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# A systematic review of the 5-year survival and complication rates of implant-supported single crowns

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**Key words:** biological complications, complication rates, failures, implant dentistry, longitudinal, peri-implantitis, single crowns, success, survival, systematic review, technical complications

**Abstract**

**Objectives:** The objective of this systematic review was to assess the 5-year survival of implant-supported single crowns (SCs) and to describe the incidence of biological and technical complications.

**Methods:** An electronic MEDLINE search complemented by manual searching was conducted to identify prospective and retrospective cohort studies on SCs with a mean follow-up time of at least 5 years. Failure and complication rates were analyzed using random-effects *Poisson's* regression models to obtain summary estimates of 5-year proportions.

**Results:** Twenty-six studies from an initial yield of 3601 titles were finally selected and data were extracted. In a meta-analysis of these studies, survival of implants supporting SCs was 96.8% [95% confidence interval (CI): 95.9–97.6%] after 5 years. The survival rate of SCs supported by implants was 94.5% (95% CI: 92.5–95.9%) after 5 years of function. The survival rate of metal–ceramic crowns, 95.4% (95% CI: 93.6–96.7%), was significantly ($P = 0.005$) higher than the survival rate, 91.2% (95% CI: 86.8–94.2%), of all-ceramic crowns.

Peri-implantitis and soft tissue complications occurred adjacent to 9.7% of the SCs and 6.3% of the implants had bone loss exceeding 2 mm over the 5-year observation period. The cumulative incidence of implant fractures after 5 years was 0.14%. After 5 years, the cumulative incidence of screw or abutment loosening was 12.7% and 0.35% for screw or abutment fracture. For supra-structure-related complications, the cumulative incidence of ceramic or veneer fractures was 4.5%.

**Conclusion:** It can be concluded that after an observation period of 5 years, high survival rates for implants and implant-supported SCs can be expected. However, biological and particularly technical complications are frequent.

The range of indications in implant dentistry was broadened in the past decades from fully edentulous to partially edentulous jaws. The therapy of a missing single tooth has become a frequent and important indication in current dentistry. A variety of therapeutic options are available to restore a missing single tooth. These therapies range from resin-bonded bridges, to fixed partial dentures (FPDs) up to the use of implant-supported single crowns (SCs) (Palmqvist & Swartz 1993; Kerschbaum et al. 1996; Romeo et al. 2004). Decision making in these indications should be based on clinical and radiographic assessments and on the knowledge of the long-term

survival and complication rates of each of these therapeutic options.

The outcome of implant therapy has been presented in the majority of clinical studies by focusing only on implant survival without providing detailed information on the reconstructions (e.g., Buser et al. 1996; Vigolo & Givani 2000; Romeo et al. 2004). However, for decision making, it is important to know the survival proportions and the determination of the incidence of biological and technical complications not only for the implants but also for the reconstructions. In addition, for a meaningful interpretation of the survival and complication rate, a mean follow-up period of at least 5 years would be required (Pjetursson et al. 2004a).

In order to evaluate the outcome of a treatment modality on the highest level of evidence, the use of systematic reviews has been proposed to be an appropriate method (Egger et al. 2001). Hence, systematic reviews are used in medicine and dentistry to summarize cumulative information on the optimal treatment for clinically important questions.

Recent systematic reviews have evaluated the survival of tooth and implant-supported reconstructions of different designs and described the incidence of biological and technical complications after an observation period of at least 5 years (Lang et al. 2004; Pjetursson et al. 2004a, 2004b; Tan et al. 2004). It was demonstrated that after 5 years of service, the survival of FPD with two different designs ranged from 92.5% for cantilever FPDs to 93.8% for conventional FPDs (Lang et al. 2004; Pjetursson et al. 2004a).

In order to compare the results of survival and complication rates for tooth-supported FPDs with optional treatments like the use of resin-bonded bridges and implant-supported SCs, it would be of great importance to perform systematic reviews based on the same level of evidence and accomplished in exactly the same way. The therapeutic effectiveness of single-tooth replacements with implant-borne reconstructions has been demonstrated in several studies (e.g., Avivi-Arber & Zarb 1996; Henry et al. 1996). However, the longevity of implant-supported single-tooth crowns has not yet been reviewed systematically.

Hence, the objective of the present systematic review was to assess the 5-year survival of implant-supported SCs and to describe the incidence of biological and technical complications.

## Materials and methods

### Search strategy and study selection

A MEDLINE search 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' and 'implants' and 'retrospective.' Additional search strategies included the terms 'single-tooth,' 'failure,' 'peri-implantitis,' 'fracture,' 'complication,' 'technical complication,' 'biological complication,' 'screw loosening' and 'maintenance.'

Manual searches of the bibliographies of all full-text articles and related reviews, selected from the electronic search, were also performed. Furthermore, manual searching was conducted in the following journals from 1966 (or for newer Journals since the appearance of the first issue) up to and including July 2006: *American Journal of Dentistry*, *Australian Dental Journal*, *British Journal of Oral and Maxillofacial Surgery*, *Clinical Implant Dentistry & Related Research*, *Clinical Oral Implants Research*, *Deutsche Zahnärztliche Zeitschrift*, *European Journal of Oral Sciences*, *International Dental Journal*, *International Journal of Oral & Maxillofacial Implants*, *International Journal of Periodontics and Restorative Dentistry*, *International Journal of Prosthodontics*, *Journal de Parodontologie*, *Journal of Clinical Periodontology*, *Journal of Dental Research*, *Journal of Oral Implantology*, *Journal of Oral Rehabilitation*, *Journal of Periodontology*, *Journal of Prosthetic Dentistry*, *Quintessence International*, *Swedish Dental Journal*, *Schweizerische Monatsschrift Zahnmedizin*.

From this extensive search, it was obvious that there were no randomized-controlled clinical trials (RCTs) available comparing implant therapy with conventional reconstructive dentistry.

### 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,
- that the publications be reported in English or German and in the Dental literature,
- that the patients included had been examined clinically at the follow-up visit, i.e., publications based on patient records only, questionnaires or interviews were excluded,
- that the studies reported details on the characteristics of the suprastructures and
- publications that combined findings for both implant-supported FPDs and single-tooth crowns allowed for extraction of the data for the group of STCs.

### Selection of studies

Titles and abstracts of the searches were initially screened by two independent reviewers (R. G., R. E. J. or A. Z.) for possible inclusion in the review. The full text of all studies of possible relevance was then obtained for independent assessment by the two reviewers. Any disagreement was resolved by discussion.

Figure 1 describes the process of identifying the 26 studies selected from an initial yield of 3601 titles. Data were extracted independently by two reviewers using a data extraction form. Disagreement regarding data extraction was resolved by consensus.

### Excluded studies

Of the 54 full-text articles examined, 28 were excluded from the final analysis (see reference list).

The main reasons for exclusion were a mean observation period of $<5$ years, no distinction between the type of reconstructions or between totally/partially edentulous patients and single-tooth reconstructions, and no data available with respect to characteristics of the reconstruction.

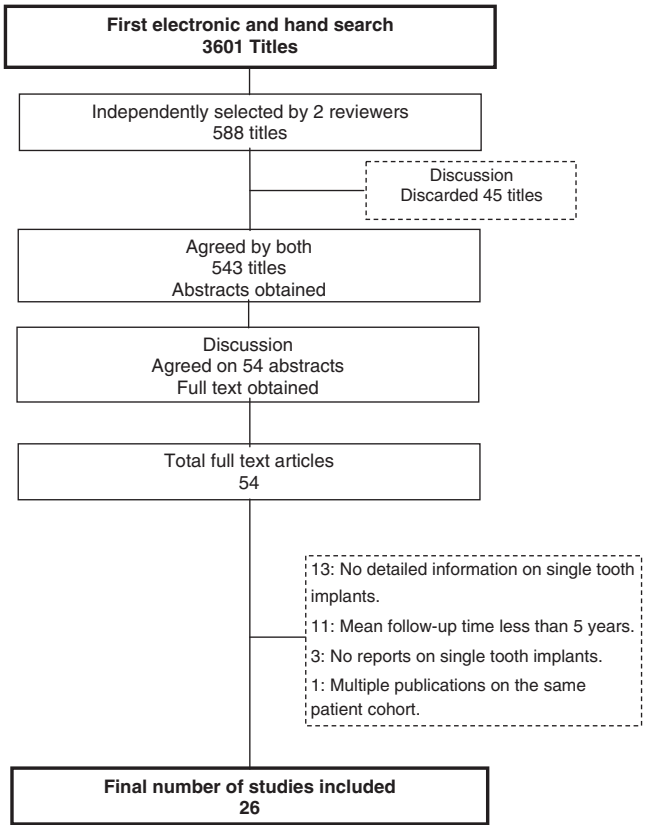


*Fig. 1.* Search strategy.

### Data extraction

Of the 26 studies included, information on the survival proportions of the reconstructions and on biological and technical complications was retrieved. Biological complications included disturbances in the function of the implant characterized by a biological process affecting the supporting tissues. 'Peri-implantitis' and 'soft tissue complications' were included in this category.

Technical complications denoted mechanical damage of implants, implant components and/or the supra-structures. Among these, 'fractures of the implants, 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. From the studies included, the number of events for all of these categories were abstracted and the corresponding total exposure time of the reconstruction was calculated.

### Statistical analysis

By definition, failure and complication rates are calculated by dividing the number of events (failures or complications) in the numerator by the total exposure time (SC time and/or implant 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 SCs/implants that could be followed for the whole observation time,
(2) exposure time up to a failure of the SCs/implants that were lost due to failure during the observation time and
(3) exposure time up to the end of observation time for SCs/implants 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 SCs and/or implants were calculated by dividing the total number of events by the total SCs or implant 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).

Robust standard errors were calculated to obtain 95% confidence intervals (CIs) 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 $\gamma$-distributed random effects) was used to obtain a summary estimate of the event rates. Five-year and 10-year survival proportions were calculated via the relationship between event rate and survival function $S$, $S(T) = \exp(-T \times \text{event rate})$, by assuming constant event rates (Kirkwood & Sterne 2003b). The 95% CIs for the survival proportions were calculated using the 95% confidence limits of the event rates.

Multivariable Poisson regression was used to investigate formally whether event rates varied by crown material (metal–ceramic vs. all-ceramic) or crown design (cemented vs. screw retained).

All analyses were performed using Stata®, version 8.2.

## Results

### Included studies

A total of 26 studies of implant-supported SCs were included in the analysis. The characteristics of the selected studies are shown in Table 1.

All of the studies were published within the past 10 years. Twenty-one of the studies were prospective and the remaining five were retrospective studies (Table 1).

The studies included patients between the age of 13 and 94 years, and the total number of inserted implants was 1558 (Table 2). The number of patients who could not be followed for the complete study period varied from 0% to 30%. Five studies did not report on drop-out patients.

In 19 of the studies [Henry et al. 1996; Andersson et al. 1998a, 1998b, 2002;

**Table 1.** Study and patient characteristics of the reviewed studies

| Study | Year of publication | Implant system sampling method | Study design | No. of patients in study | Age range | Mean age | Setting | Drop-out (%) |
|---|---|---|---|---|---|---|---|---|
| Wagenberg & Froum | 2006 | Brånemark® and 3i® | Retrospective | 891* | 14–94 | 57.9 | Specialist clinic | NR |
| Bornstein et al. | 2005 | ITI® | Prospective | 28 | NR | NR | University | 4 |
| Elkhoury et al. | 2005 | 3i® | Retrospective | 39 | NR | 49.2 | University | NR |
| De Boever & De Boever | 2005 | ITI® | Prospective | 16 | 25–61 | NR | University | 0 |
| Wennström et al. | 2005 | Astra® Tech | Prospective | 40 | 20–71 | 40.9 | University | 9 |
| Levin et al. | 2005 | NR | Retrospective | 48 | 18–65 | 36.2 | Specialist | NR |
| Jemt & Lekholm | 2005 | Brånemark® | Prospective | 10 | 21–36 | 26.3 | Specialist clinic | 20 |
| Brägger et al. | 2005 | ITI® | Prospective | 48 | 19–78 | 49.3 | University | 30 |
| Taylor et al. | 2004 | Biolok® | Prospective | 39 | NR | NR | University | 0 |
| Bernard et al. | 2004 | ITI® | Retrospective | 28 | 15–55 | 31 | University | NR |
| Romeo et al. | 2004 | ITI® | Prospective | 250* | 20–67 | 53 | University | 14 |
| Bianchi & Sanfilippo | 2003 | ITI® | Prospective | 116 | 19–73 | 45.4 | Private practice | 4 |
| Gotfredsen | 2004 | Astra® Tech | Prospective | 20 | 18–59 | 33 | University | 0 |
| Andersen et al. | 2002 | ITI® | Prospective | 8 | 17–28 | 21 | University | 0 |
| Haas et al. | 2002 | Brånemark® | Prospective | 71 | NR | 32 | University | 3 |
| Gibbard & Zarb | 2002 | Brånemark® | Prospective | 42 | 15–64 | 33.4 | University | 8 |
| Mericske-Stern et al. | 2001 | ITI® | Prospective | 72 | 19–82 | 50.1 | University | 0 |
| Palmer et al. | 2000 | Astra® Tech | Prospective | 15 | 16–48 | 49.5 | University | 7 |
| Vigolo & Givani | 2000 | 3i® Implants | Retrospective | 44 | 18–74 | 35 | Specialist clinic | 0 |
| Thilander et al. | 1999 | Brånemark® | Prospective | 10 | 14–19 | 15.3 | Specialist clinic | 0 |
| Polizzi et al. | 1999 | Brånemark® | Prospective | 21 | 13–58 | 30 | Specialist clinic | NR |
| Andersson et al. | 1998a | Brånemark® | Prospective | 38 | 20–45 | 31 | Specialist clinic and private practice | 8 |
| Andersson et al. | 1998b | Brånemark® | Prospective | 57 | NR | 32 | University | 9 |
| Scheller et al. | 1998 | Brånemark® multicenter, 12 centers | Prospective | 82 | 14–73 | 35 | University and private practice | 18 |
| Henry et al. | 1996 | Brånemark® multicenter, seven centers | Prospective | 92 | NR | NR | University and private practice | 16 |
| Buser et al. | 1996 | ITI® | Prospective | 5 | NR | NR | University | 0 |

*Total number of patients in the study with various types of reconstructions.
NR, not reported.

Scheller et al. 1998; Polizzi et al. 1999; Thilander et al. 1999; Palmer et al. 2000; Mericske-Stern et al. 2001; Gibbard & Zarb 2002; Haas et al. 2002; Gotfredsen 2004 (Group B), Bernard et al. 2004; Romeo et al. 2004; Taylor et al. 2004; Bornstein et al. 2005; Brägger et al. 2005; Levin et al. 2005; Wennström et al. 2005 (26 out of 52)], the implants were placed using a standard surgical protocol in a healed implant site (Type III or IV, Hämmerle et al. 2004). In two studies [Gotfredsen 2004 (Group A) and Vigolo & Givani 2000], an 'early' implant placement (Type II) was performed and in three other studies [Bianchi & Sanfilippo 2004; Levin et al. 2005 (26 out of 52) and Wagenberg & Froum 2006], immediate implant placement (Type I) was performed. In the three remaining studies, guided bone regeneration (GBR) was performed in combination with (De Boever & De Boever 2005) or before the implant insertion (Buser et al. 1996; Jemt & Lekholm 2005).

Several of the studies addressed some special issues, such as implants that were loaded after only 6 weeks (Bornstein et al. 2005) or implants that were loaded immediately after placement (Andersen et al. 2002). Moreover, two studies reported on small-diameter implants, where implants with diameters of 3 mm (Polizzi et al. 1999) and 2.9 mm (Vigolo & Givani 2000) were used to support SCs. Andersson et al. (1998b) compared implants placed by general practitioners with implants placed at a specialist clinic. In one study (Taylor et al. 2004), the patients were randomized into three groups that received different implant designs: Biolok® titanium cylinder-type, Biolok® titanium screw-type or Biolok® hydroxyapatite-coated cylinder-type implant (Biolok, Deerfield, FL, USA).

The studies reported on five commercially available implant systems: Astra® Tech Implants Dental System (Astra® Tech AB, Mölndal, Sweden), Brånemark® System (Nobel Biocare AB, Göteborg, Sweden), ITI® Dental Implant System (Straumann AG, Waldenburg, Switzerland) and 3i® Implants (Implant Innovations, Palm Beach Gardens, FL, USA), Biolok® Implants (Biolok). One out of all included studies did not report the commercial name of the implant system that had been used (Levin et al. 2005).

*Table 2.* **Information on implants and single crowns in the reviewed studies**

| Study | Year of publication | Total no. of implants | Total no. of crowns | Metal/ceramic | Gold/resin | All ceramic | Cemented | Screw retained | Follow-up range | Mean follow-up |
|---|---|---|---|---|---|---|---|---|---|---|
| Wagenberg & Froum | 2006 | 401 | 383 | NR | NR | NR | NR | NR | 1–16 | 5.9 |
| Bornstein et al. | 2005 | 39 | 39 | NR | NR | NR | NR | NR | 5 | 5 |
| Elkhoury et al. | 2005 | 39 | 39 | NR | NR | NR | NR | NR | 5 | 5 |
| De Boever & De Boever | 2005 | 10* | 10 | NR | NR | NR | NR | NR | 3–10* | 5 |
| Wennström et al. | 2005 | 45 | 44 | 44 | 0 | 0 | 44 | 0 | 5 | 5 |
| Levin et al. | 2005 | 30* | 29 | NR | NR | NR | NR | NR | 3–9* | 5.1 |
| Jemt & Lekholm | 2005 | 10 | 10 | 10 | 0 | 0 | 10 | 0 | 5 | 5 |
| Brägger et al. | 2005 | 69 | 69 | 69 | 0 | 0 | 67 | 2 | 8–12 | 10 |
| Taylor et al. | 2004 | 39 | 38 | NR | NR | NR | NR | NR | 5 | 5 |
| Bernard et al. | 2004 | 32 | 32 | 32 | 0 | 0 | NR | NR | 2–9 | 5 |
| Romeo et al. | 2004 | 123 | 121 | 121 | 0 | 0 | NR | NR | 1–7 | 5.8 |
| Bianchi & Sanfilippo | 2003 | 116 | 116 | 116 | 0 | 0 | 116 | 0 | 1–9 | 5.1 |
| Gotfredsen | 2004 | 20 | 20 | 20 | 0 | 0 | 20 | 0 | 5 | 5 |
| Andersen et al. | 2002 | 8 | 8 | 8 | 0 | 0 | 0 | 8 | 5 | 5 |
| Haas et al. | 2002 | 76 | 75 | NR | NR | NR | 75 | 0 | 4–10 | 5.5 |
| Gibbard & Zarb | 2002 | 49 | 48 | NR | NR | NR | 2 | 46 | 4–13 | 5.9 |
| Mericske-Stern et al. | 2001 | 26 | 26 | 24 | 0 | 0 | 2 | 24 | 5–9 | 6.5 |
| Palmer et al. | 2000 | 15 | 15 | 15 | 0 | 0 | 15 | 0 | 5 | 5 |
| Vigolo & Givani | 2000 | 52 | 52 | 36 | 16 | 0 | 52 | 0 | 5 | 5 |
| Thilander et al. | 1999 | 15 | 15 | NR | NR | NR | NR | NR | 8 | 8 |
| Polizzi et al. | 1999 | 30 | 30 | 30 | 0 | 0 | 30 | 0 | 3–7 | 5.3 |
| Andersson et al. | 1998a | 38 | 38 | NR | NR | NR | NR | NR | 5 | 5 |
| Andersson et al. | 1998b | 65 | 65 | 3 | 0 | 62 | 65 | 0 | 5 | 5 |
| Scheller et al. | 1998 | 99 | 97 | 16 | 0 | 81 | 97 | 0 | 5 | 5 |
| Henry et al. | 1996 | 107 | 106 | 61 | 45 | 0 | NR | NR | 5 | 5 |
| Buser et al. | 1996 | 5 | 5 | NR | NR | NR | NR | NR | 5 | 5 |
| Total | | 1558 | 1530 | | | | | | 1–13 | 5.5 |

*Implants with <3 years follow-up time were excluded from the meta-analysis.
NR, not reported.

The studies were mainly conducted in an institutional environment, such as universities or specialized implant clinics. Two of the studies were multi-center studies.

The 26 studies included a total of 1530 SCs. Fifteen of the studies reported on crown material, 75% of the crowns were metal–ceramic, 18% were all-ceramic while the remainder were of gold-acrylic design. Only 12% of the crowns were screw retained and 88% were cemented (Table 2).

Fifteen studies reported on patient cohorts in which all the patients were followed for the same observation period, and the other 11 studies represented studies with variable individual observation periods ranging from 1 to 16 years (Table 2).

### Implant survival

All of the 26 studies reported on the survival of the implants (Table 3). Of the originally 1558 implants placed, 54 implants were known to be lost. Thirty percent or 1.9% of the inserted implants were lost before functional loading and the remaining 24 implants were lost in function. For failures after loading, the estimated annual failure rate was 0.28 (95% CI: 0.14–0.59).

The study-specific 5-year survival proportion varied between 90.5% and 100% (Table 3), and the estimated failure rate per 100 implant years ranged from 0 to 2 (Fig. 2). In meta-analysis, a failure rate of 0.64 failures per 100 implant years (95% CI: 0.49–0.84) was estimated (Fig. 2) and a survival rate after 5 years for implants supporting SCs of 96.8% (95% CI: 95.9–97.6%) (Table 3).

### SC survival

SC survival was defined as the SCs remaining *in situ* with or without modification for the observation period. Thirteen studies with a total of 534 SCs provided data on the survival of the reconstructions after a mean follow-up time of 5 years (Table 4).

Thirty-three out of 534 SCs were lost and the study-specific 5-year survival varied between 89.6% and 100% (Table 4). Fifteen out of the 33 SCs were lost while the supporting implants were lost but in the remaining 18 cases only the reconstructions failed. The failure rate per 100 SC years ranged from 0 to 2.19 (Fig. 3), and, in meta-analysis, we estimated an

***Table 3.*** **Annual failure rates and survival of implants**

| Study | Year of publication | Total no. of implants | Mean follow-up time | No. of failure | Total implant exposure time | Estimated failure rate (per 100 implant years) | Estimated survival after 5 years (%) |
|---|---|---|---|---|---|---|---|
| Wagenberg & Froum | 2006 | 401 | 5.9 | 18 | 2266 | 0.79 | 96.1 |
| Bornstein et al. | 2005 | 39 | 5 | 0 | 190 | 0 | 100 |
| Elkhoury et al. | 2005 | 39 | 5 | 0 | 195 | 0 | 100 |
| De Boever & De Boever | 2005 | 10 | 5 | 1 | 50 | 2 | 90.5 |
| Wennström et al. | 2005 | 45 | 5 | 1 | 208 | 0.48 | 97.6 |
| Levin et al. | 2005 | 30 | 5.1 | 2 | 153 | 1.31 | 93.7 |
| Jemt & Lekholm | 2005 | 10 | 5 | 0 | 48 | 0 | 100 |
| Brägger et al. | 2005 | 69 | 10 | 5 | 672 | 0.74 | 96.3 |
| Taylor et al. | 2004 | 39 | 5 | 1 | 190 | 0.53 | 97.4 |
| Bernard et al. | 2004 | 32 | 5 | 0 | 158 | 0 | 100 |
| Romeo et al. | 2004 | 123 | 5.8 | 7 | 711 | 0.98 | 95.2 |
| Bianchi & Sanfilippo | 2004 | 116 | 5.2 | 0 | 594 | 0 | 100 |
| Gotfredsen | 2004 | 20 | 5 | 0 | 100 | 0 | 100 |
| Andersen et al. | 2002 | 8 | 5 | 0 | 40 | 0 | 100 |
| Haas et al. | 2002 | 76 | 5.5 | 5 | 407 | 1.23 | 94 |
| Gibbard & Zarb | 2002 | 49 | 5.9 | 1 | 287 | 0.35 | 98.3 |
| Mericske-Stern et al. | 2001 | 26 | 6.5 | 2 | 169 | 1.18 | 94.3 |
| Palmer et al. | 2000 | 15 | 5 | 0 | 70 | 0 | 100 |
| Vigolo & Givani | 2000 | 52 | 5 | 3 | 245 | 1.22 | 94.1 |
| Thilander et al. | 1999 | 15 | 8 | 0 | 120 | 0 | 100 |
| Polizzi et al. | 1999 | 30 | 5.3 | 1 | 158 | 0.63 | 96.9 |
| Andersson et al. | 1998a | 38 | 5 | 0 | 182 | 0 | 100 |
| Andersson et al. | 1998b | 65 | 5 | 1 | 305 | 0.33 | 98.4 |
| Scheller et al. | 1998 | 99 | 5 | 3 | 411 | 0.73 | 96.4 |
| Henry et al. | 1996 | 107 | 5 | 3 | 477 | 0.63 | 96.9 |
| Buser et al. | 1996 | 5 | 5 | 0 | 25 | 0 | 100 |
| Total | | 1558 | | 54 | 8431 | | |
| Summary estimate (95% CI)* | | | | | | 0.64 (0.49–0.84) | 96.8 (95.9–97.6) |

*Based on standard Poisson regression, test for heterogeneity $P = 0.64$.
CI, confidence interval.

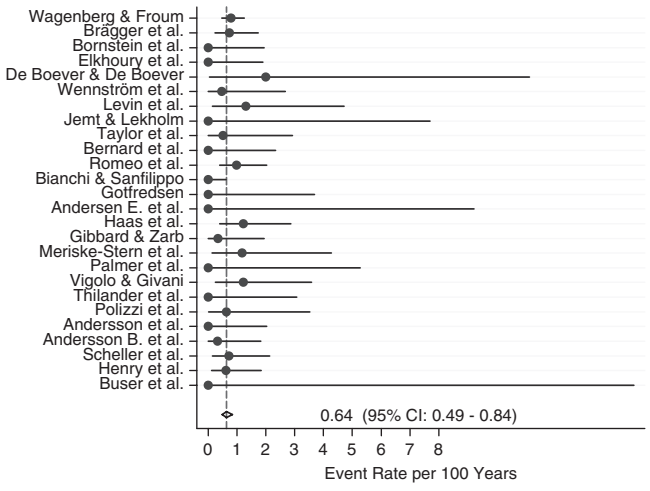


*Fig. 2.* Annual failure rates (per 100 years) of implants.

annual failure rate of 1.14% (95% CI: 0.83–1.56) (Fig. 3) translating into a survival after 5 years for implant-supported SCs of 94.5% (95% CI: 92.5–95.9%) (Table 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 proportion 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.

**Biological complications**

Peri-implant mucosal lesions were reported in 10 studies but in various ways by the different authors. Two studies (Henry et al. 1996; Scheller et al. 1998) used the general term 'soft tissue complications'; four other studies reported on 'signs of inflammation' (Gibbard & Zarb 2002), 'gingival inflammation' (Vigolo & Givani 2000), 'gingivitis' (Andersen et al. 2002) or 'bleeding' (Andersson et al. 1998a, 1998b). Brägger et al. (2005) reported on 'peri-implantitis' defined as probing pocket depth (PPD) $\geq$ 5 mm combined with bleeding on probing (BOP) or suppuration, and Gotfredsen (2004) described cases with 'soft tissue dehiscence.' Other studies (Henry et al. 1996; Andersson et al. 1998a, 1998b, 2002; Gotfredsen 2004) reported on fistula formation.

In a *random-effects* Poisson-model analysis, the estimated cumulative rate of various peri-implant mucosal lesions after 5 years was 9.7% (95% CI: 5.1–17.9%) (Table 5).

In 10 studies, the marginal bone height was evaluated by radiographic analysis. In meta-analysis, the cumulative rate of

***Table 4.*** **Annual failure rate and survival of single crowns**

| Study | Year of publication | Total no. of single crowns | Mean follow-up time | No. of failure | Total crown exposure time | Estimated failure rate (per 100 crown years) | Estimated survival after 5 years (%) |
|---|---|---|---|---|---|---|---|
| Wennström et al. | 2005 | 44 | 5 | 1 | 208 | 0.48 | 97.6 |
| Brägger et al. | 2005 | 69 | 10 | 7 | 623 | 1.12 | 94.5 |
| 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 |
| Mericske-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 | | 534 | | 33 | 2903 | | |
| Summary estimate (95 CI)* | | | | | | 1.14 (0.83–1.56) | 94.5 (92.5–95.9) |

*Based on standard Poisson regression, test for heterogeneity $P = 0.79$.
CI, confidence interval.

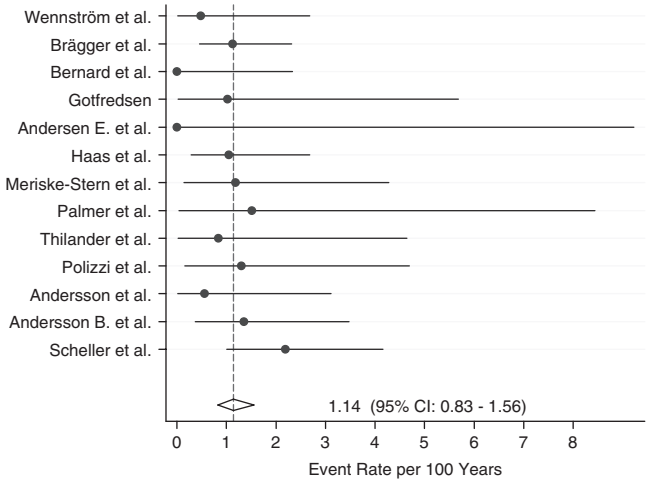


*Fig. 3.* Annual failure rates (per 100 years) of single crowns.

implants having bone loss exceeding 2 mm after 5 was 6.3% (95% CI: 3–13%) (Table 5).

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 0.84) was detected regarding influence of crown design on these biological complications.

#### Esthetic

Seven studies reported on the esthetic outcome of the treatment. The esthetic appearance was evaluated either by dental professionals (Henry et al. 1996; Andersson et al. 1998a; Gibbard & Zarb 2002; Haas et al. 2002; Bernard et al. 2004; Levin et al. 2005) or by the patient himself (Gibbard & Zarb 2002). In a meta-analysis, the cumulative rate of crowns having unacceptable or semi-optimal esthetic appearance was 8.7% (95% CI: 3.2–22.6%) (Table 5).

#### Technical complications

The most common technical complication, abutment or occlusal screw loosening, was reported in 13 studies and its cumulative incidence after 5 years of follow-up was 12.7% (95% CI: 5.7–27%) (Table 6). In this aspect, one study (Henry et al. 1996) reporting on SCs on Brånemark® implants that were tightened with gold-screws was a clear outlier. If this study is excluded from the analysis, the cumulative incidence goes down to 5.8% (95% CI: 2.9–11.5%).

The second most common technical complication, fractures of the luting cement (loss of retention), was reported in six studies, and its cumulative incidence after 5 years was 5.5% (95% CI: 2.2–13.5%) (Table 6).

The third most common technical complication was fracture of a veneer material (ceramic or acrylic). After 5 years, 4.5% (95% CI: 2.4–8.4%) of the crowns had some kind of fracture or chipping of the veneer material (Table 6). Fracture of the crown framework (coping) was reported in seven studies, and its cumulative incidence after 5 years was 3% (95% CI: 1.1–8.3%) (Table 6). This technical complication was significantly higher ($P = 0.016$) in studies reporting on all-ceramic crowns.

Fractures of components, implants, abutments and occlusal screws were rare complications. The cumulative incidence of abutment or screw fracture was 0.35% (95% CI: 0.09–1.4%), and the cumulative incidence of implant fracture was only 0.14% (95% CI: 0.03–0.64%) after a follow-up time of 5 years.

## Discussion

This systematic review is part of a series of systematic reviews addressing the survival and complication rates of different treatment options for the therapy of partially edentulous jaws (Lang et al. 2004; Pjetursson et al. 2004a, 2004b; Tan et al. 2004). It was demonstrated that implant-supported single-tooth crowns show a high survival rate after 5 years but also a particularly high rate of biological and most notably technical complications.

A missing single tooth can possibly be treated by a conventional FPD, an FPD with a cantilever or an implant-supported single

***Table 5.*** **Biological and esthetic complications**

| Study | Year of publication | Total no. of implants | Total implant exposure time | Estimated rate of bone loss >2 m (per 100 implant years) | Estimated rate of soft tissue complications (per 100 implant years) | Estimated rate of esthetic complications (per 100 crown years) |
|---|---|---|---|---|---|---|
| Bornstein et al. | 2005 | 39 | 190 | 0 | 0 | NR |
| Elkhoury et al. | 2005 | 39 | 195 | 3.08 | NR | NR |
| De Boever & De Boever | 2005 | 10 | 50 | 2 | NR | NR |
| Wennström et al. | 2005 | 45 | 208 | 0.96 | NR | NR |
| Levin et al. | 2005 | 51 | 195 | NR | NR | 3.59 |
| Jemt & Lekholm | 2005 | 10 | 48 | 0 | NR | NR |
| Brägger et al. | 2005 | 69 | 672 | NR | 1.93 | NR |
| Bernard et al. | 2004 | 32 | 158 | 0 | NR | 0 |
| Gotfredsen | 2004 | 20 | 100 | NR | 3 | NR |
| Andersen et al. | 2002 | 8 | 40 | 2.5 | 7.5 | NR |
| Haas et al. | 2002 | 76 | 382 | NR | NR | 0.52 |
| Gibbard & Zarb | 2002 | 49 | 287 | NR | 1.05 | 1.05 |
| Mericske-Stern et al. | 2001 | 26 | 169 | 0.59 | NR | NR |
| Palmer et al. | 2000 | 15 | 70 | NR | 0 | NR |
| Andersson et al. | 1998a | 38 | 182 | 1.1 | 1.1 | 0.56 |
| Andersson et al. | 1998b | 65 | 305 | NR | 0.33 | 0 |
| Scheller et al. | 1998 | 99 | 411 | NR | 1.22 | NR |
| Henry et al. | 1996 | 107 | 477 | NR | 6.08 | 6.71 |
| Buser et al. | 1996 | 5 | 25 | 8 | NR | NR |
| Summary estimate event rates (95% CI) | | | | 1.31* (0.61–2.79) | 2.03* (1.05–3.95) | 1.82* (0.64–5.12) |
| Cumulative 5-year complication rates (95% CI) | | | | 6.3%* (3–13%) | 9.7%* (5.1–17.9%) | 8.7%* (3.2–22.6%) |

*Based on random-effects Poisson regression.
CI, confidence interval; NR, not reported.

tooth crown (SC). In order to compare these treatment modalities, RCTs would be the most favorable study designs. However, no RCTs were available comparing these different treatment modalities. In the absence of RCTs, a lower level of evidence, i.e., prospective and retrospective cohort studies, were included in the present systematic review. In multiple clinical indications, it is of great importance to compare and to evaluate the different treatment modalities in order to choose the appropriate treatment and to advise the patient properly. Therefore, the different above-mentioned systematic reviews were performed based on the same criteria, including prospective and retrospective studies with an observation period of at least 5 years.

It can be argued that a follow-up period of 5 years is too short to obtain reliable information on survival rates and complication rates. The fact that all studies included in the present review were published within the last 10 years and more than one-third within the last 2 years indicates that the use of dental implants to support SCs is relatively new. Hence, a mean follow-up period of at least 5 years was a necessary compromise. In contrast, 10-year studies on the longevity of conventional FPDs date back to the 1980s and 1990s, and there is a paucity of studies performed in the new century (Tan et al. 2004). Consequently, caution must be exercised in the comparison of technical complications (i.e., veneer fractures) of conventional FPDs made more than 20 years ago and implant-supported SCs made 5–10 years ago. The majority of the studies on conventional FPDs reported on gold-acrylic FPDs whereas the implant-supported SCs are mainly made of metal–ceramic.

### Implant survival

The present systematic review revealed a survival rate of 96.8% for implants supporting single-tooth crowns after an observation period of at least 5 years. This evidence derived from 26 studies including 1558 placed implants. The evaluation of 15 studies on implant-supported FPD including 3549 originally placed implants estimated an implant survival rate of 95.4% (95% CI: 93.9–96.5%) after 5 years (Pjetursson et al. 2004a). This indicates that implant survival after 5 years seems to be slightly higher for implants supporting SCs compared with implants supporting FPDs. In agreement with previous systematic reviews on the outcome of dental implants, the present study revealed that approximately half of the implants were lost before functional loading (Berglundh et al. 2002; Pjetursson et al. 2004a). However, it was reported that the percentage of single-tooth implants lost before loading decreased when 'immediate placement following tooth extraction,' 'early loading' and 'ridge augmentation procedures' were excluded for the analysis of single-tooth implants (Berglundh et al. 2002).

### SC survival

In the present study, the survival rate of the implant-supported single-tooth crowns was 94.5% after 5 years. This evidence derived from 13 studies including 534 implant-supported SCs. The analysis of 1289 implant-supported FPDs demonstrated a very similar survival proportion after 5 years of 95% (95% CI: 92.2–96.8%). In order to compare the different treatment modalities for a missing single tooth, the outcome for the implant-supported SCs must be compared with the outcomes of conventional and cantilever FPDs. The meta-analysis of a total number of 2881 conventional FPDs indicated an estimated survival of 93.8% (95% CI: 87.9–96.9%) after 5 years and 89.1% (95% CI:

***Table 6.*** **Technical complications**

| Study | Year of publication | Total no. of implants | Estimated rate of implant fracture (per 100 implant years) | Total no. of crowns | Estimated rate of abutment or screw fracture (per 100 crown years) | Estimated rate of loose abutments or screws (per 100 crown years) | Estimated rate of loss of retention (per 100 crown years) | Estimated rate of ceramic chipping (per 100 crown years) | Estimated rate of framework fracture (per 100 crown years) |
|---|---|---|---|---|---|---|---|---|---|
| Wagenberg & Froum | 2006 | 409 | 0 | 383 | NR | NR | NR | NR | NR |
| Bornstein et al. | 2005 | 39 | 0 | 39 | NR | NR | NR | NR | NR |
| Elkhoury et al. | 2005 | 39 | 0 | 39 | NR | NR | NR | NR | NR |
| De Boever & De Boever | 2005 | 10 | 0 | 10 | NR | NR | NR | NR | NR |
| Wennström et al. | 2005 | 45 | 0 | 44 | 0 | 1.44 | NR | NR | 0 |
| Jemt & Lekholm | 2005 | 10 | 0 | 10 | NR | NR | NR | NR | NR |
| Brägger et al. | 2005 | 69 | NR | 69 | 0 | 0.48 | 0 | 0.48 | 0 |
| Taylor et al. | 2004 | 39 | 0 | 38 | NR | NR | NR | NR | NR |
| Bernard et al. | 2004 | 32 | 0 | 32 | NR | NR | NR | NR | NR |
| Romeo et al. | 2004 | 123 | 0 | 121 | 0 | 0 | 0.56 | 0.28 | NR |
| Bianchi & Sanfilippo | 2004 | 94 | 0 | 94 | NR | NR | NR | NR | NR |
| Gotfredsen | 2004 | 20 | 0 | 20 | NR | 2.04 | 2.04 | 2.04 | 0 |
| Andersen et al. | 2002 | 8 | 0 | 8 | 0 | 7.5 | NR | NR | NR |
| Haas et al. | 2002 | 76 | 0.26 | 77 | NR | 3.14 | NR | NR | NR |
| Gibbard & Zarb | 2002 | 49 | 0 | 48 | NR | 1.39 | NR | NR | NR |
| Palmer et al. | 2000 | 15 | 0 | 15 | 0 | 0 | 1.52 | NR | 1.52 |
| Vigolo & Givani | 2000 | 52 | 0 | 52 | 0 | 0.41 | 2.86 | NR | NR |
| Thilander et al. | 1999 | 15 | 0 | 15 | NR | NR | NR | NR | NR |
| Polizzi et al. | 1999 | 30 | 0.63 | 30 | 0.65 | 0 | NR | 0 | NR |
| Andersson et al. | 1998a | 38 | 0 | 38 | NR | NR | NR | NR | 0.56 |
| Andersson et al. | 1998b | 65 | 0 | 65 | 0 | 0.34 | NR | 0.34 | 0.68 |
| Scheller et al. | 1998 | 99 | NR | 97 | NR | 0.97 | 0.73 | 1.7 | 1.7 |
| Henry et al. | 1996 | 107 | 0 | 106 | 0.21 | 18.03 | NR | 1.89 | NR |
| Buser et al. | 1996 | 5 | 0 | 5 | NR | NR | NR | NR | NR |
| Summary estimate event rates (95% CI) | | | 0.03* (0.006–0.13) | | 0.07* (0.018–0.28) | 2.72† (1.17–6.3) | 1.13† (0.44–2.91) | 0.92† (0.48–1.75) | 0.61† (0.22–1.73) |
| Cumulative 5 year complication rates (95% CI) | | | 0.14%* (0.03–0.64%) | | 0.35%* (0.09–1.4%) | 12.7%† (5.7–27%) | 5.5%† (2.2–13.5%) | 4.5%† (2.4–8.4%) | 3%† (1.1–8.3%) |

*Based on standard Poisson regression.
†Based on random-effects Poisson regression.
CI, confidence interval; NR, not reported.

81–93.8%) after 10 years (Tan et al. 2004). The estimated survival of 671 cantilever FPDs was 92.5% (95% CI: 87.3–95.7%) after 5 and 81.8% (95% CI: 78.2–84.9%) after 10 years (Pjetursson et al. 2004b). Comparing the survival rates after 5 years, the values for the implant-supported SCs are very similar to the ones from the conventional FPDs and slightly better compared with the cantilever FPDs. For the implant-supported FPDs and the cantilever FPDs, the failure proportion increased over the second 5-year period (Pjetursson et al. 2004a, 2004b). Therefore, it would be of great importance to gather long-term data for the implant-supported SCs.

The present study additionally evaluated the influence of the crown material on the survival rate. It was demonstrated that metal–ceramic crowns (95.4%) showed a statistically significantly higher survival rate compared with all-ceramic crowns (91.2%). However, no studies are included in this review comparing the outcome of metal–ceramic crowns with all-ceramic crowns within the same study. The values for all-ceramic implant crowns in the present investigation were similar to the values of a recent systematic review evaluating all-ceramic crowns on tooth abutments (Wassermann et al. 2006). In 12 included studies, a total number of 1724 In-Ceram Aluminia crowns were observed over a minimum period of 1.3 months up to a maximum period of 100 months. Survival rates ranged form 86.5% to 100%. They reported a cumulative survival rate according to the Kaplan–Meier method for In-Ceram Aluminia crowns of 92% after 5 years.

#### Biological complications

The most frequent biological complications for implant-supported SCs are peri-implant mucosal lesions (9.7% after 5 years). This value is similar to the pooled cumulative survival rate of biological complications after 5 years [8.6% (95% CI: 5.1–14.1%)] for patients treated with implant-supported FPDs (Pjetursson et al. 2004a).

In the present study, it was demonstrated that the crown design (screw-retained vs. cemented) did not had an influence on these biological complications. This finding is in agreement with a clinical study evaluating the peri-implant microflora of implants with cemented and screw-retained suprastructures (Keller et al. 1998). It was concluded that the impact of the dental microflora on the microbial colonization of the implants appears to be more important than the mode of fixation of the suprastructure.

Comparing implant-supported SCs with tooth-supported FPDs, the latter showed more biologic complications. It was reported that about 10% of the tooth abutment lost vitality after 10 years and about 9.1–9.5% revealed caries on the tooth abutments (Pjetursson et al. 2004a, 2004b; Tan et al. 2004). Regarding the therapeutic consequences of these biological complications, the treatment of non-vital teeth and caries is generally more technique sensitive and more time consuming than the local treatment of the majority of the described peri-implant mucosal lesions.

#### Esthetic

Although the esthetic outcome has become a main focus of interest in partially edentulous patients, only seven out of 26 of the included studies evaluated the esthetic appearance of implant-supported SCs. The cumulative rate of crowns having unacceptable or semi-optimal esthetic appearance was 8.7%. This value is difficult to interpret because of a lack of standardized esthetic criteria and the fact that either dental professionals or the patients have evaluated the esthetic outcome. Hence, there is a need for widely accepted and reproducible esthetic scores, not only for the evaluation of teeth but also for the peri-implant soft tissues (Furhauser et al. 2005).

#### Technical complications

The distribution of the technical complications regarding implant-supported FPDs vs. SCs was found to be different. For implant-supported SCs, the incidence of abutment or screw loosening (12.7% after 5 years) was about two times higher compared with implant-supported FPDs revealing 5.8% abutment or screw loosening after 5 years (Pjetursson et al. 2004a, 2004b). However, it must be emphasized that one study using an old gold-screw design was mainly responsible for the high number of screw loosening (Henry et al. 1996). Excluding this study from the analysis, the cumulative incidence decreases to 5.8%. Hence, this value is very similar to the incidence reported for implant-supported FPDs. Regarding the incidence of veneer fractures, implant-supported FPDs demonstrated, after 5 years, approximately three times more complications (13.2%) compared with SCs (4.5%) (Pjetursson et al. 2004a). This difference might be explained by the high number of veneer fractures of FPDs with a gold framework and acrylic veneers compared with the SCs mainly made of metal–ceramics.

Tooth-supported FPDs show generally smaller incidences of technical complications than implant-supported SCs (Tan et al. 2004). The therapeutic consequences of these complications have not yet been systematically evaluated. However, it might be speculated that a loss of retention is in the majority of the situations more difficult to treat for a tooth-supported FPD than for an implant-supported SC.

## Conclusion

It can be concluded that after an observation period of 5 years, high survival rates for implants and implant-supported SCs can be expected. However, biological and particularly technical complications are frequent. This, in turn, means that substantial amounts of chair time have to be accepted by the clinician following the incorporation of implant-supported SCs.

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