CLINICAL ORAL IMPLANTS RESEARCH

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Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years

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Abstract

Objective: To assess the 5-year survival of implant-supported single crowns (SCs) and to describe the incidence of biological, technical, and aesthetic complications. The focused question was: What is the survival rate of implants supporting single crowns and implant-supported crowns with a mean follow-up of 5 years and to which extent do biological, technical, and aesthetic complications occur?

Methods: A Medline search (2006–2011) was performed for clinical studies focusing on implant-supported SCs with a mean follow-up of at least 5 years. The search was complemented by an additional hand search and the inclusion of 24 studies from a previous systematic review (Jung et al. 2008a). Survival and complication rates were analyzed using random-effects Poisson's regression models to obtain summary estimates of 5- and 10-year proportions.

Results: Forty-six studies derived from an initial search count of 1083 titles and the complementary publications from the previous systematic review (Jung et al. 2008a) were selected and the data were extracted. Based on the meta-analysis, survival of implants supporting SCs at 5 years amounted to 97.2% (95% CI: 96.3–97.9%), and at 10 years amounted to 95.2% (95% CI: 91.8–97.2%). The survival of implant-supported SCs was 96.3% (95% CI: 94.2–97.6%) after 5 years and 89.4% (95% CI: 82.8–93.6%) after 10 years. For biological complications, a 5-year cumulative soft tissue complication rate of 7.1% (95% CI: 4.4–11.3%) and a cumulative complication rate for implants with bone loss >2 mm of 5.2% (95% CI: 3.1–8.6%) were calculated. Technical complications reached a cumulative incidence of 8.8% (95% CI: 5.1–15.0%) for screw-loosening, 4.1% (95% CI: 2.2–7.5%) for loss of retention, and 3.5% (95% CI: 2.4–5.2%) for fracture of the veneering material after 5 years. The cumulative 5-year aesthetic complication rate amounted to 7.1% (95% CI: 3.6–13.6%).

Conclusions: The outcomes of the meta-analysis demonstrated high implant survival rates for both the single tooth implants and the respective single crowns after 5 and 10 years. However, technical, biological, and aesthetic complications were frequent.

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The advent of osseointegration has had a fundamental impact on the therapeutic approaches and strategies implemented today in the field of prosthetic rehabilitation of various types of edentulism. The results from better oral prophylaxis and maintenance of patients have led today to a shift from fully edentulous patients to an increased number of partially edentulous jaws and single tooth gaps. Hence, the treatment of a single tooth gap worldwide has become an important indication within the daily dental practice.

When it comes to the decision-making process between implant-supported single crowns (SCs) and tooth-supported fixed dental prosthesis (FDP), the related decision cri-

teria should be essentially derived from scientific evidence and objective surgically/prosthetically oriented risk assessments as well as patient-related factors including cost effectiveness and quality of life. In terms of a hierarchy of decisions the most important question is, whether or not the prognosis of implant-supported reconstruction is similar to those of tooth-supported FDP.

To answer this question 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 employed in medicine and dentistry to summarize cumulative information on the optimal treatment for clinically important questions. Based on the results of systematic reviews, the clinicians should be able to make appropriate decisions and recommendations for individual clinical indications and to treat patients in an evidence-based way.

A former systematic review of the survival and complication rates of implant-supported SCs was performed from the years 1966 to 2006 (Jung et al. 2008a). During this time period 26 prospective and retrospective cohort studies met the inclusion criteria. In a meta-analysis of these studies the survival rates of implant-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. This information helped the dentists worldwide in their decision-making process and to inform the patients about the treatment outcomes. However, this information is only valuable when it is going to be continuously updated to prevent the clinicians from using the most current data derived from the literature.

Therefore, it was decided to perform an additional literature search from 2006 to 2011 to identify clinical studies reporting on implant-supported SCs and to update the former systematic review (Jung et al. 2008a).

The objective of this systematic review was to assess the 5-year survival of implant-supported SCs and to describe the rate of biological, technical, and aesthetic complications.

Material and methods

Search strategy

This systematic review was designed as an update to a previously prepared publication with the same objectives (Jung et al. 2008a). For that purpose, a Medline (PubMed) search was performed for clinical studies, including articles published from 1 August 2006 up to 31 August 2011 in the dental literature. The search was limited to the English and German language. In addition, full-text articles of reviews published between January 2008 and August 2011 were obtained. An additional hand search was performed identifying relevant studies by screening these reviews and the reference list of all included publications (reference list "list of reviews")

Search terms

The following search terms (all MeSH terms) were selected: "dental implants" AND ("crowns" OR "survival"). The search was limited to "humans" (MeSH term), "Dental Journals", and "Medline".

Inclusion criteria

Clinical publications were considered if all the following criteria were suitable: (i) human trials with a minimum amount of 10 patients with SCs; (ii) mean follow-up of at least 5 years in function; (iii) randomized controlled trials (RCT), controlled clinical trials (CCT), prospective case series, cohort studies, and retrospective studies; (iv) patients needed to be examined clinically; and (v) reported details of suprastructures.

Exclusion criteria

Studies not meeting all inclusion criteria were excluded from the review. Publications dealing with the following topics were also excluded: studies not reporting in detail the prosthodontic component, reports based on questionnaires, interviews, and charts.

Selection of studies

Two authors (DTH and AZE) independently screened the titles derived from this broad search based on the inclusion criteria. Disagreements were resolved by discussion. Following this, abstracts of all titles agreed on by both authors were obtained and screened for meeting the inclusion criteria. If no abstract was available in the database, the abstract of the printed article was used. Based on the selection of abstracts, articles were then obtained in full text. If title and abstract did not provide sufficient information regarding the inclusion criteria, the full report was obtained as well. Again, disagreements were resolved by discussion and Cohen's Kappa-coefficient was calculated as a measure of agreement between the two readers.

Finally, the selection based on inclusion/exclusion criteria was made for the full-text articles. For this purpose materials and methods, results, and discussions of these studies were screened. This step was carried out by three readers (RJU, DTH, and AZE) and double-checked. Any questions that came up during the screening were discussed within the group to aim for consensus. In addition, all but two publications (24 studies) from the previous systematic review (Jung et al. 2008a) were included in the analyses.

Data extraction and method of analysis

Due to the high number of included articles, three reviewers (RJU, DTH, and AZE) extracted the data. For standardization purposes, five of the included studies were randomly selected and data extracted independently by all three readers. Any disagreements were discussed to aim for consensus and to standardize the subsequent analyses. The three reviewers then independently extracted the data of all included studies using data extraction tables. In case the publication did not provide sufficient information, authors of the respective publication were contacted by e-mail. In addition, data of the included publications of the previously published review (Jung et al. 2008a) were extracted as well. All extracted data were double-checked, and any questions that came up during the screening and the data extraction were discussed within the group to aim for consensus.

Information on the following parameters was extracted: author(s), year of publication, implant system, study design, number of patients, number of implants, number of crowns, dropouts, reconstruction material, type of fixation, follow-up, implant and crown survival, as well as the number of complications (technical, biological) and aesthetic outcomes. Based on the included studies, the number of events for all technical, biological and aesthetic complications was extracted 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
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, nonresponse, 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 additional analysis, the total number of events was considered to be Poisson distributed for a given sum of implant exposure years and Poisson regression with a logarithmic link-function and total exposure time per study as an offset variable were used (Kirkwood & Sterne 2003b, a).

Robust standard errors were calculated to obtain 95% CI 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 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 through the relationship between event rate and survival function S, S(T) = exp(-T *event rate), by assuming constant event rates (Kirkwood & Sterne 2003b, a). The 95% CI for the survival proportions were calculated by using the 95% confidence limits of the event rates.

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

All analyses were performed using Stata®, version 12.0 (StataCorp, College Station, TX, USA).

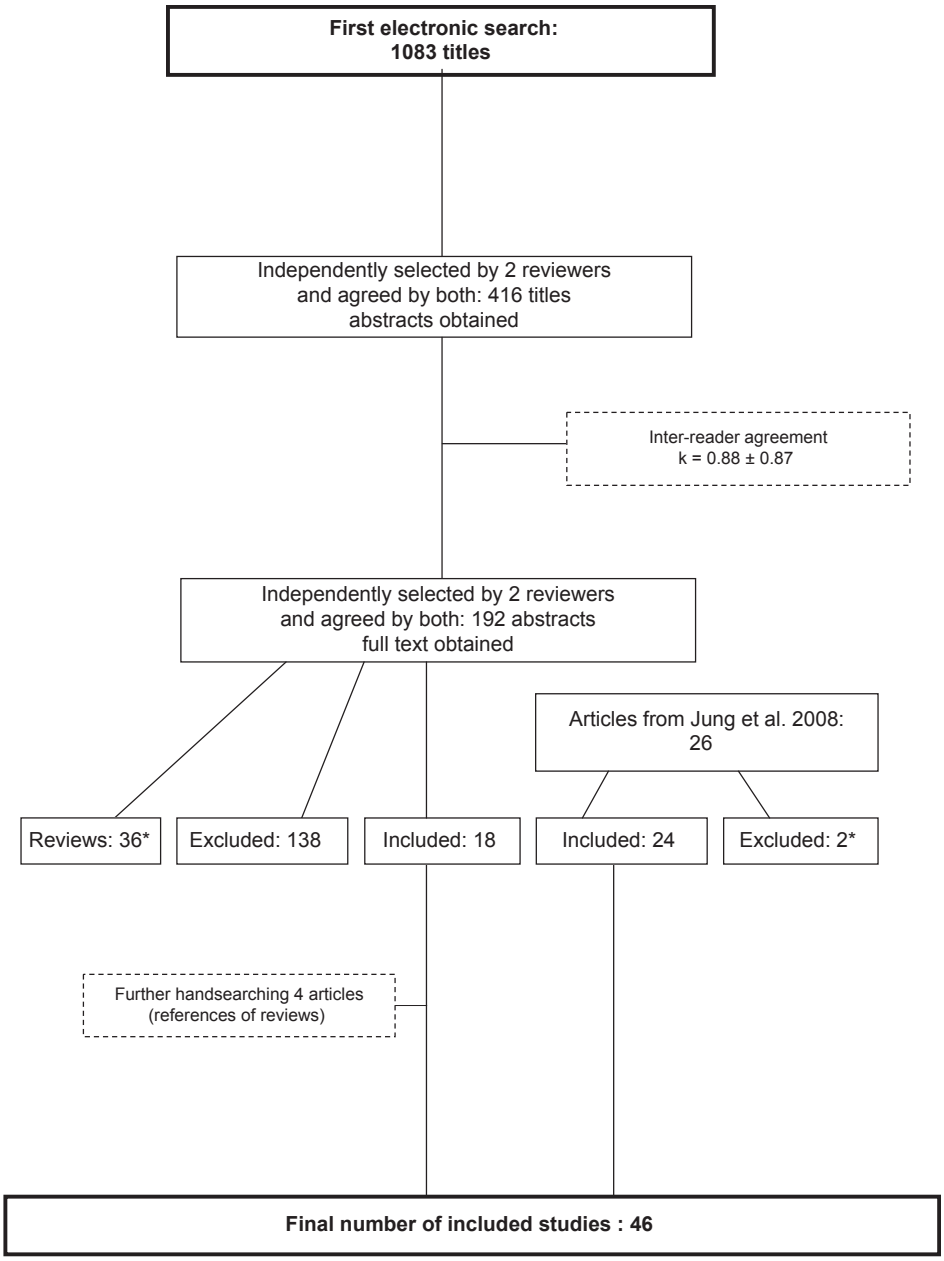

Fig. 1. Search strategy. *For details see reference lists "List of reviews" and "List of excluded full text articles and the reasons for exclusion".

Results

Study characteristics

The electronic search identified a total of 1083 titles (for details refer to Fig. 1). From assessing the titles, 667 were excluded after discussion. The resulting number of abstracts obtained was 416 of which 224 were excluded (inter-reader agreement $k = 0.88 \pm 0.87$). Thereafter, 192 full-text articles were obtained including 36 review articles. Hand searching provided four more studies. Finally, 22 articles met the inclusion criteria. Twenty-four publications were included from the previously published review (Jung et al. 2008a). This resulted in a final number of 46 publications for the present data analyses (Table 1).

Exclusion of studies

The reasons for excluding studies ($n = 138$, see reference list "List of excluded full-text articles and the reason for exclusion") after the full text was obtained were: less than 10 patients or SCs (six studies), chart review without clinical examination (5), edentulous patient/no SCs (1), mean follow-up less than 5 years (30), mixed data with no information on SCs (2), multiple publications on same patient cohort (2), no clinical study (1), limited information on failed implants (1), limited information on prosthetics (60), no information on prosthetics (26), not all patients clinically examined (1), only demographic data (1), tooth-supported SCs (1), only provisional crowns (1). Two publications (Buser et al. 1996; Andersen et al. 2002) from the previous review (Jung et al. 2008a) were excluded due to insufficient number of patients.

Included studies

The 46 studies that met the inclusion criteria are presented in Table 1. All studies were

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

Study	Implant System	Study design	Number of patients	Drop-out (%)	Age range	Mean age	Setting
Jung et al. (2012b)	Straumann	Prospective	29	6.9	28–87	53–60	University
Jung et al. (2012a)	Brånemark/3i/IMZ	Retrospective	20	10	32–87	67.5	University
Schneider et al. (2011)	Straumann/Brånemark	Retrospective	70	NR	19.8–76.6	50.7	University
Bonde et al. (2010)	Brånemark	Retrospective	51	5.9	19–79	43	University students
Krennmair et al. (2010)	Camlog	Retrospective	216	8.3	NR	54.3	Private practice
Matarasso et al. (2010)	Brånemark/Straumann	Retrospective	80	0.0	0	47	University
Schmidlin et al. (2010)	Straumann	Retrospective	64	35.9	33–83	60	University
Urdaneta et al. (2010)	Bicon	Retrospective	108	25.0	27.8–91.8	58.7	Specialist clinic
Zafiropoulos et al. (2010)	Straumann/Camlog	Retrospective	252	4.4	43–70	49	Private practice
Krieger et al. (2009)	Straumann	Retrospective	49	4.1	16.6–24.7	19.3	University
MacDonald et al. (2009)	Endopore	Prospective	20	15.0	NR	43.5	University
Vigolo & Givani (2009)	3i	Prospective	144	0.0	25–55	37	Private practice
Gotfredsen (2009)	Astra Tech	Prospective	20	5.0	18–59	33	University
Degidi et al. (2008)	BioHorizons	Prospective	155	0.0	18–78	54	Private practice
Hälg et al. (2008)	Straumann	Retrospective	54	1.9	25–68	50.2	Private practice
Jemt (2009)	Brånemark	Retrospective	35	31.4	18–72	32	Specialist clinic
Jemt (2008)	Brånemark	Retrospective	38	32	NR	25.4	Specialist clinic
Schropp & Isidor (2008)	3i	Prospective	45	24.4	20–74	48	University
Pikner et al. (2008)	Brånemark	Retrospective	1346	52.5	NR	NR	Specialist clinic
Kreissl et al. (2007)	3i	Prospective	76	0	18–76	45	University
De Boever et al. (2006)	Straumann	Retrospective	105	0.0	25–86	59.1	University
Romeo et al. (2006)	Straumann	Prospective	129	17.8	NR	53	University
Wagenberg & Froum (2006)	Brånemark, 3i	Retrospective	891*	NR	14–94	57.9	Specialist clinic
Bornstein et al. (2005)	ITI	Prospective	28	4	NR	NR	University
Elkhoury et al. (2005)	3i	Retrospective	39	NR	NR	49.2	University
De Boever & De Boever (2005)	ITI	Prospective	16	0	25–61	NR	University
Wennström et al. (2005)	Astra Tech	Prospective	40	9	20–71	40.9	University
Levin et al. (2005)	NR	Retrospective	48	NR	18–65	36.2	Specialist
Jemt & Lekholm (2005)	Brånemark	Prospective	10	20	21–36	26.3	Specialist clinic
Brägger et al. (2005)	ITI	Prospective	48	30	19–78	49.3	University
Taylor et al. (2004)	Biolok	Prospective	39	0	NR	NR	University
Bernard et al. (2004)	ITI	Retrospective	28	NR	15–55	31	University
Romeo et al. (2004)	ITI	Prospective	250*	14	20–67	53	Private practice
Bianchi & Sanfilippo (2004)	ITI	Prospective	116	4	19–73	45.5	University
Gotfredsen (2004)	Astra Tech	Prospective	20	0	18–59	33	University
Haas et al. (2002)	Brånemark	Prospective	71	3	NR	32	University
Gibbard & Zarb (2002)	Brånemark	Prospective	42	8	15–64	33.4	University
Mericske-Stern et al. (2001)	ITI	Prospective	72	0	19–82	50.1	University
Palmer et al. (2000)	Astra Tech	Prospective	15	7	16–48	49.5	University
Vigolo & Givani (2000)	3i	Retrospective	44	0	18–74	35	Specialist clinic
Thilander et al. (1999)	Brånemark	Prospective	10	0	14–19	15.3	Specialist clinic
Polizzi et al. (1999)	Brånemark	Prospective	21	NR	13–58	30	Specialist clinic
Andersson et al. (1998a)	Brånemark	Prospective	38	8	20–45	31	Specialist clinic and private practice
Andersson et al. (1998b)	Brånemark	Prospective	57	9	NR	32	University
Scheller et al. (1998)	Brånemark multicenter, 12 centers	Prospective	82	18	14–73	35	University and private practice
Henry et al. (1996)	Brånemark multicenter, 7 centers	Prospective	92	16	NR	NR	University and private practice

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

published between 1996 and 2012. A total of 27 of the studies were prospective, whereas the remaining 19 were retrospective studies (Table 1). The patients were treated at university settings (29 studies), at specialist clinics (11 studies), or in private practices (6 studies). Two of the studies were multicenter studies (Henry et al. 1996; Scheller et al. 1998). A total number of 3223 implants were placed in patients with age range 13–94 years. The dropout rate varied between 0% and 52.5%, but was not reported in six studies (Table 1).

The studies reported on 10 commercially available implant systems: 3i Implants (Implant Innovations, Palm Beach Gardens, FL, USA), Astra Tech Implants Dental System (Astra Tech AB, Mölndal, Sweden), Bicon Dental Implants (Bicon, Boston, MA, USA), BioHorizons Dental Implants (BioHorizons, Birmingham, AL, USA), Biolok Implants (BioHorizons, Birmingham, AL, USA), Brånemark System (Nobel Biocare AG, Zurich, Switzerland), CAMLOG (CAMLOG Biotechnologies AG, Stuttgart, Germany), Endopore Dental

Implants (Sybron Implant Solutions), IMZ implants (Dentsply-Friadent, Mannheim, Germany), ITI/Straumann Dental Implant System (Straumann AG, Waldenburg, Switzerland). Only one study did not report on the commercial name of the implant system that had been used (Levin et al. 2005).

The 46 studies included a total number of 3199 SCs. The material of the reconstruction was reported in 28 studies and included metal-ceramic (76%), gold-resin (14%), or all-ceramic (10%). Thirty percent of the crowns were screw-retained, whereas 70% were cemented (Table 2).

In 26 studies, all patients in the respective cohorts were followed for the same observation period (5, 10, or 15 years), whereas in 20 studies, variable observation periods were reported with follow-up time-points between 1 and 26 years (Table 2).

Implant survival

All 46 studies reported on implant survival rates (Tables 3 and 4). At the beginning of the studies, 3223 implants were placed. Of these, 104 were known to be lost. Forty-one implants were lost before loading (1.3% of all placed

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

Study	Number of implants	Number of crowns	Metal/ ceramic	Gold/ resin	All-ceramic	Cemented	Screw-retained	Follow-up range	Mean follow-up time
Jung et al. (2012b)	29	29	NR	NR	NR	NR	NR	NR	4.7
Jung et al. (2012a)	20	20	NR	NR	NR	NR	NR	12–14	12.5
Schneider et al. (2011)	100	100	100	0	0	74	26	4.7–11.7	6.2
Bonde et al. (2010)	55	52	0	0	52	52	0	7.5–12	9.4
Krennmair et al. (2010)	112	112	NR	NR	NR	NR	NR	5–7	5.7
Matarasso et al. (2010)	80	80	NR	NR	NR	NR	NR	NR	9.7
Schmidlin et al. (2010)	39	39	39	0	0	35	4	0.8–26.4	6.2
Urdaneta et al. (2010)	326	326	82	228	16	0	326	NR	5.9
Zafiropoulos et al. (2010)	252	252	252	0	0	252	0	NR	4.8
Krieger et al. (2009)	24	24	24	0	0	NR	NR	4.6–15.3	8.0
MacDonald et al. (2009)	20	20	20	0	0	0	20	7–9	7.7
Vigolo & Givani (2009)	182	182	182	0	0	182	0	NR	5.0
Gotfredsen (2009)	20	20	20	0	0	20	0	NR	10.0
Degidi et al. (2008)	45	45	NR	NR	NR	NR	NR	NR	5.0
Hälg et al. (2008)	22	22	22	0	0	22	0	3–12.7	5.0
Jemt (2009)	41	41	41	0	0	23	18	NR	10.0
Jemt (2008)	47	47	47	0	0	0	47	NR	12.3
Schropp & Isidor (2008)	45	42	42	0	0	40	2	NR	4.7
Pikner et al. (2008)	45	45	NR	NR	NR	NR	NR	NR	5.0
Kreissl et al. (2007)	46	46	46	0	0	0	46	NR	5.0
De Boever et al. (2006)	80	80	NR	NR	NR	NR	NR	3.3–12	5.2
Romeo et al. (2006)	58	58	58	NR	NR	49	9	3–14	5.0
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	3–10*	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 (2004)	116	116	116	0	0	116	0	1–9	5.2
Gotfredsen (2004)	20	20	20	0	0	20	0	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	5
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
Total	**3223**	**3199**	**1572**	**289**	**211**	**1344**	**570**	**1–26.4**	**6.2**

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

Table 3. **Annual failure rates and 5-year survival of implants**

Study	Total number of implants	Mean follow-up time	Number of failure	Total implant exposure time	Estimated failure rate (per 100 implant years)	Estimated survival rate after 5 years (in percent)
Prospective studies						
Jung et al. (2012b)	29	4.7	0	137	0	100.0
Vigolo & Givani (2009)	182	5	0	910	0	100.0
Degidi et al. (2008)	45	5	0	225	0	100.0
Schropp & Isidor (2008)	45	4.7	3	210	1.43	93.1
Kreissl et al. (2007)	46	5	1	230	0.43	97.8
Romeo et al. (2006)	58	5	1	288	0.35	98.3
Bornstein et al. (2005)	39	5	0	190	0	100.0
De Boever & de Boever (2005)	10	5	1	50	2	90.5
Wennström et al. (2005)	45	5	1	208	0.48	97.6
Jemt & Lekholm (2005)	10	5	0	48	0	100.0
Taylor et al. (2004)	39	5	1	190	0.53	97.4
Romeo et al. (2004)	123	5.8	7	711	0.98	95.2
Bianchi & Sanfilippo (2004)	116	5.2	0	594	0	100.0
Gotfredsen (2004)	20	5	0	100	0	100.0
Haas et al. (2002)	76	5.5	5	407	1.23	94.0
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	100.0
Polizzi et al. (1999)	30	5.3	1	158	0.63	96.9
Andersson et al. (1998a)	38	5	0	182	0	100.0
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
Total	**1312**	**5.2**	**31**	**6557**		
Summary estimate (95% CI)*					**0.46 (0.26–0.80)**	**97.7% (96.1–98.7%)**
Retrospective studies						
Schneider et al. (2011)	100	6.2	6	620	0.97	95.3
Krennmair et al. (2010)	112	5.7	4	642	0.62	96.9
Urdaneta et al. (2010)	326	5.9	6	1921	0.31	98.5
Zafiropoulos et al. (2010)	252	4.8	11	1205	0.91	95.5
Hälg et al. (2008)	22	5	1	111	0.9	95.6
Pikner et al. (2008)	45	5	1	225	0.44	97.8
De Boever et al. (2006)	80	5.2	0	417	0	100.0
Wagenberg & Froum (2006)	401	5.9	18	2266	0.79	96.1
Elkhoury et al. (2005)	39	5	0	195	0	100.0
Levin et al. (2005)	30	5.1	2	153	1.31	93.7
Bernard et al. (2004)	32	5	0	158	0	100.0
Vigolo & Givani (2000)	52	5	3	245	1.22	94.1
Total	**1491**	**5.3**	**52**	**8158**		
Summary estimate (95% CI)*					**0.78 (0.28–2.20)**	**96.2% (89.6–98.6%)**
Total	**2803**	**5.2**	**83**	**14715**		
Overall summary estimate (95% CI)*					**0.56 (0.42–0.76)**	**97.2% (96.3–97.9%)**

*Based on standard Poisson regression, test for heterogeneity $P = 0.141$

implants); Forty-nine implants were lost after loading (1.5% of all placed implants). In one study, only the number of implants lost in function ($n = 2$) was reported (Schmidlin et al. 2010), whereas two studies did not specify the time-point of implant failure (Krieger et al. 2009; Zafiropoulos et al. 2010). For failures after loading, the estimated annual failure rates were 0.29 (95% CI: 0.17–0.47; 36 studies) over 5 years and 0.35 (95% CI: 0.15–0.83; 10 studies) over 10 years.

The study-specific 5-year survival proportion varied between 90.5% and 100% (Table 3) with an estimated failure rate per 100 implant years between 0 and 2 (Fig. 2). Similar calculations for the 10-year survival proportion ranged between 85.5% and 100% (Table 4), whereas the estimated failure rate per 100 implant years was between 0 and 1.56 (Fig. 3). Based on the meta-analysis, this estimated failure rate per 100 implant years resulted in 0.56 (95% CI: 0.42–0.76; all 36 studies; Fig. 2), 0.46 (95% CI: 0.26–0.80; 23 prospective studies), and 0.78 (95% CI: 0.28–2.20; 13 retrospective studies) over 5 years (Table 3), and in 0.49 (95% CI: 0.28–0.85; all 10 studies; Fig. 3), 0.52 (95% CI: 0.25–1.08; 4 prospective studies), and 0.48 (95% CI: 0.22–1.03; 6 retrospective studies) over 10 years (Table 4). The respective implant survival rates for implants supporting SCs at 5 years amounted to 97.2% (95% CI: 96.3–97.9%; all 36 studies), 97.7% (95% CI: 96.1–98.7%; 4 prospective studies), and 96.2% (95% CI: 89.6–98.6%; 6 retrospective studies) (Table 3), and at 10 years to 95.2% (95% CI: 91.8–97.2%; all 36 studies), 94.9% (95% CI: 89.7–97.5%; 4 prospective studies), and 95.3% (95% CI: 90.2–97.8%; 6 retrospective studies) (Table 4).

SC survival

The survival of SC was defined as SCs remaining *in situ* with or without modification during the observation period. Twenty studies provided data with a mean follow-up of 5 years and a total number of 1385 SCs (Table 5). Of 1385 SCs, 53 crowns were lost, resulting in a study-specific 5-year survival rate between 89.6% and 100% (Table 5). Twenty-eight SCs were lost because the implants were lost, whereas in 25 SCs only the reconstructions failed. The failure rate per 100 SC years ranged between 0 and 2.19 (Table 5). The meta-analysis demonstrated an

Table 4. **Annual failure rates and 10-year survival of implants**

Study	Total number of implants	Mean follow-up time	Number of failure	Total implant exposure time	Estimated failure rate (per 100 implant years)	Estimated survival rate after 10 years (in percent)
Prospective Studies						
MacDonald et al. (2009)	20	7.7	1	154	0.65	93.7
Gotfredsen (2009)	20	10	0	200	0	100.0
Brägger et al. (2005)	69	10	5	672	0.74	97.6
Thilander et al. (1999)	15	8	0	120	0	100.0
Total	**124**	**8.9**	**6**	**1146**		
Summary estimate (95% CI)*					**0.52 (0.25–1.08)**	**94.9% (89.7–97.5%)**
Retrospective Studies						
Jung et al. (2012a)	20	12.5	1	250	0.4	96.1
Bonde et al. (2010)	55	9.4	3	515	0.58	94.3
Matarasso et al. (2010)	80	9.7	6	773	0.78	92.5
Krieger et al. (2009)	24	8	3	192	1.56	85.5
Jemt (2009)	41	10	0	410	0	100.0
Jemt (2008)	47	12.3	0	576	0	100.0
Total	**267**	**10.3**	**13**	**2716**		
Summary estimate (95% CI)*					**0.48 (0.22–1.03)**	**95.3% (90.2–97.8%)**
Total	**391**	**9.9**	**19**	**3862**		
Overall summary estimate (95% CI) *					**0.49 (0.28–0.85)**	**95.2% (91.8–97.2%)**

*Based on standard Poisson regression, test for heterogeneity $P = 0.152$

annual failure rate of 0.75 (95% CI: 0.48 – 1.18; all 20 studies; Fig. 4), 0.76 (95% CI: 0.38–1.54; 14 prospective studies), and 0.68 (95% CI: 0.41–1.10; 6 retrospective studies) (Table 5). This translated into a survival rate for implant-supported SCs of 96.3% (95% CI: 94.2–97.6%; all 20 studies), 96.5% (95% CI: 92.6–98.1%; 14 prospective studies), and of 96.7% (95% CI: 94.6–97.7%; 6 retrospective studies) after 5 years (Table 5). Similar calculations were performed for studies with a mean observation period of 10 years and included seven studies and 268 SCs (Table 6). Twenty-eight failures were reported (8 in combination with implant failure; 20 failure of the reconstruction only). The failure rate per 100 SC years ranged from 0.58 to 2.19. The meta-analysis revealed an annual failure rate of 1.12 (95% CI: 0.66 – 1.89; all 7 studies; Fig. 5), 1.07 (95% CI: 0.97–1.19; 3 prospective studies), and 1.14 (95% CI: 0.48–2.73; 4 retrospective studies) (Table 5). The calculated survival rate for implant-supported SCs was 89.4% (95% CI: 82.8–93.6%; all seven studies), 89.8% (95% CI: 88.8–90.8%; three prospective studies), and of 89.2% (95% CI: 76.1–95.3%; four retrospective studies) after 10 years (Table 6).

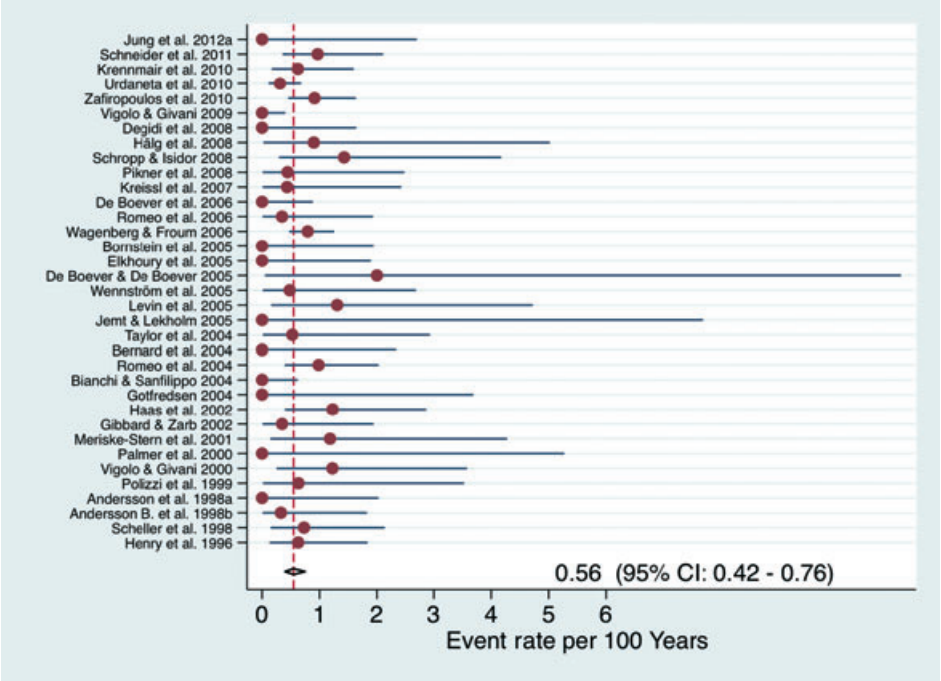

Fig. 2. Annual failure rates (per 100 years) of implants after 5 years.

In addition, multivariate Poisson regression was applied to account for the influence of the type of fixation on the survival rate of SCs. The calculated survival rate of cemented SCs (15 studies, 872 crowns) was 95.6% (95% CI: 93.0–97.2%) and 95.0% (95% CI: 92.1–96.9%) for screw-retained SCs (5 studies, 545 crowns). This difference was not statistically significant ($P > 0.05$).

To take into account the reconstruction materials, studies were also divided into groups with metal-ceramic crowns (17 studies, 799 SCs) and all-ceramic crowns (2 studies, 117 SCs) (Andersson et al. 1998a; Bonde et al. 2010). The stratified summary estimated of the survival proportion after 5 years of loading amounted to 95.8% (95% CI: 93.1–97.5%) for metal-ceramic crowns and 95.8% (95% CI: 90.7–98.1%) for all-ceramic crowns. The annual failure rates of 0.85 (95% CI: 0.51–1.42) for metal-ceramic crowns and 0.86 (95% CI: 0.38–1.95) for all-ceramic crowns did not reveal statistical significance ($P > 0.05$) based on standard Poisson regression.

Biological outcomes

Biological complications were reported in 15 studies and included various descriptions of any kind of soft tissue complications: signs of inflammation, mucosal inflammation, mucositis, bleeding, suppuration, and soft tissue dehiscences. The meta-analysis revealed an estimated rate of various types of soft tissue complications (per 100 implant years) of 1.47 (95% CI: 0.90–2.39). This resulted in a 5-year cumulative soft tissue complication rate of 7.1% (95% CI: 4.4–11.3%) (Table 7).

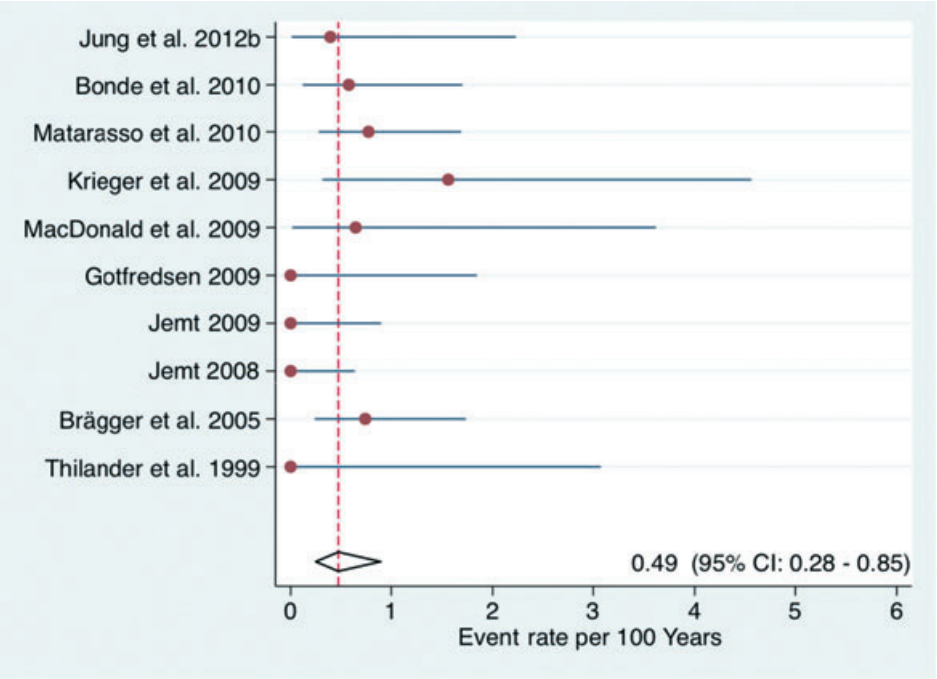

Fig. 3. Annual failure rates (per 100 years) of implants after 10 years.

In 17 studies, a radiographic analysis was performed to evaluate the peri-implant bone levels. Based on the meta-analysis, the cumulative 5-year complication rate (implants with bone loss >2 mm) was 5.2% (95% CI: 3.1–8.6%). The estimated rate of bone loss >2 mm per 100 implant years amounted to 1.06 (95% CI: 0.62–1.79) (Table 7).

Multivariate Poisson regression was used to account for the influence of the type of fixation of the reconstruction (cemented, screw-retained) on marginal bone loss >2 mm. The 5-year complication rate (implants with bone loss >2 mm) was slightly higher for cemented reconstructions (2.8%; 95% CI: 2.1–3.7%) than that for screw-retained reconstructions (1.1%; 95% CI: 0.2–7.1%). However, the annual complication rate of 0.56 (95% CI: 0.42–0.76) for cemented SCs and 0.22 (95% CI: 0.03–1.46) for screw-retained SCs did not reveal a statistically significant influence of the crown design ($P > 0.05$).

Aesthetic outcomes

A variety of studies reported on aesthetic outcomes. Outcome measures were evaluated by dental professionals or by patients and included the use of a questionnaire to rate the appearance of the crown or an index system to rate the interdental papilla height (Schropp & Isidor 2008; Gotfredsen 2009; MacDonald et al. 2009; Krennmair et al. 2010). Twelve studies reported on aesthetic complications with crowns having a semi-optimal or even an unacceptable aesthetic appearance due to soft tissue recessions, an unfavorable color, and visible crown margins. The cumulative

Table 5. **Annual failure rates and 5-year survival of implant-supported SCs**

Study	Total number of single crowns	Mean follow-up time	Number of failure	Total crown exposure time	Estimated failure rate (per 100 crown years)	Estimated survival rate after 5 years (in percent)
Prospective Studies						
Jung et al. (2012b)	29	4.7	0	137	0	100.0
Vigolo & Givani (2009)	182	5	0	910	0	100.0
Degidi et al. (2008)	45	5	0	225	0	100.0
Schropp & Isidor (2008)	42	4.7	2	200	1	95.1
Kreissl et al. (2007)	46	5	1	230	0.43	97.8
Wennström et al. (2005)	44	5	1	208	0.48	97.6
Gotfredsen (2004)	20	5	1	98	1.02	95.0
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
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	**754**	**5.1**	**28**	**3664**		
Summary estimate (95% CI)*					**0.76 (0.38–1.54)**	**96.3% (92.6–98.1%)**
Retrospective Studies						
Schneider et al. (2011)	100	6.2	6	620	0.97	95.3
Krennmair et al. (2010)	112	5.7	0	642	0	100.0
Schmidlin et al. (2010)	39	6.2	2	243	0.82	96.0
Urdaneta et al. (2010)	326	5.9	16	1921	0.83	95.9
Hälg et al. (2008)	22	5	1	111	0.9	95.6
Bernard et al. (2004)	32	5	0	158	0	100.0
Total	**631**	**5.7**	**25**	**3695**		
Summary estimate (95% CI)*					**0.68 (0.41–1.10)**	**96.7% (94.6–97.7%)**
Total	**1385**	**5.3**	**53**	**7359**		
Overall summary estimate (95% CI)*					**0.75 (0.48–1.18)**	**96.3% (94.2–97.6%)**

*Based on standard Poisson regression, test for heterogeneity $P = 0.024$

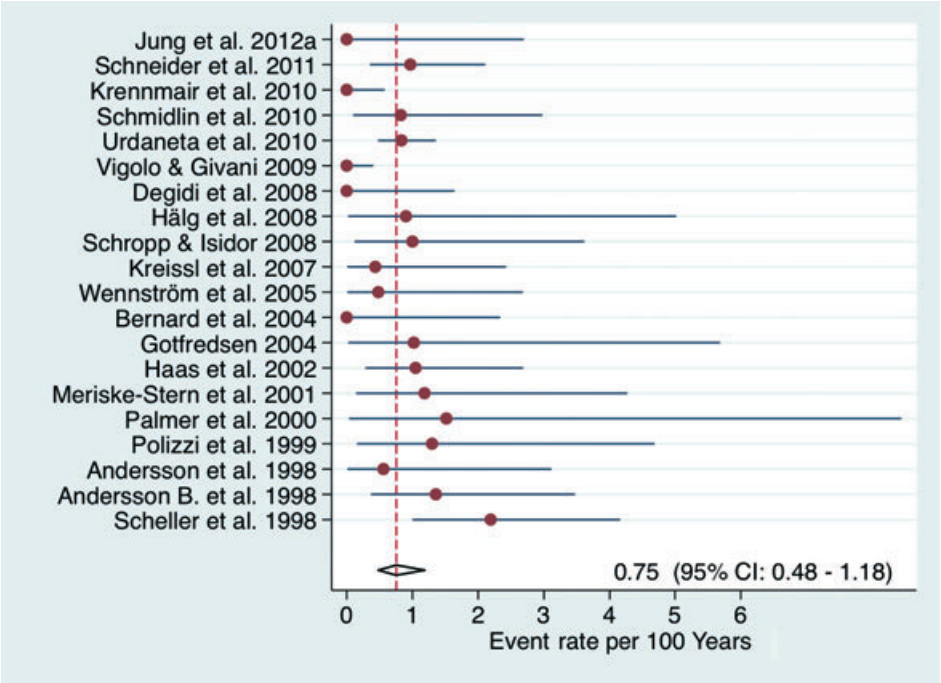

Fig. 4. Annual failure rates (per 100 years) of SCs after 5 years.

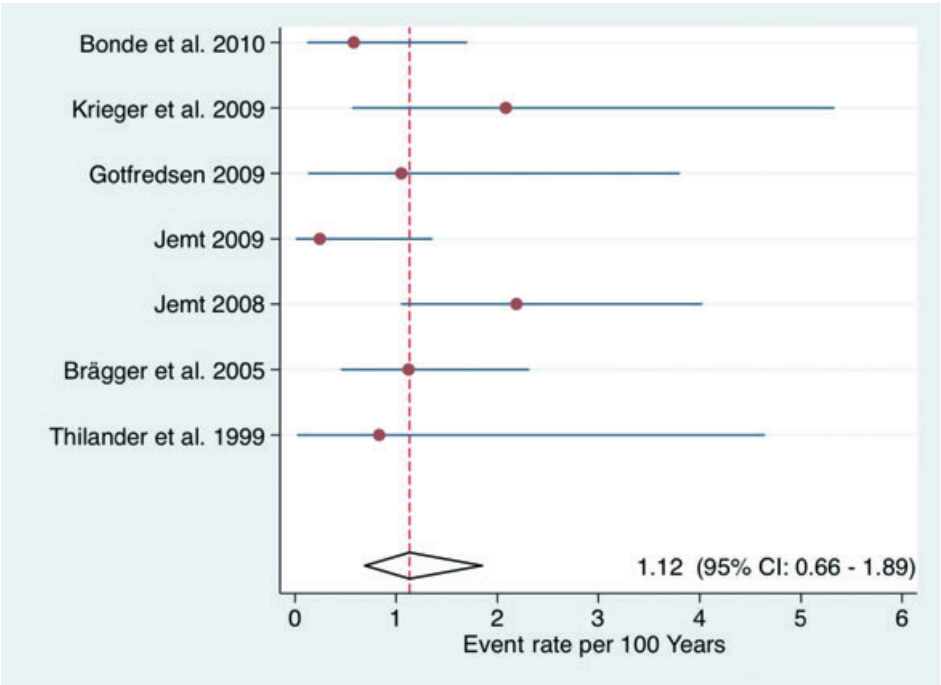

Fig. 5. Annual failure rates (per 100 years) of SCs after 10 years.

5-year aesthetic complication rate was 7.1% (95% CI: 3.6–13.6%) (Table 7).

Technical outcomes

A variety of technical complications were reported in 36 studies. The most common technical complication was abutment- or screw-loosening, reaching a cumulative incidence of 8.8% (95% CI: 5.1–15.0%) after 5 years (Table 8). Although no such complications were reported in six studies, one study was a clear outlier with an estimated rate of 18.03 (Henry et al. 1996). In that study, SCs were mounted on Brånemark implants using gold screws.

The second most common technical complication was loss of retention (fracture of the luting cement), reported in 13 studies and reaching a cumulative incidence of 4.1% (95% CI: 2.2–7.5%) after 5 years (Table 8).

The third most common technical complication was reported for fracture of the veneering material (acrylic or ceramic chippings). The cumulative complication rate amounted to 3.5% (95% CI: 2.4–5.2%) after 5 years. These incidences include minor (chippings that can be polished) and major (repair necessary) fractures of the veneering material. No statistically significant differences with respect to the incidence of veneer fractures were observed between porcelain fused to metal crowns and all-ceramic crowns ($P > 0.05$). Fracture of the framework material was reported in 16 studies, but it only happened in 6 studies, resulting in a cumulative complication rate of 3.5% (95% CI: 2.4–4.1%) after 5 years. The incidence of framework fractures between porcelain fused to metal crowns and all-ceramic crowns was not statistically significantly different ($P > 0.05$).

Additional technical complications were rarely observed. The cumulative 5-year complication rates amounted to 0.18% (95% CI: 0.03–0.4%) for implant fractures and to 0.18% (95% CI: 0.03–0.4%) for abutment or screw fractures. Loss of the access hole restoration was never observed and only reported by three studies.

Discussion

This systematic review addressed the survival and complication rates of implant-supported SCs based on clinical studies with a mean observation period of at least 5 years. The outcomes of the meta-analysis demonstrated both high implant survival rates for single tooth implants and high survival rates of the respective SCs after 5 and 10 years. It must be noted, however, that the most common complications reached 8.8% (technical), 7.1% (biological), and 7.1% (aesthetic) over 5 years.

Implant survival

The calculated implant survival based on 46 included studies with a mean observation period of 5 years amounted 97.2% (95% CI: 96.3–97.9%) after 5 years and 95.2% (95% CI: 91.8–97.2%) after 10 years. The implant survival rate at 5 years was based on 2803 implants and even slightly higher than that in the previous systematic review (96.8%) with a lower number of implants (1558) (Jung et al. 2008a). Based on 10 studies, the estimated implant survival rate after 10 years

Table 6. **Annual failure rates and 10-year survival of implant-supported SCs**

Study	Total number of single crowns	Mean follow-up time	Number of failure	Total crown exposure time	Estimated failure rate (per 100 crown years)	Estimated survival rate after 5 years (in percent)
Prospective Studies						
Gotfredsen (2009)	20	10	2	190	1.05	90.0
Brägger et al. (2005)	69	10	7	623	1.12	89.4
Thilander et al. (1999)	15	8	1	120	0.83	92.0
Total	**104**	**9.3**	**10**	**933**		
Summary estimate (95% CI)*					**1.07 (0.97–1.19)**	**89.8% (88.8–90.8%)**
Retrospective Studies						
Bonde et al. (2010)	52	9.4	3	515	0.58	94.3
Krieger et al. (2009)	24	8	4	192	2.08	81.2
Jemt (2009)	41	10	1	410	0.24	97.6
Jemt (2008)	47	12.3	10	457	2.19	80.3
Total	**164**	**9.9**	**18**	**1574**		
Summary estimate (95% CI)*					**1.14 (0.48–2.73)**	**89.2% (76.1–95.3%)**
Total	**268**	**9.4**	**28**	**2507**		
Overall summary estimate (95% CI)*					**1.12 (0.66–1.89)**	**89.4% (82.8–93.6%)**

*Based on standard Poisson regression, test for heterogeneity $P = 0.105$

could be calculated, and revealed an even lower estimated annual failure rate (per 100 implant years) of 0.49 after 10 years compared to 0.56 after 5 years. It is not uncommon to observe higher implant failure rates in shorter termed studies, because in this review roughly half of all implant failures were early failures before loading. With a respective 10-year implant survival rate of 95.2% this treatment modality can be considered as safe and predictable. The lowest implant survival rate of all included studies was 85.5% after 10 years (Krieger et al. 2009). This particular retrospective study exclusively reported on patients with birth defects affecting the formation of teeth. They concluded that especially in cases with cleft lip, alveolus, and palate (CLAP), in which anatomical conditions render implant placement difficult and in which teeth adjacent to the cleft require aesthetic corrections, the conventional FDP on teeth might be the treatment of choice.

SC survival

In this systematic review, the survival rate for implant-supported SCs was 96.3% after 5 years of loading. This value is slightly higher compared to the results of the previous systematic review reporting a survival rate of 94.5% after 5 years for implant-supported SCs (Jung et al. 2008a). Based on this comparison and on Table 5, a trend can be recognized with newer studies reporting higher survival rates for implant-supported SCs. Consequently, the highest failure rate after 5 years (10.4%) was reported by the oldest included study within this systematic review (Scheller et al. 1998). This trend might be explained by the fact that newer studies included implant systems with improved implant types and designs as well as enhanced prosthetic components, which may allow reducing the incidence of failures.

After 10 years, this meta-analysis reveals a survival rate for implant-supported SCs of 89.4% derived from seven studies including 268 implant-supported SCs. This is an important number when it comes to the decision-making process between the different treatment modalities for a single tooth gap. Hence, the 10-year outcome for the implant-supported SCs must be compared to the outcomes of conventional and cantilever FDPs. The meta-analysis of conventional FDPs indicated an estimated survival rate of 89.1% (95% CI: 81.0–93.8%) after 10 years (Tan et al. 2004). The estimated survival rate of cantilever FDPs was 81.8% (95% CI: 78.2–84.9%) after 10 years (Pjetursson et al. 2004). This comparison of the survival rates after 10 years demonstrates that the calculated numbers for the implant-supported SCs are very similar to the ones from the conventional FDPs and more favorable compared to cantilever FDPs.

Biological outcomes

Biological complications have been reported in the dental literature very inconsistently and without any standardization and classification. This results in a large variety of clinical reports ranging form signs of inflammation, mucosa inflammation, mucositis, bleeding, and suppuration to soft tissue dehiscences. Summarizing all these complications independent of their severity, the cumulative soft tissue complication rate was 7.1% after 5 years. Compared to the previous systematic review demonstrating a soft tissue complication rate of 9.7% after 5 years, there is also a trend to less soft tissue complications when more and especially newer studies are analyzed (Jung et al. 2008a).

Looking at the cumulative 5-year complication rates of implants with bone loss exceeding 2 mm can identify the same trend. This review revealed a complication rate of 5.2% after 5 years, whereas in the former review a complication rate of implants having bone loss >2 mm of 6.3% was calculated (Jung et al. 2008a).

The type of fixation of the reconstruction (cemented, screw-retained) did not have any significant influence on the estimated rate of biological complications ($P > 0.05$).

Aesthetic outcomes

The aesthetic outcome has certainly been not only considered as the major focus from a patient's perspective but also from the clinician's side. Currently available indices to rate the aesthetic outcomes of SCs include measurements of the papilla height and questionnaires for patients and lay persons (Jemt 1999; Schropp & Isidor 2008; Gotfredsen 2009; MacDonald et al. 2009; Krennmair et al. 2010). In this systematic review, a variety of the included publications reported on aesthetic complications (e.g., dehiscences of the soft tissue with exposure of the crown margin, suboptimal color of the prosthetic reconstruction) and on general aesthetic outcomes (e.g., papilla height measurements, questionnaires). However, due to a lack of standardized parameters and indices to evaluate the aesthetic appearance, a large heterogeneity exists between the different studies. This may limit the scientific value of the calculated cumulative 5-year aesthetic complication rate of 7.1%, because this is based on various

Table 7. **Biological and aesthetic complications**

Study	Total number of implants	Total implant exposure time	Estimated rate of bone loss >2 mm (per 100 implant years)	Estimated rate of soft tissue complications (per 100 implant years)	Estimated rate of aesthetic complications (per 100 crown years)
Jung et al. (2012a)	20	250	1.2	NR	1.29
Schneider et al. (2011)	100	620	1.77	0	NR
Bonde et al. (2010)	55	515	NR	1.36	NR
Matarasso et al. (2010)	80	773	3.49	NR	NR
Schmidlin et al. (2010)	39	243	NR	2.06	0
MacDonald et al. (2009)	20	154	0.65	NR	NR
Gotfredsen (2009)	20	200	0.5	1	NR
Hälg et al. (2008)	22	111	0	NR	NR
Jemt (2009)	41	410	0.49	0.98	0.49
Jemt (2008)	47	576	0	2.26	1.97
Schropp & Isidor (2008)	45	210	0.95	1.43	1
Bornstein et al. (2005)	39	190	0	0	NR
Elkhoury et al. (2005)	39	195	3.08	NR	NR
De Boever & deBoever (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	NA	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
Summary estimate event rates (95% CI)			**1.06* (0.62–1.79)**	**1.47* (0.90–2.39)**	**1.47* (0.74–2.92)**
Cumulative 5 year complication rates (95% CI)			**5.2%* (3.1–8.6%)**	**7.1%* (4.4–11.3%)**	**7.1%* (3.6–13.6%)**

NR, not reported; NA, not analyzed;
*Based on random-effects Poisson regression.

measurements and parameters. A scientific consensus on an accepted and reproducible method to evaluate the aesthetic outcome of SCs on the soft tissue level and on the level of the crown itself would therefore be needed.

Technical outcomes

In agreement with previous systematic reviews, this study also revealed that abutment- or screw-loosening are the most common technical complications (Berglundh et al. 2002; Jung et al. 2008a; Sailer et al. 2009). For implant-supported SCs the incidence of abutment or screw-loosening was 8.8% after 5 years. However, it must be emphasized that two studies using an old gold-screw design were mainly responsible for the high number of screw-loosening (Henry et al. 1996; Jemt 2008).

When it comes to the comparison of all-ceramic vs. porcelain-fused to metal (PFM) crowns, the overall survival rate, the fracture rate of the veneering ceramic, and the incidence of framework fractures are of primary interest. The type of the reconstruction did not influence the survival rate of SCs based on standard Poisson regression. This is in contrast to the previously published systematic review (Jung et al. 2008a), but in agreement with a more recently published systematic review focusing specifically on the comparison between metal-ceramic and all-ceramic reconstructions (Sailer et al. 2009). In the latter, no statistically significant differences were found between metal-ceramic and all-ceramic crowns based on the calculated estimated 5-year cumulative survival rate (Sailer et al. 2009). The overall cumulative fracture rate of the veneering material amounted to 3.5% after 5 years with no statistically significant differences between all-ceramic and PFM crowns. This was also true for the incidence of framework fractures (3.5% after 5 years) with no significant difference between all-ceramic and PFM crowns. This is confirmed by a recent systematic review comparing the performance of all-ceramic and metal abutments and the corresponding reconstructions (Sailer et al. 2009). They provided no statistically significant differences for technical complications of ceramic and metal abutments after at least 3 years. However, it was emphasized that the information for ceramic abutments was limited in the number of studies and abutments analyzed as well as the accrued follow-up time.

Conclusion

The outcomes of the meta-analysis demonstrated both, high implant survival rates for single tooth implants and the respective single crowns after 5 and 10 years. Despite varying rates of technical, biological, and aesthetic complications that need to be expected, this treatment modality for the restoration of a single tooth gap can be considered as a safe and predictable therapeutic option.

Clinical recommendations

Considering high implant and SC survival rates observed in prospective and retrospective studies with a mean follow-up of 5 and 10 years, this treatment modality can be recommended for single tooth gaps. Clinicians must be aware that complications may occur to various extents. Most notably, abutment and screw-loosening were reported with the highest technical complications. Although the dental literature reports soft tissue and

Table 8. **Technical complications**

Study	Total number of implants	Estimated rate of implant fracture (per 100 implant years)	Total number 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)	Estimated rate of loss of access hole restoration (per 100 crown years)
Schneider et al. (2011)	100	0	100	0	1.29	0.81	0.65	0	0
Bonde et al. (2010)	55	0	52	0	0.58	NR	0.58	0.19	NR
Krennmair et al. (2010)	112	0	112	0	0.78	1.71	0.78	0	NR
Schmidlin et al. (2010)	39	0	39	0	0.82	0.41	0.82	0	0
Urdaneta et al. (2010)	326	0	326	0.16	0.94	NR	0.94	NR	NR
MacDonald et al. (2009)	20	0	20	0	1.3	NR	0	0	0
Vigolo & Givani (2009)	182	0	182	0	0	0	0	1.39	NR
Gotfredsen (2009)	20	0	20	0	1.05	1.05	1.58	0	NR
Hälg et al. (2008)	22	0.9	22	0	0	0	0	0	NR
Jemt (2009)	41	0	41	0	1.22	NR	NR	NR	NR
Jemt (2008)	47	0	47	NR	6.13	NR	NR	NR	NR
Schropp & Isidor (2008)	45	0	42	0	0	1.5	0	0	NR
Kreissl et al. (2007)	46	0	46	0.87	2.61	NR	0.87	0	NR
Romeo et al. (2006)	58	0	58	NR	NR	0.36	1.39	NR	NR
Wagenberg & Froum (2006)	401	0	383	NR	NR	NR	NR	NR	NR
Bornstein et al. (2005)	39	0	39	NR	NR	NR	NR	NR	NR
Elkhoury et al. (2005)	39	0	39	NR	NR	NR	NR	NR	NR
De Boever & de Boever (2005)	10	0	10	NR	NR	NR	NR	NR	NR
Wennström et al. (2005)	45	0	44	0	1.44	NR	NR	0	NR
Jemt & Lekholm (2005)	10	0	10	NR	NR	NR	NR	NR	NR
Brägger et al. (2005)	69	NR	69	0	0.48	0	0.48	0	NR
Taylor et al. (2004)	39	0	38	NR	NR	NR	NR	NR	NR
Bernard et al. (2004)	32	0	32	NR	NR	NR	NR	NR	NR
Romeo et al. (2004)	123	0	121	0	0	0.56	0.28	NR	NR
Bianchi & Sanfilippo (2004)	94	0	94	NR	NR	NR	NR	NR	NR
Gotfredsen (2004)	20	0	20	NR	NA	NA	NA	NA	NR
Haas et al. (2002)	76	0.26	77	NR	3.14	NR	NR	NR	NR
Gibbard & Zarb (2002)	49	0	48	NR	1.39	NR	NR	NR	NR
Palmer et al. (2000)	15	0	15	0	0	1.52	NR	1.52	NR
Vigolo & Givani (2000)	52	0	52	0	0.41	2.86	NR	NR	NR
Thilander et al. (1999)	15	0	15	NR	NR	NR	NR	NR	NR
Polizzi et al. (1999)	30	0.63	30	0.65	0	NR	0	NR	NR
Andersson et al. (1998a)	38	0	38	NR	NR	NR	NR	0.56	NR
Andersson et al. (1998b)	65	0	65	0	0.34	NR	0.34	0.68	NR
Scheller et al. (1998)	99	NR	97	NR	0.97	0.73	1.7	1.7	NR
Henry et al. (1996)	107	0	106	0.21	18.03	NR	1.89	NR	NR
Summary estimate event rates (95% CI)		**0.03* (0.007–0.19)**		**0.08* (0.027–0.23)**	**1.84* (1.04–3.25)**	**0.84* (0.45––1.56)**	**0.72* (0.48–1.08)**	**0.26* (0.08–0.84)**	**0 (0–0.36)**
Cumulative 5 year complication rates (95% CI)		**0.18%* (0.03–0.4%)**		**0.4%* (0.14–1.1%)**	**8.8%* (5.1–15.0%)**	**4.1%* (2.2––7.5%)**	**3.5%* (2.4–5.2%)**	**1.3%* (0.4–4.1%)**	**0%**

NR, not reported; NA, not analyzed;
*Based on random-effects Poisson regression.

aesthetic complications very inconsistently and without any standardization and classification, these complications have to be considered and strengthen the need for a well-established maintenance program.

Research recommendations

The outcomes of this systematic review are based on a large variety of studies with differing levels of evidence. Although basic biological parameters (e.g., marginal bone levels) were frequently reported in the studies, technical outcome measures were inconsistently analyzed. In addition, many of the long-term studies include reconstruction materials that are no longer in use. It is therefore of great interest to perform prospective long-term studies evaluating current implant types, design, and prosthetic components and to assure that standardized technical, biological, and aesthetic outcome measures are used.

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

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Aglietta, M., Siciliano, V.I., Rasperini, G., Cafiero, C., Lang, N.P. & Salvi, G.E. (2011) A 10-year retrospective analysis of marginal bone-level changes around implants in periodontally healthy and periodontally compromised tobacco smokers. *Clinical Oral Implants Research* **22**: 47–53. [Exclusion criteria: no information on prosthetics.]

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Cosyn, J. & De Rouck, T. (2009) Aesthetic outcome of single-tooth implant restorations following early implant placement and guided bone regeneration: crown and soft tissue dimensions compared with contralateral teeth. *Clinical Oral Implants Research* **20**: 1063–1069. [Exclusion criteria: follow-up <5 years.]

Creton, M., Cune, M., Verhoeven, W., Muradin, M., Wismeijer, D. & Meijer, G. (2010) Implant treatment in patients with severe hypodontia: a retrospective evaluation. *Journal of Oral and Maxillofacial Surgery* **68**: 530–538. [Exclusion criteria: no detailed information on prosthetics]

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Degidi, M., Nardi, D. & Piattelli, A. (2008a) Peri-implant tissue and radiographic bone levels in the immediately restored single-tooth implant: a retrospective analysis. *Journal of Periodontology* **79**: 252–259. [Exclusion criteria: follow-up < 5 years.]

Degidi, M., Piattelli, A. & Carinci, F. (2008b) Clinical outcome of narrow diameter implants: a retrospective study of 510 implants. *Journal of Periodontology* **79**: 49–54. [Exclusion criteria: no information on prosthetics.]

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Deporter, D., Ogiso, B., Sohn, D.S., Ruljancich, K. & Pharoah, M. (2008) Ultrashort sintered porous-surfaced dental implants used to replace posterior teeth. *Journal of Periodontology* **79**: 1280–1286. [Exclusion criteria: < 10 patients with SCI.]

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Doyle, S.L., Hodges, J.S., Pesun, I.J., Law, A.S. & Bowles, W.R. (2006) Retrospective cross sectional comparison of initial nonsurgical endodontic treatment and single-tooth implants. *Journal of Endodontics* **32**: 822–827. [Exclusion criteria: chart review (no clinical examination).]

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Farino, M., Branscum, A., Robinson, F.G., Jasper, S., Al-Sabbagh Dds, M., Puleo, D.A.& Thomas, M.V. (2010) Programmatic effectiveness of a university-based implant training program: long-term, patient-centered outcomes. *Journal of Long-Term Effects of Medical Implants* **20**: 343–351. [Exclusion criteria: no detailed information on prosthetics.]

Franchini, I., Capelli, M., Fumagalli, L., Parenti, A. & Testori, T. (2011) Multicenter retrospective analysis of 201 consecutively placed camlog dental implants. *The International Journal of Periodontics & Restorative Dentistry* **31**: 255–263. [Exclusion criteria: no detailed information on prosthetics.]

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Franco, M., Viscioni, A., Rigo, L., Guidi, R., Zollino, I., Avantaggiato, A.& Carinci, F. (2009b) Clinical outcome of narrow diameter implants inserted into allografts. *Journal of Applied Oral Science: Revista Fob* **17**: 301–306. [Exclusion criteria: no detailed information on prosthetics.]

Friberg, B. & Jemt, T. (2010) Clinical experience of TiUnite implants: a 5-year cross-sectional, retrospective follow-up study. *Clinical implant dentistry and related research* **12**(Suppl 1): e95–103. [Exclusion criteria: no detailed information on prosthetics.]

Froum, S.J., Cho, S.C., Cho, Y.S., Elian, N. & Tarnow, D. (2007) Narrow-diameter implants: a restorative option for limited interdental space. *The International Journal of Periodontics & Restorative Dentistry* **27**: 449–455. [Exclusion criteria: follow-up < 5 years.]

Fugazzotto, P.A. (2008a) Implant placement at the time of maxillary molar extraction: treatment protocols and report of results. *Journal of Periodontology* **79**: 216–223. [Exclusion criteria: follow-up < 5 years]

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Gatti, C., Gatti, F., Chiapasco, M. & Esposito, M. (2008) Outcome of dental implants in partially edentulous patients with and without a history of periodontitis: a 5-year interim analysis of a cohort study. *European Journal of Oral Implantology* **1**: 45–51. [Exclusion criteria: no detailed information on prosthetics.]

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Gianserra, R., Cavalcanti, R., Oreglia, F., Manfredonia, M.F. & Esposito, M. (2010) Outcome of dental implants in patients with and without a history of periodontitis: a 5-year pragmatic multicentre retrospective cohort study of 1727 patients. *European Journal of Oral Implantology* **3**: 307–314. [Exclusion criteria: no detailed information on prosthetics.]

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Grant, B.T., Pancko, F.X. & Kraut, R.A. (2009) Outcomes of placing short dental implants in the posterior mandible: a retrospective study of 124 cases. *Journal of Oral and Maxillofacial Surgery* **67**: 713–717. [Exclusion criteria: follow-up < 5 years.]

Grossmann, Y. & Levin, L. (2007) Success and survival of single dental implants placed in sites of previously failed implants. *Journal of Periodontology* **78**: 1670–1674. [Exclusion criteria: follow-up < 5 years.]

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Hu, X.L., Li, J.H., Luo, J., Qiu, L.X. & Lin, Y. (2011) Multidisciplinary management of congenitally missing teeth with osseointegrated dental implants: a long-term report. *The Chinese journal of dental research: the official journal of the Scientific Section of the Chinese Stomatological* **14**: 29–36. [Exclusion criteria: < 10 patients with SCI.]

Hussaini, S., Weiner, S. & Ahmad, M. (2010) Implant survival rates in a condensed surgical and prosthetic training program for general practitioners in dental implants. *Implant Dentistry* **19**: 73–80. [Exclusion criteria: no information on prosthetics.]

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Jemt, T., Ahlberg, G., Henriksson, K. & Bondevik, O. (2007) Tooth movements adjacent to single-implant restorations after more than 15 years of follow-up. *The International Journal of Prosthodontics* **20**: 626–632. [Exclusion criteria: multiple publications on same patient cohort.]

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Juodzbalys, G., Raustia, A.M. & Kubilius, R. (2007) A 5-year follow-up study on one-stage implants inserted concomitantly with localized alveolar ridge augmentation. *Journal of Oral Rehabilitation* **34**: 781–789. [Exclusion criteria: no information on prosthetics.]

Kacer, C.M., Dyer, J.D. & Kraut, R.A. (2010) Immediate loading of dental implants in the anterior and posterior mandible: a retrospective study of 120 cases. *Journal of Oral and Maxillofacial Surgery* **68**: 2861–2867. [Exclusion criteria: no detailed information on prosthetics]

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Knauf, M., Gerds, T., Muche, R. & Strub, J.R. (2007) Survival and success rates of 3i implants in partially edentulous patients: results of a prospective study with up to 84-months' follow-up. *Quintessence International* **38**: 643–651. [Exclusion criteria: no information on prosthetics.]

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