may argue that such a period is still too short to obtain reliable information on survival and complication rates. Due to the fact that the use of dental implants for rehabilitation of partially edentulous patients is relatively recent, a mean follow-up period of at least 5 years was a necessary compromise.

After an observation period of 5 years, the lowest annual failure rates were seen for implant-supported FDPs (0.99 per 100 FDP years) and combined tooth-implant-supported FDPs (0.92 per 100 FDP years). Multivariable random-effect Poisson's regression showed that cantilever FDPs had significantly higher annual failure rates of about 1.8 per 100 FDP years. Furthermore, analyzing studies reporting on reconstructions with a mean follow-up time of 10 years or more, the annual failure rates ranged from 1.12 to 2.51, translating into 10-year survival rates ranging from 77.8% to 89.4%. Combined tooth-implant-supported FDPs had the lowest annual failure rate (0.92) after 5 years, but over a 10-years observation period the annual failure rate increased to 2.51. This highest failure rate observed and the difference was statistically significant. Nevertheless, the failure rates of abutment teeth and implant abutments were not significantly different from each other, indicating that neither the tooth nor the implant may be held responsible for this relatively low survival.

Over a 10-year observation period, implant-supported SCs (1.12), conventional tooth-supported FDPs (1.14) and solely implant-supported FDPs (1.43) had the lowest annual failure rates. It must by kept in mind, however, that the results for implant-supported SCs and combined tooth-implant-supported FDPs after 10 years are based on very few observations.

In trying to eliminate the influence of different centers, data from one clinic on different types of reconstructions were analyzed after a 10-year observation period.

The annual failure rates for different reconstructions ranged from 0.48 to 3.54. From this single clinic, the highest failures rates after 10 years were seen for cantilever FDPs and combined tooth-implant-supported FDPs and corresponded well to those of the meta-analysis of the dental prosthetic literature.

Analyzing the proportion of patients free of all complications, the conventional tooth-supported FDPs had the lowest annual complications rate (3.41), followed by cantilever FDPs (4.62) and solely implant-supported FDPs (9.78). The 5-year success proportion for tooth-supported FDPs was 84.3% significantly ($P = 0.008$) higher than for the implant-supported FDPs (61.3%).

For conventional tooth-supported FDPs, the most frequent complications were biological complications like caries and loss of pulp vitality. For cantilever FDP, the incidence of biological complications was similar to that of conventional FDPs. Technical complications like loss of retention and material fractures was more frequent.

For implant-supported reconstructions, the incidence of biological complications was similar for all three groups. However, the incidence of technical complications was significantly higher for implant-supported than for tooth-supported reconstructions. Fracture of the veneer material (ceramic fracture or chipping), abutment or screw loosening and loss of retention were the most frequently encountered technical complications. Fracture of the veneer material was more frequent in studies reporting on gold-acryl reconstructions. The high failure rate of the FDPs with a gold framework and acrylic veneers is thought to be due to high numbers of veneer fractures and esthetic complications. For abutment or screw loosening, one study (Henry et al. 1996), reporting on the first generation of SCs on Brånemark implants, was a clear outlier. This groups reported that when the titanium screws were replaced with new gold abutment screws and when new abutment replaced the older one, this incidence of this complication was dramatically reduced. Fracture of components like framework, implants, abutment or screws were a rare complication with one study on crowns made on prefabricated ceramic caps (Scheller et al. 1998) reporting an unusually high incidence of core fractures.

This systematic review addressing the survival and complication rates of FDP of different designs was based on a series of five systematic reviews that all used the same search strategy, the same inclusion/exclusion criteria and the same statistical methodology.

Instead of performing a formal quality assessment of the included studies and sensitivity analysis (Juni et al. 1999), this review used stringent inclusion criteria. For example, only studies with a clinical follow up examination were included to avoid the potential inaccuracies in event description in studies that based their analysis on subjective patient self-reports.

One 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. A further limitation is that the published information did not allow estimating annual failure rates separately for different time periods or years after insertion of the reconstruction. Thus, it was not possible to assess whether annual failure rates increased over time.

Moreover, two of the three literature searches only included English-language publications. This could be problematic for two reasons: (a) the precision of summary estimates is reduced if a substantial number of additional studies published in other languages exist; (b) bias may be introduced if the results of studies published in English differ systematically from those published in other languages. However, in the third search, in which German- and French-language literature was also included, it was seen that all 26 included studies were published in English. This is in agreement with an empirical study from Egger et al. (2003) that found little effect of the inclusion/exclusion of trials published in languages other than English on combined effect estimates in meta-analyses of RCTs.

Research implications

It was evident from the search of the entire dental literature of FDP that there is a need for longitudinal studies with 10 or more years of observation. This is especially evident for implant-supported reconstructions and there is a definitive need for more longitudinal studies addressing such reconstructions.

The present systematic review revealed several shortcomings in the conduct and reporting of clinical studies of FDP resulting in the following recommendations: Long-term cohort studies on reconstructions should have complete follow-up information preferentially with similar length of follow-up for all patients. This means that data on well-defined time periods should be reported for the entire cohort. Owing to various definitions of success, authors should report data on survival in combination with incidence of complications. Survival and success (free of all complications) of the suprastructures should be reported. Well-defined criteria should be used for the assessment of the biological and technical complications. Data from clinical and radiographic assessments should be described using frequency distributions. Collaborative efforts to conduct a pooled individual patient data analysis of the patients and implants in the various studies would allow development and use common definitions of complications and to obtain a clearer picture of the long-term survival.

Biological complications defined by (1) the threshold level of pocket-probing depth (PPD), (2) the presence/absence of bleeding on probing (BOP)/suppuration assessed at any examination interval and (3) crestal bone loss over time should be described for implants and neighboring teeth.

Technical complications should be divided into (1) major; such as, implant fracture, loss of suprastructures, (2) medium; such as, abutment or abutment fracture, veneer or framework fractures, esthetic and phonetic complications and (3) minor; such as abutment and screw loosening, loss of retention, loss of screw hole sealing, veneer chipping (to be polished) and occlusal adjustments. The type and number of events of technical complications per time interval as well as time/cost required should also be reported.

Clinical implications

Based on the results of the present systematic review, planning of prosthetic

rehabilitations should preferentially include conventional end abutment tooth-supported FDPs, solely implant-supported FDPs or implant-supported SCs. Only for reasons of anatomical structures or patient-centered preferences, and as a second option should cantilever tooth-supported FDPs or FDPs supported by combination of implants and teeth be chosen.

Despite high survival of FDP, biological and technical complications were frequent. This, in turn, means that substantial amounts of chair time have to be accepted by the patient, by dental services and by society at large following the incorporation of FDPs.

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