GROUP 2

Restorative Materials and Techniques for Implant Dentistry

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Clinical Performance of Screw- Versus Cement-Retained Fixed Implant-Supported Reconstructions—A Systematic Review

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Purpose: *To assess the survival outcomes and reported complications of screw- and cement-retained fixed reconstructions supported on dental implants.* ***Materials and Methods:*** *A Medline (PubMed), Embase, and Cochrane electronic database search from 2000 to September 2012 using MeSH and free-text terms was conducted. Selected inclusion and exclusion criteria guided the search. All studies were first reviewed by abstract and subsequently by full-text reading by two examiners independently. Data were extracted by two examiners and statistically analyzed using a random effects Poisson regression.* ***Results:*** *From 4,324 abstracts, 321 full-text articles were reviewed. Seventy-three articles were found to qualify for inclusion. Five-year survival rates of 96.03% (95% confidence interval [CI]: 93.85% to 97.43%) and 95.55% (95% CI: 92.96% to 97.19%) were calculated for cemented and screw-retained reconstructions, respectively (P = .69). Comparison of cement and screw retention showed no difference when grouped as single crowns (I-SC) (P = .10) or fixed partial dentures (I-FDP) (P = .49). The 5-year survival rate for screw-retained full-arch reconstructions was 96.71% (95% CI: 93.66% to 98.31). All-ceramic reconstruction material exhibited a significantly higher failure rate than porcelain-fused-to-metal (PFM) in cemented reconstructions (P = .01) but not when comparing screw-retained reconstructions (P = .66). Technical and biologic complications demonstrating a statistically significant difference included loss of retention (P ≤ .01), abutment loosening (P ≤ .01), porcelain fracture and/or chipping (P = .02), presence of fistula/suppuration (P ≤ .001), total technical events (P = .03), and total biologic events (P = .02).* ***Conclusions:*** *Although no statistical difference was found between cement- and screw-retained reconstructions for survival or failure rates, screw-retained reconstructions exhibited fewer technical and biologic complications overall. There were no statistically significant differences between the failure rates of the different reconstruction types (I-SCs, I-FDPs, full-arch I-FDPs) or abutment materials (titanium, gold, ceramic). The failure rate of cemented reconstructions was not influenced by the choice of a specific cement, though cement type did influence loss of retention.* INT J ORAL MAXILLOFAC IMPLANTS 2014;29(SUPPL):84–98. doi: 10.11607/jomi.2014suppl.g2.1

Key words: *cement, dental implants, fixed dental prostheses, prosthodontics, screw, single crown*

Implant-supported reconstructions are well-established treatment options and have evolved to a standard of care in dental medicine. The possibilities and expectations of achieving a successful, functional, and stable treatment outcome have increased with the evolution of implant surfaces and designs, prosthetic components, clinical techniques, and dental materials. One of the important decisions in implant prosthodontics is the choice of the connection type of the final restoration to the implant via the screw-retained abutment. The restorative connection can be either screw- or cement-retained. With screw-retained restorations, an abutment or a mesostructure may be separate to the restoration (two-piece) or combined as part of the fabrication procedure (one-piece). In general, both retention types have their advantages and limitations.[1–5]

Despite patients showing no preference for either retention system,[6] there are relevant clinical and technical issues. These include ease of fabrication,

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precision, passivity of the framework, retention provided by cement and abutment, occlusion, esthetics, accessibility, retrievability, complications, and cost. These are not easily examined objectively together, and to single out the effect of a specific factor seems to be very demanding. A previous systematic review has focused on implant and prosthesis survival, finding no statistically significant differences between screw and cement retention.[7] In vitro and animal studies have been conducted to more closely examine technical and biologic complications in screw- and cement-retained prostheses.[8–10] While these may give useful information to help design future human trials, this information cannot routinely be related to a clinical situation.

The survival rates of implant-supported reconstructions and the associated technical complication rates have been well established. Implant-supported single crowns (I-SC), fixed partial dentures (I-FDP), and I-FDPs with cantilever extensions demonstrate survival rates of 94.5%, 95.2%, and 94.3% at 5 years, respectively.[11–13] The prevalence of technical complications is higher for implant reconstructions compared to those on teeth,[12] and the most commonly reported technical complications are veneer fracture, screw loosening, and loss of retention.[11–13] With respect to biologic complications, peri-implantitis and bone loss are reported to have the highest prevalence.[11,14] Although these figures are now commonly cited, they have not been attributed to screw or cement retention.

A recent and comprehensive systematic review on this subject was presented at the European Association of Osseointegration Consensus Conference 2012.[15] This review focused on implant and reconstruction survival, reporting estimated rates for 5 and 10 years, as well as technical and biologic complications in studies with a mean follow-up of at least 1 year. The authors grouped the event rate data by cement- or screw-retained single crowns, I-FDPs, and full arch I-FDPs. No statistically significant differences were reported for restoration survival. Estimated biologic complication rates (bone loss > 2 mm) were found to be higher in cemented reconstructions, whereas screw-retained reconstructions exhibited more technical complications. Based on their improved retrievability, the screw-retained reconstructions were given preference.

The objective of the present review was to retrieve a detailed data pool from published clinical studies on biologic and technical failure and complication rates observed with cement- and screw-retained fixed implant-supported reconstructions. The aim was also to associate the observed differences in the estimated event risks with a list of additional prosthetic characteristics such as type of reconstruction, material of the supra-structure (restorative and abutment material), and cement type.

MATERIALS AND METHODS

A PICO (population, intervention, comparison, and outcome) question was agreed upon between the authors. This question asked what the clinical performance (including complications and failures) of implant-supported reconstructions was in patients with edentulous sites treated with either screw or cement retention.

Systematic Search Design and Strategy

An electronic search of publications from 2000 to September 2012 was established using three electronic databases: EMBASE, Medline (via PubMed), and the Cochrane Library. The search included peer-reviewed publications in the English, German, and French languages. MeSH and free-text terms were used in the search and included the terms listed in Table 1.

The search was then narrowed by exclusion of non-dental studies by adding the terms "dental" OR "dentist*" OR "tooth" OR "teeth." All articles were selected by well-defined inclusion and exclusion criteria (Table 1).

The inclusion criteria included study designs of randomized controlled trials (RCTs), clinical trials, prospective studies, and retrospective cohort studies. Patients in the studies had to have been followed clinically for the observation period. Studies using telephone interviews or patient records were not included.

Other inclusion criteria for study selection were studies with:

- A mean follow-up time of at least 3 years
- A minimum number of 10 patients
- A report of the restoration retention used (screw or cement)
- Implant-supported fixed reconstructions
- English, German, or French language

Case reports, animal studies, in vitro studies, abstracts, and letters were excluded from review. Studies with a mean follow-up of < 3 years; not reporting on retention type; not written in English, German, or French; or examining removable prostheses were also excluded from the review. Data from patient cohorts used for repeated publications were limited to the most recent version.

The selection strategy of the articles is outlined in Fig 1. Following the electronic search, titles and abstracts were screened by two independent reviewers (JW, UB) to assess their suitability for inclusion in the review. Following discussion, a consensus was reached regarding disputed articles. Subsequently, a full-text search was performed by two reviewers (JW, CM). In addition, a manual search (CM) was conducted of the bibliographies of recently published relevant reviews.

Table 1 Systematic Search Strategy

Focus question	**What is the clinical performance of implant-supported reconstructions (including complications and failures) in patients with edentulous sites treated with either screw or cement retention?**
Search strategy	
Population	#1 (implant*) OR (full arch) OR (cross arch) OR (crossarch) OR (abutment) OR (dental abutments [MeSHTerms]) OR (dental arch [MeSH Terms]) OR (dental implants [MeSH Terms])
Intervention or exposure	#2 (implant supported prosthesis) (Dental Prosthesis, Implant supported [MeSH Terms])OR (insertion) OR (crown [MeSH Terms]) OR (fixed partial dentures) OR (denture, Partial, Fixed [MeSH Terms]) OR (FPD) OR (FDP) OR (bridge) OR (reconstruct*) OR (passive fit) OR (crown margin) OR (marginal adapation[MeSH Terms]) OR (interface*) OR (implant bridge) OR (laborator*) OR (friction[MeSH Terms]) OR (clamping force) OR (fixture) OR (insert lodges) OR (suprastructure)
Comparison	#3 (screw*) OR (cement*) OR (retain*) OR (retention*) OR (fixation) OR (transvers*) OR (retrievab*) OR (torque) OR (transfer) OR (access hole) OR (torque wrench) OR (retrieval) OR (tight*) OR (transocclusal) OR (Bone Screws [MeSH Terms]) OR (dental cements [MeSH Terms]) OR (dental prosthesis retention[MeSH Terms]) OR (denture retention [MeSH Terms]) OR (cementation[MeSH Terms]) OR (torque[MeSH Terms]) OR (seat*)
Outcome	#4 (loss of retention) OR (precision) OR (fit) OR (seal) OR (loosening) OR (fracture) OR (fatigue) OR (leakage) OR (gap) OR (cement rest) OR (deformation) OR (cement dissolution) OR (survival) OR (complicat*) OR (risk) OR (success) OR (rate) OR (failure) OR (prosthesis failure [MeSH Terms]) OR (dental leakage[MeSH Terms]) OR (treatment outcome[MeSH Terms]) OR (dental restoration failure[MeSH Terms])
Search combination	#1 AND #2 AND #3 AND #4
Database search	
Language	English, German, and French
Electronic	EMBASE, Medline (via PubMed), and Cochrane Library
Selection criteria	
Inclusion criteria	RCTs Clinical trials Prospective studies Retrospective studies with patient recall (clinical examination) Written in English, German, or French Minimum follow-up time of 3 y Report of retention type Studies including implant supported fixed reconstructions (single crowns or FDPs) Report of clinical performance (including complications and failure) of fixed implant-supported reconstructions
Exclusion criteria	Not written in English, German, or French Minimum follow-up time < 3 y Studies that were based on patients' charts Case reports Animal studies In vitro studies No report on retention type No report on clinical performance of implant-supported reconstructions Studies on removable reconstructions

The manual search included articles that were published prior to the year 2000.

Data of each individual study were extracted by two authors (CM, JW) and broken down on an Excel (Microsoft) spreadsheet by: author, year, type of study (prospective/retrospective), planned number of patients, actual number of patients, mean age patient, age range patient, study setting (university/private practice), location (anterior/posterior), restoration type, abutment material, restoration material, retention type, cement type, implant brand, implant types, and total implant number. The total exposure time of the reconstructions was calculated, and survival of the restorations was defined as remaining in situ throughout the study period.

Data regarding technical complications were also extracted, including loss of retention, loosening of the occlusal/abutment screws, loss of screw access filling, fracture and/or chipping of the veneer, fracture of the implant/abutment/framework/screw, and any other complications.

The data for biologic complications included bone loss > 2 mm, peri-implantitis, peri-implant mucositis, general soft tissue complications (including fistula-swelling), recession, loss of the implant, any esthetic complication, and any other reported complications.

Statistical Analysis

Failure and complication rates of single studies were calculated by dividing the number of events by the total exposure time of the I-FDPs. Estimated failure rates, event rates, and 95% confidence intervals (CI) were calculated by assuming Poisson distributed number of events. Random effects Poisson regression was used when several studies were summarized.

Five- and 10-year survival rates were calculated through the relationship between event rate and the survival function S by assuming constant event rates as follows:

$$S(T) = \exp(-T \times \text{event rate})$$

All statistical analysis was performed using Stata 11.2. Significance level was set at $P = .05$.

The estimated event rate per 100 years was calculated using the observation time of the studies together with the number of reconstructions observed (eg, 100 reconstructions observed for 1 year each, with only one failure, would have an event rate of 1 per 100 years).

Comparisons included differences in event rates per 100 reconstruction years between cemented and screw-retained reconstructions in total and when grouped according to reconstruction type, reconstruction material, and abutment material. The compared events were failures, single technical and biologic complications, and combined (total) technical and combined (total) biologic complications.

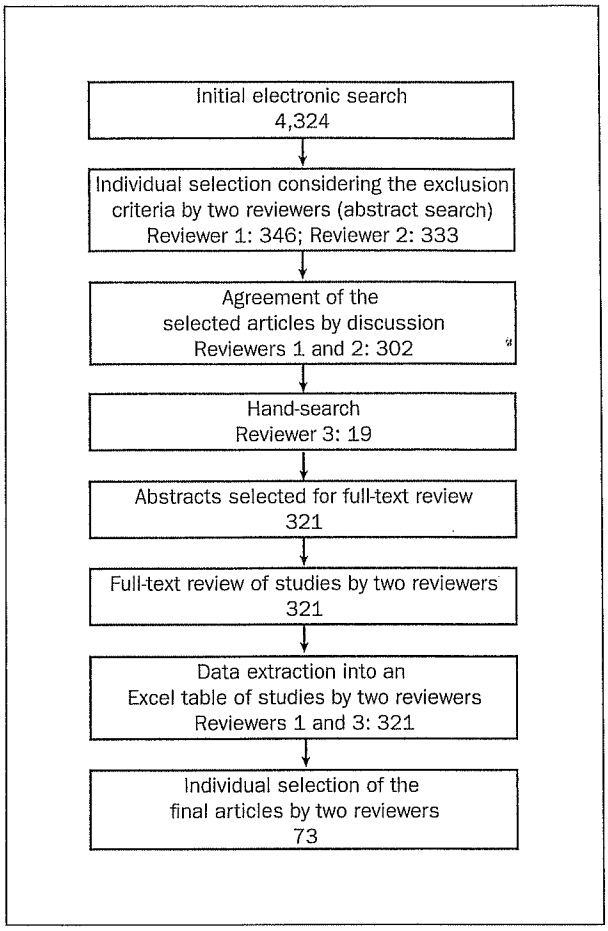

Fig 1 Flow diagram describing the search design and strategy.

RESULTS

The titles and abstracts of 4,324 articles (initial search) were screened independently by two authors (JW, UB) to assess their suitability for inclusion in the review (Fig 1). Following discussion, a consensus was reached regarding disputed articles. There were 302 full-text articles obtained for screening. In addition, a further 19 articles were obtained from a manual search of the bibliographies of review articles identified within the initial search and recently published relevant reviews. Two authors (JW, CM) independently reviewed the 321 articles. Of these full-text articles, 73 were found to qualify for inclusion in the review.

The study designs of these articles were: 52 prospective cohort studies (71.2%), 13 retrospective (17.8%), 2 split-mouth design, and 6 RCT (8.3%) (Table 2). Most studies were carried out in a university setting (63%) (Table 3).

Table 2 Study Designs

	Studies	%
Prospective cohort	52	71.2
Retrospective cohort	13	17.8
Split mouth	2	2.7
RCT	6	8.3
Total	73	100

Table 3 Study Settings

	Studies	%
Private practice	13	17.8
University	46	63.0
Specialist clinic	6	8.2
Multicenter	6	8.2
Not reported	2	2.8
Total	73	100

Failures

A total of 5,858 fixed implant reconstructions were analyzed with a mean exposure time of 5.40 years.

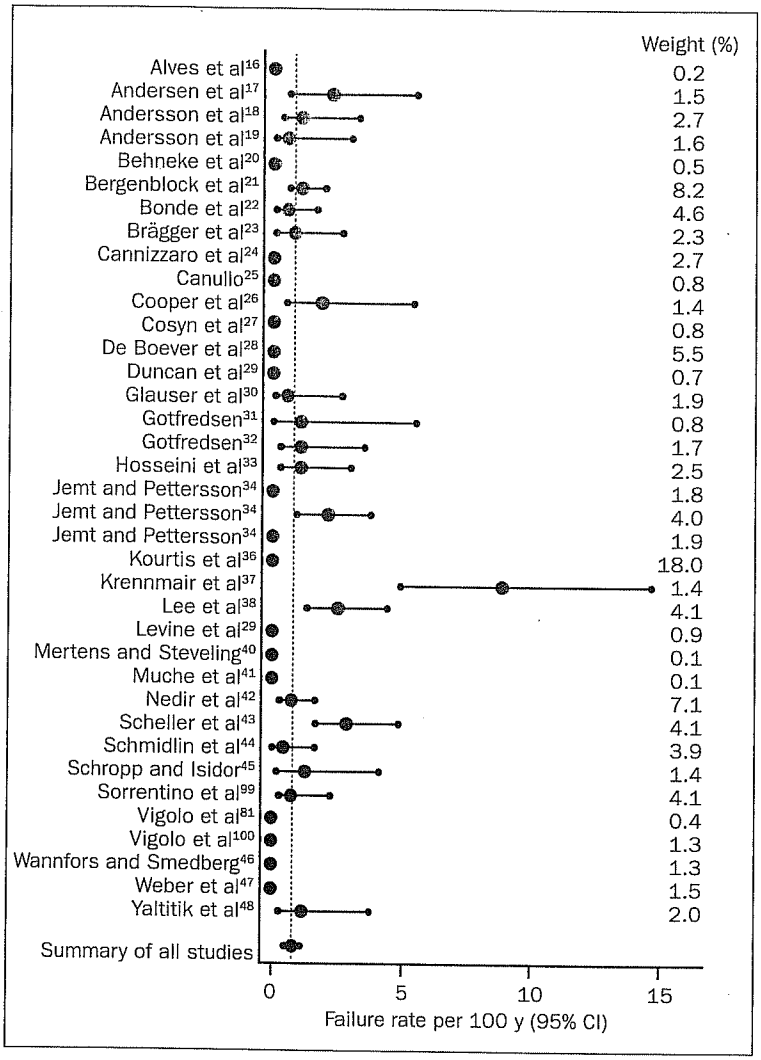

Fig 2 Failure rate and weight of all included studies on cement-retained reconstructions (n = 37).

Of these 3,471 (59%) were screw-retained and 2,387 (41%) were cement-retained. The failure rates and weighting of each study are shown in Figs 2 and 3. Based on a random-effects Poisson regression analysis, overall 5-year survival rates of 96.03% (95% CI: 93.85% to 97.43%) and 95.55% (95% CI: 92.96% to 97.19%) were calculated for cement- and screw-retained reconstructions, respectively. Ten-year survival rates were also estimated and revealed survival rates of 92.22% (95% CI: 88.07% to 94.93%) and 91.30% (95% CI: 86.42% to 94.46%) for cement- and screw-retained reconstructions, respectively. Overall estimated failure rates of 0.81 (95% CI: 0.52 to 1.27) and 0.91 (95% CI: 0.57 to 1.46) per 100 restoration years were calculated for cement- and screw-retained reconstructions, respectively. This difference was not statistically significant ($P = .69$) (Table 4). However the estimated failure rate of two-piece screw-retained reconstructions (0.45 [95% CI: 0.32 to 0.64]) was significantly different compared to the cemented types ($P = .00$).

Of the 5,858 reconstructions, 1,720 were I-SC, 979 were I-FDP, 928 were full-arch reconstructions, and 61 were cantilever I-FDPs (Table 5). In some studies, several types of reconstructions were used and not reported separately in the article. These data have therefore been used for the calculation of the overall reconstruction failure and survival rate of screw versus cement retention but have not been included in the separate reconstruction groups.

Failures by Reconstruction Type

Single Crowns (I-SC). A total of 25 studies reported on cemented and 9 on screw-retained single crowns (I-SC) with a mean follow-up time of 4.92 years. A total of 1,720 SCs were analyzed; 1,316 were cemented and 404 screw-retained. The failure rate of the cemented I-SCs (0.74 [95% CI: 0.44 to 1.24]) was not significantly different from the screw-retained I-SCs (1.85 [95% CI: 0.65 to 5.29]) ($P = .10$) (Table 6). The 5-year survival rate was 96.37% (95% CI: 93.99 to 97.82) for cement- and 91.16% (95% CI: 76.76 to 96.80) for screw-retained single crowns (Table 7).

Fixed Partial Dentures (I-FDP) and Cantilever I-FDP. A total of 19 studies (5 on cemented and 14 on screw-retained) with a mean follow-up time of 5.73 years reported on a total of 1,040 I-FDPs (including cantilever I-FDPs) showing no significant difference between cement (1.11 [95% CI: 0.40 to 3.07]) and screw retention (1.78 [95% CI: 0.59 to 5.34]) ($P = .49$) (Table 6). The 5-year survival rate was 94.60% (95% CI: 85.77% to 98.02%) for cemented and 91.48% (95% CI: 76.57% to 97.09%) for screw-retained I-FDPs (Table 7).

Full-Arch Reconstructions. A total of 22 studies (1 on cemented and 21 on screw-retained) with a mean follow-up time of 7.46 years (Table 6) were obtained. The failure rate was estimated at 0.67 per 100 reconstruction years and the 5-year survival rate was 96.71% (95% CI: 93.66% to 98.31%) (Table 7). Further analysis was not possible due to the low number of studies with cement-retained full-arch reconstructions.

Failures by Material Type

Abutment Material. There was no significant difference between the failure rates of screw-retained reconstructions on either titanium, gold, or ceramic abutments. Neither cemented nor screw-retained reconstructions exhibited a statistically

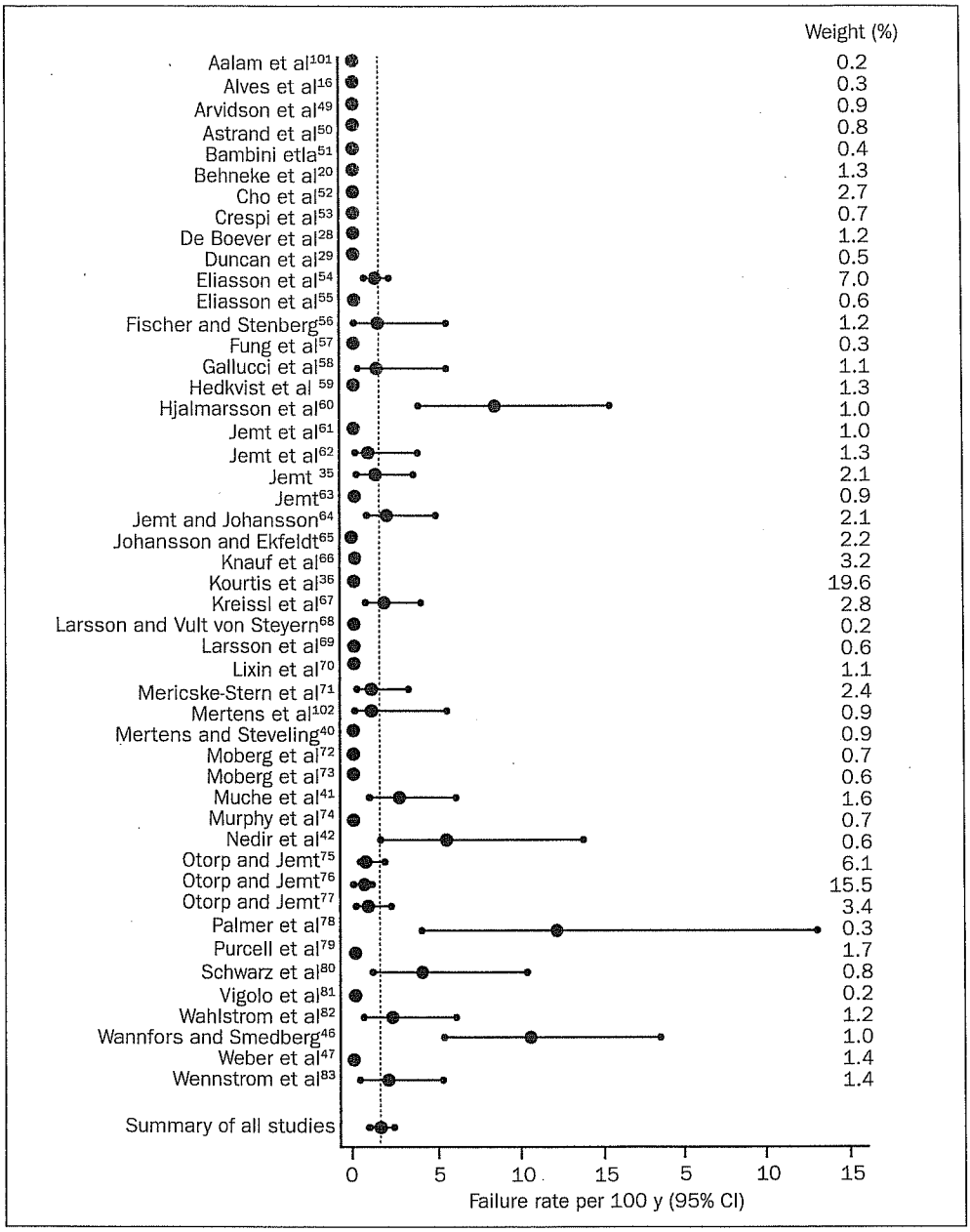

Fig 3 Failure rate and weight of all included studies on screw-retained reconstructions (n = 48).

Table 4 Overall Estimated Failure Rates

Studies	Retention type	Reconstructions	Exposure time (y)	No. of failures	Estimated failure rate per 100 y (95% CI)	*P* value
37	Cement	2,387	11861	102	0.81 (0.52 – 1.27)	
48	Screw	3,471	19799	99	0.91 (0.57 – 1.46)	.69
7	One-piece screw	276	1327	23	2.08 (0.47 – 9.27)	.08*
14	Two-piece screw	932	7481	34	0.45 (0.32 – 0.64)	.00*

*Compared with the estimated event rate of cement reconstructions.

significant difference between material types ($P = .09$ and $P = .06$ for cement and screw, respectively). These results are reported in Table 8.

Prosthetic Material. The use of all-ceramic material exhibited a significantly higher failure rate (0.88 [95% CI: 0.58 to 1.33]) than porcelain-fused-to-metal (PFM)

Table 5 Type of Reconstructions

Reported restoration	Reconstructions	%
I-SC	1,720	29.4
I-FDP	979	16.7
Full-arch	928	15.8
I-SC and full-arch	123	2.1
I-SC and I-FDP	461	7.9
Cantilever I-FDP	61	1.0
I-FDP and full-arch	56	1.0
I-SC, I-FDP, and cantilever	168	2.9
I-SC, I-FDP, full-arch, cantilever	1,308	22.3
Not reported	54	0.9
Total	5,858	100

(0.37 [95% CI: 0.22 to 0.61]) in cemented reconstructions ($P = .01$), whereas there was no significant difference in the failure rates when comparing screw-retained reconstructions fabricated with different materials ($P = .66$) (Table 9).

Cement Material. When examining the differences between failure rates for the cement types (phosphates, glass ionomers, resins and eugenol-based cements), no statistically significant difference was found ($P = .37$) (Table 10).

Complications

The data extraction of the included studies only allowed a statistical analysis if the complications were presented in the study. Where the data was not complete, the statistical analysis was not performed. Therefore, the number of studies and reconstructions varies among the complication types, and this information is listed in Table 11.

Technical Complications. Complications demonstrating a statistically significant difference between cement- and screw-retained reconstructions include loss of retention, abutment loosening, and porcelain fracture and/or chipping, as well as the total events.

The other complications including fracture of abutment, fracture of framework, fracture of implant, screw fracture, and resin chipping and/or fracture did not demonstrate statistical significance. The complications loss of cover of access hole and loosening of occlusal screw could not be compared, as they were only available for screw-retained reconstructions. Here, event rates of 1.76 per 100 reconstruction years could be calculated for loosening of occlusal screw and 0.81 for loss of cover of access hole. A full summary of the data related to technical complications is given in Table 11.

A comparison between loss of retention and cement type was carried out and showed a statistically significant difference between cement type and loss of retention ($P \leq .01$). The estimated event rates per 100 years are outlined in Table 12.

When assessing the overall technical complications between cement- and screw-retained reconstructions, the resin chipping category was removed due to the fact that no further analysis was possible on this category. This comparison of the total events demonstrated a significant difference ($P = .03$) (Table 11). However comparing one- and two-piece screw-retained reconstructions to the cemented ones demonstrated no significant difference (Table 11).

Biologic Complications. When comparing the event rates of biologic complications between screw- and cement-retained reconstructions, only the category for presence of fistula/suppuration demonstrated statistical significance, indicating a higher event rate with cement retention (1.65 [95% CI: 0.55 to 4.96]) ($P \leq .01$). Outcomes of the other event rates of bone loss (> 2 mm), peri-implantitis, presence of fistula/suppuration, peri-implant mucositis, and recession were not statistically significant among the two retention systems.

The summary of the total biological complications as shown in Table 13 shows a statistically significant result ($P = .02$). One- and two-piece screw- retained reconstructions presented no significant difference in comparison to cemented ones (Table 13).

DISCUSSION

The fabrication of an implant-supported reconstruction includes many clinical and laboratory processes and a series of decisions related to the use of implant components, materials, etc. At some point during the treatment planning stage, the treating clinician and the technician must select the method of retention, screw or cement. Both of these methods have their advantages and limitations, and it is therefore the clinician's responsibility to select the most appropriate method of retention for the individual patient.[5]

Screw-retained implant reconstructions have the advantages of predictable retrievability; require a minimal amount of interocclusal space; and are easier to remove when hygiene maintenance, repairs, or surgical interventions are required. Screw-retained implant reconstructions require precise, prosthetically driven placement of the implant due to the position of the screw access hole. The manufacturing process of screw-retained reconstructions is more technique sensitive and more demanding when compared to cement-retained reconstructions.[4]

The construction of cemented restorations is not as technically demanding as screw-retained restorations and therefore they are less cost-intensive to produce.

Table 6 Characteristics and Estimated Failure Rates of Reconstructions

Restoration type	Studies	Retention type	Reconstructions	Exposure time (y)	Failures	Estimated failure rate per 100 y (95% CI)	*P* value
I-SC	25	Cement	1,316	6,695	65	0.74 (0.44–1.24)	.10
	9	Screw	404	1,761	17	1.85 (0.65–5.29)	
I-FDP	5	Cement	309	1,343	23	1.11 (0.40–3.07)	.49
	14	Screw	731	4,618	35	1.78 (0.59–5.34)	
Full-arch	1	Cement	6	18	0	0 (—)	—
	21	Screw	922	6,905	39	0.67 (0.34–1.31)	

Table 7 Estimated Failure and Survival Rates

Restoration	Retention type	Failure rate	5-year survival	10-year survival
All	Cement	0.81 (0.52–1.27)	96.03 (93.85–97.43)	92.22 (88.07–94.93)
	Screw	0.91 (0.57–1.46)	95.55 (92.96–97.19)	91.30 (86.42–94.46)
I-SC	Cement	0.74 (0.44–1.24)	96.37 (93.99–97.82)	92.87 (88.34–95.70)
	Screw	1.85 (0.65–5.29)	91.16 (76.76–96.80)	83.11 (58.92–93.71)
I-FDP	Cement	1.11 (0.40–3.07)	94.60 (85.77–98.02)	89.49 (73.57–96.08)
	Screw	1.78 (0.59–5.34)	91.48 (76.57–97.09)	83.69 (58.63–94.27)
Full-arch	Cement	0 (—)	—	—
	Screw	0.67 (0.34–1.31)	96.71 (93.66–98.31)	93.52 (87.72–96.66)

Table 8 Abutment Material - Exposure Time and Estimated Failure Rate of Reconstructions

Retention	Studies	Abutment type	Reconstructions	Exposure time (y)	Failures	Estimated failure rate per 100 y (95% CI)	*P* value
Cement	4	Titanium	98	474	3	0.57 (0.12–2.72)	
	6	Gold	280	1,213	4	0.33 (0.04–2.59)	.09
	10	Ceramic	617	4,128	70	1.97 (0.97–3.99)	
Screw	12	Titanium	560	3,041	13	0.39 (0.16–0.97)	
	11	Gold	637	2,804	33	1.50 (0.66–3.42)	.06
	4	Ceramic	239	1,925	9	0.38 (0.09–1.57)	

Table 9 Material of Reconstructions

Retention	Studies	Material	Reconstructions	Exposure time (y)	Failures	Estimated failure rate per 100 y (95% CI)	*P* value
Cement	17	PFM	876	4,058	15	0.37 (0.22–0.61)	
	0	Acrylic	—	—		—	.01
	6	Ceramic	333	2,513	22	0.88 (0.58–1.33)	
Screw	17	PFM	868	3,420	23	0.74 (0.32–1.68)	
	14	Acrylic	741	6,113	26	0.42 (0.17–1.01)	.66
	2	Ceramic	35	155	0	0 (—)	

Table 10 Failure of Reconstructions by Cement Type

Studies	Cement type	Reconstructions	Exposure time (y)	Failures	Estimated failure rate per 100 y (95% CI)	*P* value
5	Phosphate	414	2,935	29	0.95 (0.33–2.75)	
4	GI	151	1,063	9	0.85 (0.47–1.51)	.37
3	Resin	238	1,241	4	0.32 (0.06–1.65)	
5	ZOE	226	790	15	1.90 (0.30–12.15)	

Table 11 Technical Complications

Complication	Retention type	Studies	Reconstructions	Exposure time (y)	Events	Estimated event rate per 100 y (95% CI)	*P* value
Loss of retention	Cement	30	2,015	10,394	95	5.44 (2.14–13.82)	< .01
	Screw	36	2,741	15,402	77	0.61 (0.30–1.25)	
Loss of cover of access hole	Cement	—	—	—	—	—	
	Screw	32	2,534	14,744	131	0.81 (0.33–1.99)	
Fracture and/or chipping of ceramic	Cement	31	1,958	10,063	30	1.02 (0.37–2.83)	.02
	Screw	37	3,001	17,428	212	3.56 (1.95–6.49)	
Loosening of occlusal screw	Cement	—	—	—	—	—	
	Screw	39	3,023	17,031	201	1.76 (0.98–3.19)	
Loosening of abutment	Cement	31	1,958	10,063	86	2.31 (1.09–4.89)	< .01
	Screw	36	2,786	15,970	85	0.62 (0.33–1.17)	
Fracture of abutment	Cement	31	1,958	10,063	4	0.04 (0.01–0.20)	.52
	Screw	34	2,611	14,459	20	0.07 (0.03–0.18)	
Fracture of framework	Cement	2	125	569	14	2.46 (1.63–3.72)	.35
	Screw	37	2,976	16,727	59	0.28 (0.11–0.71)	
Fracture of implant	Cement	31	1,958	10,063	2	0.02 (0.00–0.15)	.27
	Screw	37	2,893	16,291	11	0.16 (0.03–0.79)	
Screw fracture	Cement	31	1,958	10,063	10	0.10 (0.02–0.49)	.85
	Screw	39	3,125	18,051	47	0.20 (0.09–0.44)	
Resin chipping and/or fracture	Cement	1	28	84	0	0 (—)	—
	Screw	35	2,757	15,846	539	4.40 (1.50–12.88)	
Other	Cement	29	1,790	8,903	33	2.29 (0.74–7.11)	.52
	Screw	39	2,980	17,518	243	1.73 (0.77–3.89)	
Summary (all except resin chipping)	Cement	33	2,078	10,778	274	9.81 (6.60–14.60)	.03
	Screw	42	3,226	18,480	1,086	7.50 (5.37–10.47)	
	One-piece screw	6	236	1,127	83	9.47 (4.83–18.59)	.93*
	Two-piece screw	12	857	7,052	394	6.27 (3.35–11.74)	.166*

*Compared with the estimated event rate of cement reconstructions.

Table 12 Cement Type and Loss of Retention

Studies	Cement type	Reconstructions	Exposure time (y)	Events	Estimated event rate per 100 y (95% CI)	*P* value
4	Phosphate	183	2,089	0	0 (—)	< .01
4	GI	151	1,063	8	1.04 (0.22–4.98)	
2	Resin	208	1,141	20	1.75 (0.52–5.95)	
5	ZOE	226	790	5	0.72 (0.15–3.41)	

Other advantages of this retention type include compensation of implant position discrepancies, passivity of fit, improved esthetics, and easier control of occlusion.[2,4,84] A major problem of cement retention is the difficulty of removing excess cement,[85,86] which has been associated with the development of peri-implant diseases such as peri-implant mucositis and peri-implantitis.[84,87]

A considerable emphasis can be seen in the dental literature concerning screw versus cement retention. Several conventional and systematic reviews have already been published exploring the advantages and disadvantages of cement- versus screw-retained implant-supported reconstructions,[5,7,15,88–90] leaving the clinician with conflicting information.

There are a large variety of methods to connect a restoration to the implant other than just cement or screw retention. An attempt to address this problem was made in this review by attempting to differentiate between one- and two-piece screw-retained restorations. Unfortunately, however, the number of studies that accurately reported the method of restoration at-

Table 5 Biologic Complications Summary

Complication	Retention type	Studies	Reconstructions	Exposure time (y)	Events	Estimated event rate per 100 y (95% CI)	*P* value
Bone loss (> 2 mm)	Cement	27	1,780	9,497	39	0.81 (0.29–2.24)	.07
	Screw	32	2,632	15,415	470	2.09 (1.11–3.93)	
Peri-implantitis	Cement	26	1,691	8,059	46	0.54 (0.22–1.31)	.16
	Screw	29	2,549	15,112	48	0.36 (0.15–0.86)	
Presence of fistula, suppuration	Cement	27	1,713	9,102	55	1.65 (0.55–4.96)	< .01
	Screw	30	2,567	15,292	36	0.22 (0.10–0.52)	
PI mucositis	Cement	24	1,612	7,237	60	1.38 (0.60–3.17)	.75
	Screw	29	2,496	14,881	167	1.61 (0.71–3.64)	
Recession	Cement	24	1,527	7,143	6	0.12 (0.03–0.47)	.19
	Screw	28	2,365	13,737	1	0.01 (0.00–0.06)	
Any esthetic complication	Cement	27	1,786	8,969	17	0.20 (0.08–0.54)	.69
	Screw	29	2,613	16,144	24	0.24 (0.09–0.63)	
Other	Cement	27	1,811	9,429	45	1.44 (0.49–4.28)	.87
	Screw	31	2,731	16,498	207	1.31 (0.67–2.59)	
Summary	Cement	29	1,864	9,749	268	7.01 (4.66–10.55)	.02
	Screw	33	2,778	16,802	953	4.81 (3.43–6.76)	
	One Piece screw	4	114	617	39	4.87 (1.52–15.63)	.54*
	Two Piece screw	11	842	7,028	705	10.51 (5.89–18.74)	.17*

*Compared with the estimated event rate of cement reconstructions.

tachment was few and thus the results of the one- and two-piece were not further analyzed. The estimated failure rates of one- and two-piece screw-retained reconstructions were calculated and compared to the cemented ones. Studies including restorations that demonstrated a mix of types by being cemented extraorally prior to being screw-retained were excluded from this review. Analysis of further retention types was not possible due to the low numbers reported.

The present systematic review was initiated to compare failure and complication rates not only based on the type of retention but also considering additional prosthetic and material aspects and hopefully to gather new arguments to support one or the other retention type.

Failures

The estimated failure rates of the pooled cemented and the pooled screw-retained reconstructions were similar to what has been reported in other systematic reviews on implant-supported reconstructions.[11,12,15,91] In a previous systematic review by Weber and Sukotjo,[7] the prosthetic success rates of screw- and cement-retained implant-supported reconstructions were reported at the most recent examination (> 72 months) as 93.2% for cemented and 83.4% for screw-retained restorations ($P > .05$). It should be noted that this study reported on success rates and not survival as in the present review.

Failures were more frequently observed with screw-retained crowns compared to cemented single crowns. The survival rate at 5 years for screw-retained I-SC was comparably lower than that for cemented I-SCs. However, this comparison lacked statistical significance, which was in agreement with a recent review by Sailer et al.[15]

Cement- or screw-retained I-FDPs (including cantilever I-FDPs) showed no statistical differences in survival rates between the retention systems. Similar survival rates were published by Pjetursson et al[14] in a systematic review evaluating implant-supported I-FDPs (survival rates, 95% [95% CI: 92.2% to 96.8%] after 5 years).[92]

Articles examining full-arch reconstructions reported the longest mean follow-up time (7.46 years) of all reconstruction types. Only one study was included in the present review regarding cemented full-arch reconstructions; therefore, survival rates were not statistically compared to the screw-retained group.

Failures rates for cement- and screw-retained reconstructions in the present study were analyzed not only by reconstruction type (I-SC, I-FDP, and full arch), but also by the materials used (abutment material, prosthetic material, and cement type). The failure rates for cemented reconstructions were influenced by the prosthetic material, with statistically higher rates with ceramic materials.

In the systematic review by Jung et al,[11] the survival rate of PFM single crowns was 95.4% (95% CI: 93.6%

to 96.7%) which was statistically significantly higher compared to the survival rate of all ceramic crowns of 91.2% (95% CI: 86.8% to 94.2%). When the data pool was updated in a follow-up systematic review the failure rates were very similar for PFM crowns (0.85 [95% CI: 0.51 to 1.41]) and ceramic crowns (0.86 [95%CI: 0.38 to 1.95]).[93] This clearly reflects the improvement of the biomechanical characteristics of the newer ceramic materials. In the present review, survival rates of screw-retained crowns were also not influenced by prosthetic material.

Failure rates with cemented reconstructions were not influenced by the abutment material (titanium, gold, ceramic). The screw-retained reconstructions had higher failure rates in combinations with gold abutments ($P = .062$). However, the use of ceramic abutments did not increase the risk for failure which confirms the results obtained by Sailer et al[94] who reported the 5-year survival of ceramic abutments to be 99.01% (95% CI: 93.8% to 99.9%) and 97.4% (95% CI: 96% to 98.3%) for metal abutments and that the annual failure rates with all ceramic crowns on ceramic abutments were similar to the rates observed with PFM crowns on metal abutments.

The failure rate of cemented reconstructions was not influenced by the choice of a particular cement whereas the event loss of retention depended on the type of cement. This leaves the clinician to select a cement based on the amount of preferred retention.

Technical and Biologic Complications

The results of the current review indicate a statistically significant ($P = .03$) higher overall rate of technical complications with cement-retained reconstructions compared to screw-retained reconstructions (Table 11). The recent review by Sailer et al[15] did not assess the overall rate of technical complications, but reported that the estimated cumulative incidence of technical complications at 5 and 10 years was higher with only screw-retained I-SC reconstructions and not I-FDP or full-arch I-FDP. The current review did not evaluate technical complications in terms of individual reconstruction type.

The technical complication fracture/chipping of ceramic was statistically significantly more frequent in screw-retained reconstructions compared to cemented ones (Table 11). Loosening of abutment complications were more frequent with cemented reconstructions. The total rate of technical complications, however, was statistically significantly higher with cemented reconstructions (Table 11).

Chipping of the ceramic veneer may be more likely in the presence of an access opening for an occlusal/abutment screw. In this situation, the integrity of the framework and the veneer layers are interrupted, and tension might be produced while tightening the assembly and manipulations with the screwdriver, provoking stress peaks laterally in the region of the access opening.

Although chipping of the resin veneer could not be compared between retention type, this complication was extremely frequent in screw-retained reconstructions with an event rate of 4.40 (95% CI: 1.50 to 12.88), thus making it the second most common complication for screw-retained reconstructions. These complications were also mainly seen in full-arch reconstructions and this should therefore be taken into account when designing an implant-supported reconstruction for edentulous patients.

The biologic complications and the total event rate for biologic complications were significantly increased with cement- compared to screw-retained reconstructions (Table 13). Presence of fistula/suppuration appeared statistically significantly more often with cemented reconstructions.

In the chain of processes leading to biologic complications, many host factors and biologic interactions with the inserted materials play a role. The type of retention (screw/cement) seemed to have a decisive role in the risk of developing a biologic complication (Table 13).

This is in agreement with other reports that discuss the role of cement in the development of infections and progressive bone loss[87] as well the observed improvement after removal of excess cement.[84] For bacterial colonization, even a micro-gap and a small space between the implant shoulder/abutment and supra-structure may create an anaerobic niche for undisturbed growth of a biofilm,[95–97] independent of retention type.

Data Extraction, Limitation, and Future Prognosis

Stringent inclusion and exclusion criteria were selected including a minimum mean follow-up time of 3 years for the included studies. This follow-up time is greater than that of previous studies and allows for a more accurate estimation of 5-year survival rates. 8.3% of the included studies were RCT, which is a reassuringly high number compared to that usually reported in dental literature reviews. However, the main limitation of this review is the heterogeneity between the included studies, mainly their definitions of success, survival, failure, and complications, as well as the presentation of the data and design. However with a greater number of included studies compared to previous reviews, it is hoped that the negative effect of heterogeneity can be minimized. Further, If a study did not note the absence of events, it was excluded for a statistical comparison, since it was unclear if events were present.

Another limitation to this study is the lack of a standardized definition of prosthetic failure. While implant failures were well-reported, it was not always possible

to distinguish true prosthetic failures from those where the implant failed and resulted in the reporting of a prosthetic failure. As a result, there may be an overestimation of prosthetic failure in these results. Although it is not possible to determine to exactly what degree this overestimation occurs in the various groups, it must be remembered that survival of the restoration and implant together is what is important to the patient.

For the two categories of screw-retention (one-piece and two-piece screw-retained reconstructions), the estimated event rates were calculated and compared to cement-retained reconstructions; however, due to a limitation of studies, further analyses were not performed.

In addition, a further biomechanical aspect that was not separately analyzed was the effect of an external or internal connection. This has previously been shown to have an impact on screw loosening, but little else.[98]

With respect to future prognosis of a reconstruction, the determination of which retention system leads to more failures/complications has to be complemented with the question: Which retention system is more advantageous in the successful management of future failures and complications? Handling of these complications and the cost of doing so represent further questions of importance and are recommended as avenues for future research.

CONCLUSIONS

The estimated 5-year survival rate of screw-retained reconstructions (based on a random-effects Poisson regression analysis) is similar to that for cemented reconstructions. Estimated failure rates calculated for cemented and screw-retained reconstructions were not statistically significant ($P = .63$).

There were no statistically significant differences between the failure rates of the different reconstruction types (I-SC, I-FDPs, full-arch I-FDPs).

Failures of cemented reconstructions were not statistically significantly influenced by the abutment material (titanium, gold, ceramic) or the choice of a specific cement.

The total event rate of technical complications was statistically significantly higher with cemented reconstructions. The technical complication fracture/chipping of ceramic was significantly more frequent in screw-retained reconstructions compared to the cemented ones. The loosening of abutment complication was more frequent with cemented reconstructions. The remaining technical complications such as fracture of abutment, fracture of framework, fracture of implant and screw fracture did not demonstrate statistical significance.

The total event rate for biologic complications was significantly higher with cemented compared to screw-retained reconstructions. Presence of fistula/suppuration appeared statistically significantly more often with cemented reconstructions. Outcomes of the other event rates of biologic complications such as bone loss (> 2 mm), peri-implantitis, presence of fistula/ suppuration, peri-implant mucositis, recession, and loss of implant were not statistically significantly different between the two retention systems.

Considering the risks with cemented reconstructions and the limited options for interventions after definitive cementation, it seems to be appropriate to recommend a preference towards screw retention of implant-supported reconstructions.

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Systematic Review of the Survival Rate and Incidence of Biologic, Technical, and Esthetic Complications of Single Implant Abutments Supporting Fixed Prostheses

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Purpose: *To assess the 5-year survival rate and number of technical, biologic, and esthetic complications involving implant abutments.* ***Materials and Methods:*** *Electronic (Medline) and hand searches were performed to assess studies on metal and ceramic implant abutments. Relevant data from a previous review were included. Two reviewers independently extracted the data. Failure and complication rates were analyzed, and estimates of 5-year survival proportions were calculated from the relationship between event rate and survival function. Multivariable robust Poisson regression was used to compare abutment characteristics.* ***Results:*** *The search yielded 1,558 titles and 274 abstracts. Twenty-four studies were selected for data analysis. The survival rate for ceramic abutments was 97.5% (95% confidence interval [CI]): 89.6% to 99.4%) and 97.6% (95% CI: 96.2% to 98.5%) for metal abutments. The overall 5-year rate for technical complications was 11.8% (95% CI: 8.5% to 16.3%), 8.9% (95% CI: 4.3% to 17.7%) for ceramic and 12.0% (95% CI: 8.5% to 16.8%) for metal abutments. Biologic complications occurred with an overall rate of 6.4% (95% CI: 3.3% to 12.0%), 10.4% (95% CI: 1.9% to 46.7%) for ceramic, and 6.1% (95% CI: 3.1% to 12.0%) for metal abutments.* ***Conclusions:*** *The present meta-analysis on single-implant prostheses presents high survival rates of single implants, abutments, and prostheses after 5 years of function. No differences were found for the survival and failure rates of ceramic and metal abutments. No significant differences were found for technical, biologic, and esthetic complications of internally and externally connected abutments.* INT J ORAL MAXILLOFAC IMPLANTS 2014;29(SUPPL):99–116. doi: 10.11607/jomi.2014suppl.g2.2

Key words: *biologic complications, ceramics, complication rates, esthetic complications, failures, implant abutments, implant prostheses, metal, survival, systematic review, technical complications, titanium, zirconia*

Today, partially edentulous individuals represent the main group of patients requiring treatment in daily dental practice. Therefore, oral implants are the predominant treatment modality for the rehabilitation of these patients.[1] Using implants, fixed partial dentures can be applied in situations where removable dentures would previously have been necessary.[2–4] In addition, more treatment options that preserve the tooth structure are possible by replacing missing single teeth with dental implants.[5] Since most of the patients provided with oral implants are between 40 and 50 years of age, promising long-term survival rates for implants and prostheses are expected both by the clinician and the patient to ensure the longevity of the prosthesis.[6–8] The definition "long-term" has been specified as a follow-up of at least 5 years.[9] Thus, survival rates and the incidence of biologic, technical, and esthetic events should be based on mean observation periods of at least 5 years.[10]

Several years ago, hierarchies of evidence were developed as aid for the interpretation and evaluation of research findings.[11] As evidence, systematic reviews were ranked to be excellent in terms of effectiveness, appropriateness, and feasibility. An evidence level of "excellent" equates with the strongest scientific basis

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for clinical practice along with the least risk of error.[11] Consequently, systematic reviews are an optimal tool for the development of practice guidelines and clinical recommendations.

A recent systematic review confirmed single implants to be a successful treatment method with survival rates of 97.2% at 5 years and 95.2% at 10 years.[12] However, implant survival rates are not the only essential consideration when advising the patient on different treatment options. Prosthetic and implant abutment outcomes need to be considered as well. Different kinds of abutments are available with respect to material (metal and ceramic) and shape (prefabricated and customized, both with various internal designs). At this time, metal abutments are classified as the "gold standard," although high-strength zirconia abutments are being utilized more widely and may be an adequate alternative to metal abutments for the clinical use. The results of a previous systematic review showed similar outcomes for ceramic and metal abutments.[13] However, the results need to be interpreted with caution due to a high variation in the number of analyzed abutments and differing numbers of studies and follow-up times.

Since the use of ceramic abutments has spread within the last few years, an increase in clinical studies might thus be expected. An update of the available most recent clinical data may help the clinician decide upon the most ideal abutment in each individual situation.

The aim was to systematically review the existing dental literature on the survival rates of metal and ceramic abutments supporting single implant crowns with a mean observation period of at least 3 years. In addition, the occurrence of negative biologic, technical, and esthetic events was evaluated for metal and ceramic abutments.

MATERIALS AND METHODS

The PICO (population, intervention, comparison, outcome) question was stated as follows: For single-tooth implant prostheses in anterior and posterior locations, are there differences in survival/performance based on technical, biologic, and esthetic outcomes as influenced by material and design?

Search Strategy

The present systematic review was performed as an update of a previously published systematic review with the same objectives.[13]

A Medline (PubMed) search was performed for clinical studies published in dental journals from January 1, 2009 up to April 30, 2012. The search was limited to English, German, French, Dutch, and Korean language publications (Table 1).

Search Terms

The following search terms were grouped to the three main subjects (implants, abutments, and material) and linked with "and" as follows:

Implants

"Dental Implants, Single-Tooth" [MeSH] AND "dental implants" AND "dental implant* single tooth" AND "single tooth implant*" AND "single implant" AND "dental implant" AND "single tooth implant" AND "single tooth implants" AND "single implants" AND "Denture, Partial, Fixed" [MeSH] AND "Dental Prosthesis Design" [MeSH] AND "fixed restoration" AND "Denture Design" [MeSH] AND "implant*" AND "fixed prosthodontic" AND "fixed partial denture" AND "fixed prosthodontics" AND "fixed partial dentures" AND "dental implants" [MeSH] AND "Dental Prosthesis, Implant-Supported" AND "fixed dental prosthesis" AND "fixed dental prostheses".

Abutments

"Dental Abutments" [MeSH] AND "implant abutment" AND "implant* reconstruct*" AND "implant* abutment*" AND "implant abutments" AND "abutment*" AND "dental abutment*".

Material

"Titanium" [MeSH] AND "Gold" [MeSH] AND "ceramics" [MeSH] AND "aluminum" [MeSH] AND "Zirconium" [MeSH] AND "ceramic*" AND "titan*" AND "metal*" AND "zirconi*" AND "gold*" AND "alumin*" AND "metals" [MeSH].

Thereafter, the search results from the three subject groups were combined with each other using "OR." The electronic search was complemented by manual searching of the bibliographies of the most recent systematic reviews[12,14,15] and of all included publications.

Inclusion Criteria

The criteria for study inclusion were:

- Studies with at least 10 included patients
- Clinical studies only
- Studies with a mean follow-up of at least 3 years (unless there was an immediate negative effect)
- Studies reporting on details and outcomes of implant abutments
- Studies reporting on partially edentulous patients receiving implant-supported single crowns

Exclusion Criteria

Reports based on patient chart reviews, questionnaires, or interviews were excluded as were case reports and multiple publications on the same patient cohort.

Table 1 Systematic Search Strategy

Focus question	**For single-tooth implant reconstructions in anterior and posterior locations are there differences in survival/performance based on technical, biologic, and esthetic outcomes as influenced by material, design, and fabrication?**
Search strategy	
Population	Patients with single-implant reconstructions
Intervention or exposure	Single implants with a mean follow-up of 3 y
Comparison	Abutment material (metal vs ceramic)
Outcome	Survival rate of implants, abutments, reconstructions
Search combination	*Implants:* "Dental Implants, Single-Tooth" [MeSH] AND "dental implants" AND "dental implant* single tooth" AND "single tooth implant*" AND "single implant" AND "dental implant" AND "single tooth implant" AND "single tooth implants" AND "single implants" AND "Denture, Partial, Fixed" [MeSH] AND "Dental Prosthesis Design" [MeSH] AND "fixed restoration" AND "Denture Design" [MeSH] AND "implant*" AND "fixed prosthodontic" AND "fixed partial denture" AND "fixed prosthodontics" AND "fixed partial dentures" AND "dental implants" [MeSH] AND "Dental Prosthesis, Implant-Supported" AND "fixed dental prosthesis" AND "fixed dental prostheses" *Abutments:* "Dental Abutments" [MeSH] AND "implant abutment" AND "implant* reconstruct*" AND "implant* abutment*" AND "implant abutments" AND "abutment*" AND "dental abutment*" *Material:* "Titanium" [MeSH] AND "Gold" [MeSH] AND "ceramics" [MeSH] AND "aluminum" [MeSH] AND "Zirconium" [MeSH] AND "ceramic*" AND "titan*" AND "metal*" AND "zirconi*" AND "gold*" AND "alumin*" AND "metals" [MeSH] Thereafter, the search results from the three subject groups were combined with each other using "OR"
Database search	
Electronic	PubMed, Cochrane Central Register of Controlled Trials (CENTRAL)
Journals	*Clinical Oral Implants Research, International Journal of Oral Maxillofacial Implants, International Journal of Oral and Maxillofacial Surgery, Clinical Implant Dentistry and Related Research, Implant Dentistry, Journal of Implantology, Journal of Periodontology, Journal of Clinical Periodontology, Clinical Oral Investigation, Dental Materials, International Journal of Prosthodontics, European Journal of Oral Implantology*
Selection criteria	
Inclusion criteria	Studies with at least 10 included patients Clinical studies only Studies with a mean follow-up of at least 3 years; studies reporting on details and outcomes of implant abutments Studies reporting on partially edentulous patients receiving implant-supported single crowns
Exclusion criteria	Reports based on patient chart reviews, questionnaires, or interviews Case reports

CT, controlled trial; RCT, randomized controlled trial; NR, not reported.

Study Selection

All obtained titles and abstracts were checked for inclusion by two independent reviewers (SK and AZ). In case the abstract was not available, a full text article was acquired. On the basis of the chosen abstracts, full-text articles were selected for independent assessment by the reviewers. If the information in title and abstract was insufficient for inclusion or exclusion, full-text articles were also obtained. In case of any disagreement regarding inclusion, a decision was made by the three reviewers by consensus. The agreement among the three reviewers for the inclusion of full-text articles was subsequently calculated by Cohen kappa coefficient. In addition, 16 publications on single implant prostheses were included for analysis from the previous review.[13]

Data Extraction

A data extraction sheet was used by two reviewers (SK, AZ) to extract the relevant data from the included papers. Information on several parameters was recorded including: author(s), study design, year of publication, mean follow-up time, implant system, number of abutments, abutment material, drop-outs, and survival rates, as well as the incidence of biologic, technical, and esthetic complications of abutments. Disagree-

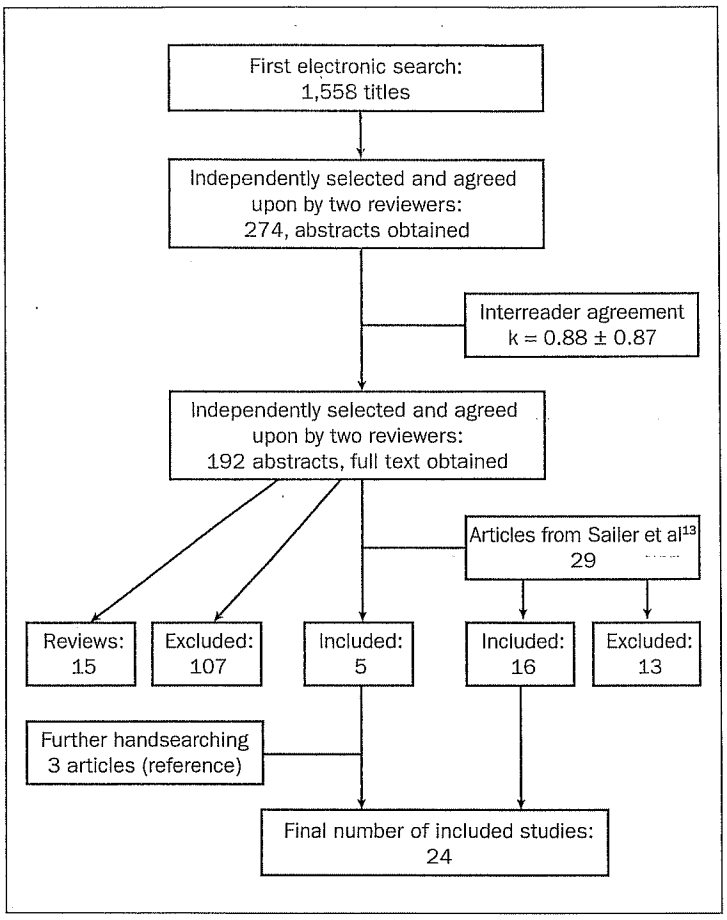

Fig 1 Search strategy.

ment regarding data extraction was resolved by consensus. The number of events and the corresponding total exposure time of the prostheses were calculated. In case the publication did not provide sufficient information, the corresponding authors of the respective publications were contacted via email. Additionally, the data from included studies on single implant crowns from the previous review were extracted.[13]

Survival was defined as the abutment/implant prosthesis remaining in situ for the observation period with or without modifications.

Technical complications included abutment fracture, abutment screw fracture, abutment screw loosening, misfit at the implant-abutment junction (gap), fracture of the implant prosthesis, chipping of the veneering ceramic, and loosening of the implant prosthesis.

The analysis of biologic complications encompassed bone loss of more than 2 mm, soft tissue recession, and general soft tissue complications.

The analysis of the esthetic complications included soft tissue discoloration and other esthetic problems.

Statistical Analysis

Failure and complication rates were calculated by dividing the number of events (failures or complications) as the numerator by the total time of the prostheses being under observation as the denominator. The numerator could usually be extracted directly from the publication. If all patients/prostheses had a fixed follow-up time point, this was taken as the observation period for all. Otherwise, the total observation time was calculated by taking the sum of the following: *(1)* exposure time of prostheses that could be followed for the full observation period; *(2)* exposure time up to failure of the prostheses that were lost due to failure; and *(3)* exposure time up to the end of observation time for prostheses that did not complete the observation period for reasons such as death, change of address, refusal to participate, nonresponse, chronic illnesses, missed appointments, and work commitments. If all three components for the calculation of the total exposure time were not available, the total exposure time was estimated by multiplying the mean follow-up time by the number of constructions under observation.

For each study, event rates for the abutments and the prostheses were calculated by dividing the total number of events by the total abutment exposure time in years. For additional analysis, the total number of events was considered to be Poisson distributed for a given sum of abutment exposure years and robust Poisson regression with a logarithmic link-function and total exposure time per study as an offset variable was used.[16] Robust Poisson regression allowed for the calculation of standard errors and 95% confidence intervals (CI), which incorporated heterogeneity among studies.

Five-year survival proportions were calculated via the relationship between event rate and survival function S(T) by assuming constant event rates[17]:

$$S(T) = \exp(-T \times \text{event rate})$$

For the 5-year survival, T was equal to 5.

The 95% CIs for the survival proportions were calculated by using the 95% CIs of the event rates. Multivariable robust Poisson regression was used to formally compare construction subtypes and to assess other study characteristics and to estimate event rate ratios and their 95% CIs. All analyses were performed using Stata, version 12.

Table 2 Characteristics of the Included Studies

Study	Year of publication	Study design	Total no. of included patients	Age range	Mean age	Setting	Mean follow-up (y)	Drop-out (%)
Avivi-Arber and Zarb[18]	1996	Prospective CT	41	14.5–3.9	33.5	University	4	5
Henry et al[19]	1996	Prospective CT	92	NR	NR	Multicenter	5	8
Andersson et al[20]	1998	Prospective CT	57	NR	32	Specialist clinic	5	5
Scheller et al[21]	1998	Multicenter prospective CT	82	14–73	35	Multicenter	5	25
Levine et al[22]	1999	Retrospective	129	NR	NR	Multicenter	3.3	19
Wannfors and Smedberg[23]	1999	Prospective	69	17–72	26	Specialist clinic	3	3
Bianco et al[24]	2000	Retrospective CT	214	16–70	NR	Multicenter	8	9
Andersson et al[25]	2001	RCT	15	17–49	32	Specialist clinic	3	0
Krennmair et al[26]	2002	Retrospective	112	NR	31.3	Private practice and university	3	NR
Muche et al[27]	2003	Retrospective	76	NR	45	University	3	NR
Glauser et al[28]	2004	Prospective CT	27	26–75	44	University	4.1	9
Romeo et al[29]	2004	Prospective CT	250	20–67	NR	University	3.9	NR
Brägger et al[30]	2005	Prospective cohort study	127	19–78	49.3	University	10	NR
Vigolo et al[31]	2006	Prospective RCT	20	NR	NR	University	4	0
Canullo[32]	2007	Prospective cohort study	25	25–70	NR	Private practice	3.3	NR
Cooper et al[33]	2007	Prospective cohort study	48	NR	30.6	University	3	9
MacDonald et al[34]	2009	Prospective	20	NR	43.5	University	8	3
Vigolo and Givani[35]	2009	Prospective	144	25–55	37	Private practice	5	0
Bonde et al[36]	2010	Retrospective	51	19–79	43	University	10	3
Urdaneta et al[37]	2010	Retrospective	81	28–92	58.7	Specialist clinic	5.9	27
Ekfeldt et al[38]	2011	Retrospective	25	NR	NR	Specialist clinic	3–5	NR
Visser et al[39]	2011	Prospective	93	18–63	33	University	5	1
Gotfredsen[40]	2012	Prospective	20	18–59	33	University	10	5
Zembic et al[41]	2013*	Prospective RCT	22	23–59	41.3	University	5.6	4

*Available ahead of print in 2012.

RESULTS

The search strategy is presented in Fig 1. The Medline search provided a total of 1,558 titles. After screening of all titles, both reviewers agreed upon 274 abstracts. Finally, 24 full-text articles reporting on the clinical performance of implant abutments were selected (Table 2). Three out of 24 studies were gained through the hand search and 16 articles were retrieved from the previous review. The studies were published from 1996 until 2012. The inter-reviewer agreement for the inclusion of the studies was $\kappa = 0.88 \pm 0.87$ (Cohen kappa coefficient).

Excluded Studies

One hundred twenty-two studies were excluded due to the following reasons: mean observation period less than 3 years (n = 27), no detailed information on abutments (n = 42), no detailed results on abutments (n = 6), data obtained from patient chart reviews (n = 3), splinted crowns (n = 8), case reports (n = 19), reviews (n = 15), or mixed data on FPDs and single implant crowns (n = 2).

Included Studies

Among the selected full-text articles, three studies[25,31,41] were randomized clinical trials (RCTs) comparing different abutment materials (zirconia vs titanium, alumina vs

Table 3 Characteristics of Abutment and Prostheses

Study	Year of publication	Implant system	Implant diameter	Location	Total abutments
Avivi-Arber and Zarb[18]	1996	Nobel Biocare	3.75, 4.0	Incisor, canine, premolar, molar	42
Henry et al[19]	1996	Nobel Biocare	NR	NR	96
Andersson et al[20]	1998	Nobel Biocare	NR	51 incisors, 1 canine, 13 premolars	65
Scheller et al[21]	1998	Nobel Biocare	3.75, 4.0	87 maxilla, 12 mandible	65
Levine et al[22]	1999	Straumann	3.5, 4.1	22 anterior, 135 posterior	157
Wannfors and Smedberg[23]	1999	Nobel Biocare	NR	40% max incisor, 20%–30% max lateral incisor, 15%–20% max canine, 5 implants in mandible	76
Bianco et al[24]	2000	Nobel Biocare	NR	anterior and posterior	229
Andersson et al[25]	2001	Nobel Biocare	3.75, 4.0	17 incisors, 2 canines, 1 premolar	10
Andersson et al[25]	2001		NR	NR	10
Krennmair et al[26]	2002	Frialit 2	NR	NR	146
Muche et al[27]	2003	3i	NR	NR	205
Glauser et al[28]	2004	Nobel Biocare	3.75, 4.0	25 incisors, 14 canines, 15 premolars	36
Romeo et al[29]	2004	Straumann	Narrow, regular, wide	Anterior, posterior	121
Brägger et al[30]	2005	Straumann	NR	NR	69
Vigolo et al[31]	2006	3i	3.75, 4.0	16 maxilla, 4 mandible, 0 anterior, 20 posterior	20
Vigolo et al[31]	2006	3i	3.75, 4.0	16 maxilla, 4 mandible, 0 anterior, 20 posterior	20
Canullo[32]	2007	TSA implants	NR	Anterior and posterior	30
Cooper et al[33]	2007	Astra Tech	NR	Incisor, canine	43
MacDonald et al[34]	2009	Endopore	3.5, 4.1	13 posterior, 7 anterior	17
Vigolo and Givani[35]	2009	3i	wide	Only molars	182
Bonde et al[36]	2010	Nobel Biocare	3.3 (4), 3.75 (51)	42 anterior, 13 premolars, 49 maxilla, 6 mandible	52
Urdaneta et al[37]	2010	Bicon	3.3–6.0	NR	326
Ekfeldt et al[38]	2011	Nobel Biocare	3.3–5.0	NR	40
Visser et al[39]	2011	Straumann	4.1	Anterior maxilla	92
Gotfredsen[40]	2012	Astra Tech	4.5	18 anterior, 2 posterior	19
Zembic et al[41]	2013*	Nobel Biocare	3.75	2 anterior, 16 posterior	18
Zembic et al[41]	2013*	Nobel Biocare	3.75	2 anterior, 8 posterior	10

*Available ahead of print in 2012. NR, not reported.

titanium, and titanium vs gold). Seventeen studies had a prospective design, seven studies were retrospective.

In total, 12 studies were performed at a university setting, 5 studies in a specialist clinic, 2 in private practice, and 1 both at university and private practice. Four studies were multicenter studies.

Overall, 1,877 patients with 2,999 abutments were involved in the included studies. Out of these, 139 (7.4%) patients and 813 (27%) abutments were dropouts and thus not followed. Six studies did not report the patient dropout rate. The mean age of all patients was 41 years, ranging from 14 to 92 years.

Abutment material	Abutment type	Fixation torque	Abutment connection	Prosthesis material	Cemented implants	Screw-retained implants
Titanium	NR	NR	External hexagon	Metal-ceramic or metal-acrylic, 1 all-ceramic	NR	NR
Titanium	NR	NR	External hexagon	NR	NR	NR
Titanium	NR	NR	External hexagon	62 all-ceramic, 3 metal-ceramic	65	0
Titanium	Prefabricated	32	External hexagon	16 porcelain fused to metal, 81 full ceramic	97	0
Titanium	NR	32	Internal	NR	76	81
Gold	Customized, prefabricated	32	External hexagon	36 gold-resin, 35 gold-ceramic, 9 all-ceramic	36	44
Titanium	NR	NR	External hexagon	Metal, metal-ceramic, all-ceramic	203	31
Alumina	NR	NR	External hexagon	All-ceramic	10	0
Titanium	NR	10–32	External hexagon	All-ceramic	10	0
Titanium	NR	NR	Internal	Metal-ceramic, all-ceramic	93	53
Metal	NR	35	External hexagon	Metal-ceramic	5	200
Zirconia	NR	32	External hexagon	All-ceramic	54	0
Titanium	NR	NR	Internal	Metal-ceramic	NR	NR
Metal (titanium, gold-alloy)	NR	32	Internal	NR	67	2
Titanium	Customized	35	External hexagon	Metal-ceramic	20	0
Gold	Customized	35	External hexagon	Metal-ceramic	20	0
Zirconia	NR	15	Internal	All-ceramic	30	0
Titanium	NR	32	Internal	Metal-ceramic, all-ceramic	54	0
Titanium	Prefabricated	NR	External hexagon	Metal-ceramic	0	20
Titanium	Customized	32	External hexagon	Metal-ceramic	182	0
Titanium	Prefabricated	NR	External hexagon	All-ceramic	55	0
Titanium	NR	NR	Internal	228 gold-resin, 82 metal-ceramic, 16 all-ceramic	326	0
Zirconia	Customized	35	External hexagon	40 all-ceramic (25 one-piece)	15	25
Titanium abutment with gold coping screwed onto it	Customized	15	Internal	All-ceramic	92	0
Titanium	Prefabricated, customized	15	Internal	Metal-ceramic	19	0
Zirconia	Customized	32	External hexagon	All-ceramic	16	2
Titanium	Customized	32	External hexagon	Metal-ceramic	10	0

In the above-mentioned three RCTs, the outcomes were compared for 10 alumina and 10 titanium abutments, 20 gold and 20 titanium abutments, and 18 zirconia and 10 titanium abutments.[25,31,41]

The majority of studies (13) reported on anterior and posterior abutment locations.[18,20,22,24,25,28,29,31,32,34,36,40,41] Three studies reported on anterior abutment locations only.[23,33,39] One study described posterior abutment locations only.[35] Seven studies did not state the exact location of the abutments with regard to anterior or posterior.[19,21,26,27,30,37,38]

Table 4 Failed Abutments and Prostheses

Study	Year of publication	Total no. of abutments/ prostheses	Mean follow-up	Abutment material	Prosthesis material
Avivi-Arber and Zarb[18]	1996	42	4	Titanium	Metal-ceramic or metal-acrylic, 1 all-ceramic
Henry et al[19]	1996	96	5	Titanium	NR
Andersson et al[20]	1998	55	5	Titanium	62 all-ceramic, 3 metal-ceramic
Scheller et al[21]	1998	65	5	Titanium	16 meta-ceramic, 81 all-ceramic
Levine et al[22]	1999	157	3.3	Titanium	NR
Wannfors and Smedberg[23]	1999	76	3	Gold	36 gold-resin, 35 gold-ceramic, 9 all-ceramic
Bianco et al[24]	2000	229	8	Titanium	Metal, metal-ceramic, all-ceramic
Andersson et al[25]	2001	10	3	Alumina	All-ceramic
Andersson et al[25]	2001	10	3	Titanium	All-ceramic
Krennmair et al[26]	2002	146	3	Titanium	Metal-ceramic, all-ceramic
Muche et al[27]	2003	205	3	Metal	Metal-ceramic
Glauser et al[28]	2004	36	4.1	Zirconia	All-ceramic
Romeo et al[29]	2004	121	3.9	Titanium	Metal-ceramic
Brägger et al[30]	2005	69	10	Metal (titanium, gold-alloy)	NR
Vigolo et al[31]	2006	20	4	Titanium	Metal-ceramic
Vigolo et al[31]	2006	20	4	Gold	Metal-ceramic
Canullo[32]	2007	30	3.3	Zirconia	All-ceramic
Cooper et al[33]	2007	43	3	Titanium	Metal-ceramic, all-ceramic
MacDonald et al[34]	2009	17	8	Titanium	Metal-ceramic
Vigolo and Givani[35]	2009	182	5	Titanium	Metal-ceramic
Bonde et al[36]	2010	52	10	Titanium	All-ceramic
Urdaneta et al[37]	2010	326	5.9	Titanium	228 gold-resin, 82 metal-ceramic, 16 all-ceramic
Ekfeldt et al[38]	2011	40	3-5	Zirconia	40 all-ceramic (25 one-piece)
Visser et al[39]	2011	92	5	Titanium abutment with gold coping	All-ceramic
Gotfredsen[40]	2012	19	10	Titanium	Metal-ceramic
Zembic et al[41]	2013*	18	5.6	Zirconia	All-ceramic
Zembic et al[41]	2013*	10	5.6	Titanium	Metal-ceramic

*Available ahead of print in 2012. Total summary estimate (95% CI, random-effects Poisson regression) for total exposure time: 11,089; estimated abutment failure rate per 100 abutment years: 0.48 (0.30–0.77); estimated prosthesis failure rate per 100 prosthesis years: 0.91 (0.62–1.32); estimated 5-year abutment failure rate per 100 abutment years: 2.37% (1.49–3.77); estimated 5-year prosthesis failure rate per 100 prosthesis years: 4.42% (3.06–6.37).

The studies reported on eight commercially available implant systems: Brånemark System (Nobel Biocare), Astra Tech Dental Implants System (Astra Tech), ITI Dental Implants System (Straumann), 3i Implants (Implant Innovations), Endopore Implants (Innova Corporation), TSA Implants (Impladent), Frialit 2 Implants (Friatek), and Bicon Dental Implants (Bicon) (Table 3).

Thus, nine studies evaluated implant systems with internal implant-abutment connections (Astra Tech, Straumann, Bicon, Frialit 2, and TSA Implants), and the remaining 15 studies evaluated implants with external implant-abutment connections (Brånemark System, 3i, and Endopore Implants) (Table 3). In total, 1,003 internally connected abutments (30 zirconia and 973 metal abutments) were evaluated and 1,183 externally connected abutments (94 zirconia, 10 alumina, and 1,079 metal abutments).

Abutment Survival

A total of 2,186 abutments were followed with a mean observation period of 5.5 years. Altogether, 134 ceramic abutments and 2,052 metal abutments were evaluated at follow-up in the included studies (Table 4).

Only two studies did not report on abutment failures.[18,22] Out of the 22 studies reporting abutment failures, two ceramic abutments (1.5%) and 45 metal abutments (2.2%) were lost, resulting in an estimated

No. of failures (abutments)	No. of failures (prostheses)	Total abutment/prosthesis exposure time
NR	NR	168
8	8	480
0	4	275
1	8	325
0	4	518
4	7	228
5	NR	1,832
2	NR	30
0	1	438
2	0	615
3	1	468
0	0	690
5	5	80
5	5	80
0	0	129
0	0	136
0	0	910
3	3	520
0	1	1,923
0	0	460
3	3	190
3	16	30
0	0	148
3	11	99
0	2	160
2	2	101
1	1	56

5-year failure rate of 2.5% (95% CI: 0.6% to 10.4%) for ceramic and 2.4% (95% CI: 1.5% to 3.8%) for metal abutments (Table 4). The failure rate of all abutments per 100 abutment years amounted to 0.48% (95% CI: 0.30% to 0.77%) (Table 4 and Fig 2). The overall estimated 5-year abutment survival rate was 97.6% (95% CI: 96.2% to 98.5%) (Table 4 and Fig 2).

Ceramic abutments showed survival of 97.5% (95% CI: 89.6% to 99.4%) at 5 years and did not differ significantly from metal abutments, which showed 97.6% survival (95% CI: 96.2% to 98.5%).

In total, six abutments fractured, two internally connected zirconia abutment (Replace Select, Nobel Biocare), two externally connected alumina abutments (Brånemark, Nobel Biocare), and three titanium abutments that were internally connected to Bicon implants.[25,37,38]

Sixty-eight abutments could not be evaluated due to implant loss as reported in 13 studies (2 ceramic, 66 metal abutments).[19,21,23,24,26,27,29,30,33,36,37,39,41] For the remaining abutments, no reason for loss was mentioned.

There was no difference in the occurrence of abutment failures for implants with internal compared to external implant-abutment connection (rate ratio = 1.0; 95% CI: 0.4 to 2.6).

Implant Survival

Since it is logical to assume that implant survival signals abutment survival, it is reasonable to use implant survival as secondary measure.

All included studies except for two[28,32] reported on the survival rates of implants. Overall, the estimated 5-year implant survival rate for single implants amounted to 96.9% (95% CI: 95.6% to 97.8%). Sixty-nine out of 2,186 followed-up implants were lost. The estimated 5-year failure rate for single implants amounted to 3.1% (95% CI: 2.2% to 4.4%).

The 5-year survival rate was similar for implants supporting metal abutments (96.9%; 95% CI: 95.6% to 97.8%) and implants supporting ceramic abutments (95.8%; 95% CI: 83.7% to 99.0%). Implants restored with ceramic abutments failed more often at 5 years (4.2%; 95% CI: 1.0% to 16.3%).

There was no difference in the occurrence of implant failures for implants with internal compared to external implant-abutment connection (rate ratio = 1.0; 95% CI: 0.5 to 2.0). The estimated implant failure per 100 implant years was 0.64% (95% CI: 0.5% to 0.9%) (Fig 3).

Prosthesis Survival

All studies reported on the survival rates of the prostheses. The reasons for failure or refabrication, respectively, were mainly major fracture or insufficient esthetics.

The estimated 5-year survival rate of single-implant prostheses was 95.6% (95% CI: 93.6% to 96.9%) (Fig 4). The failure rate for prostheses on ceramic abutments was less than for prostheses on metal abutments (2.6%; 95% CI: 0.6% to 11.3% vs 4.5%; 95% CI: 3.1% to 6.6%). This difference was not significant.

The rate of lost prostheses was similar for internal and external implant-abutment connections (rate ratio = 0.9; 95% CI: 0.4 to 2.1) (Table 4).

Technical Complications

Several technical complications were reported in 21 studies. The overall estimated 5-year rate for technical complications was 11.8% (95% CI: 8.5% to 16.3%) (Table 5; Fig 5).

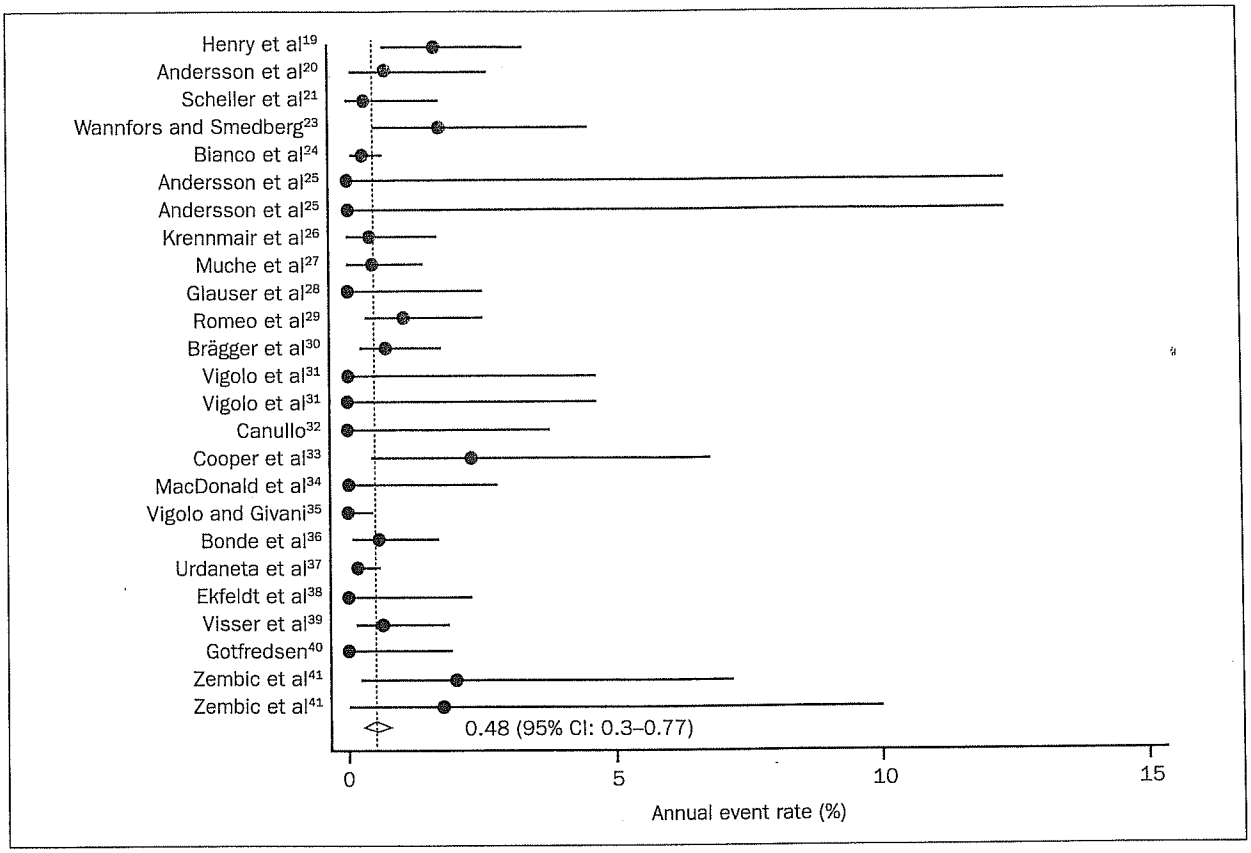

Fig 2 Annual abutment failure rates (per 100 years).

There was no significant difference with respect to the technical complication rate for ceramic and metal abutments. The estimated 5-year technical complication rate for ceramic abutments added up to 8.9% (95% CI: 4.3% to 17.7%), whereas it was 12.0% (95% CI: 8.5% to 16.8%) for metal abutments. The rate of technical complications was found to be 1.3 times (rate ratio = 1.3; 95% CI: 0.7 to 2.4) higher for implants with external implant-abutment connection than with internal implant-abutment connection.

The most common technical complication was abutment screw loosening, which was reported for 4.6% of the abutments. In total, 99 abutment screws were found loose (2 ceramic and 97 metal abutments). One of the studies was an outlier with 29.1% abutment screw loosening.[19] In that study, Brånemark gold abutment screws were used. The second most common technical complication was crown loosening, reported in 13 studies with an incidence of 4.3% (93 loosened crowns out of 2,186 evaluated crowns). In total, 9 loosened crowns were metal-ceramic and 6 were all-ceramic crowns, while 8 studies did not specify the prosthesis material of loose crowns.[18,19,22,24,26,30,33,37] Metal abutments supported all loosened crowns.The third most common complication was chipping of the veneering ceramic, which was evident in 2.7% of the abutments supporting single implant crowns (55 crowns supported by metal abutments and 4 crowns supported by ceramic abutments).

Misfit was reported in seven studies and occurred at 20 out of 2,186 implant-abutment connections (1 ceramic and 19 metal abutments).[20,23,24,32,38,39,41] Abutment fractures were found in 0.2% of abutments reported from two studies.[37,38] In one study, three abutment fractures occurred at internally connected titanium abutments with a narrow neck part connecting to Bicon implants.[37] The other retrospective study described a broken customized CAD/CAM zirconia abutment after 2 months (Procera, Nobel Biocare).[38] This abutment type is externally connected to the implant. The incidence of abutment screw fractures was low at 5 years with 0.2% and was reported at externally connected metal abutments only.[18,19,27]

Biologic Complications

Biologic complications (from a total of 2,186 abutments) affected both soft and hard tissue (Table 6). Fistulae (n = 5), general peri-implant soft tissue inflammations (n = 5), mucositis (n = 3), and bleeding (n = 2)

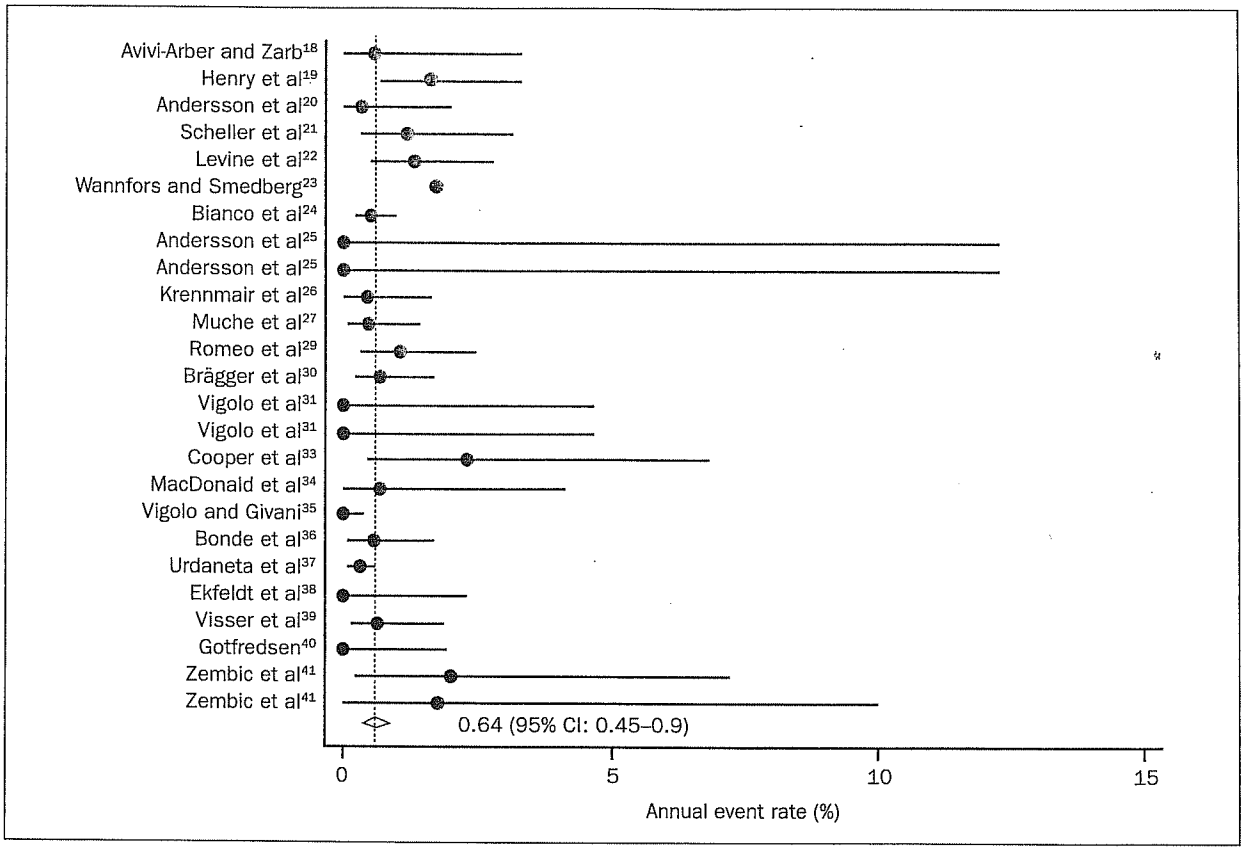

Fig 3 Annual implant failure rates (per 100 years).

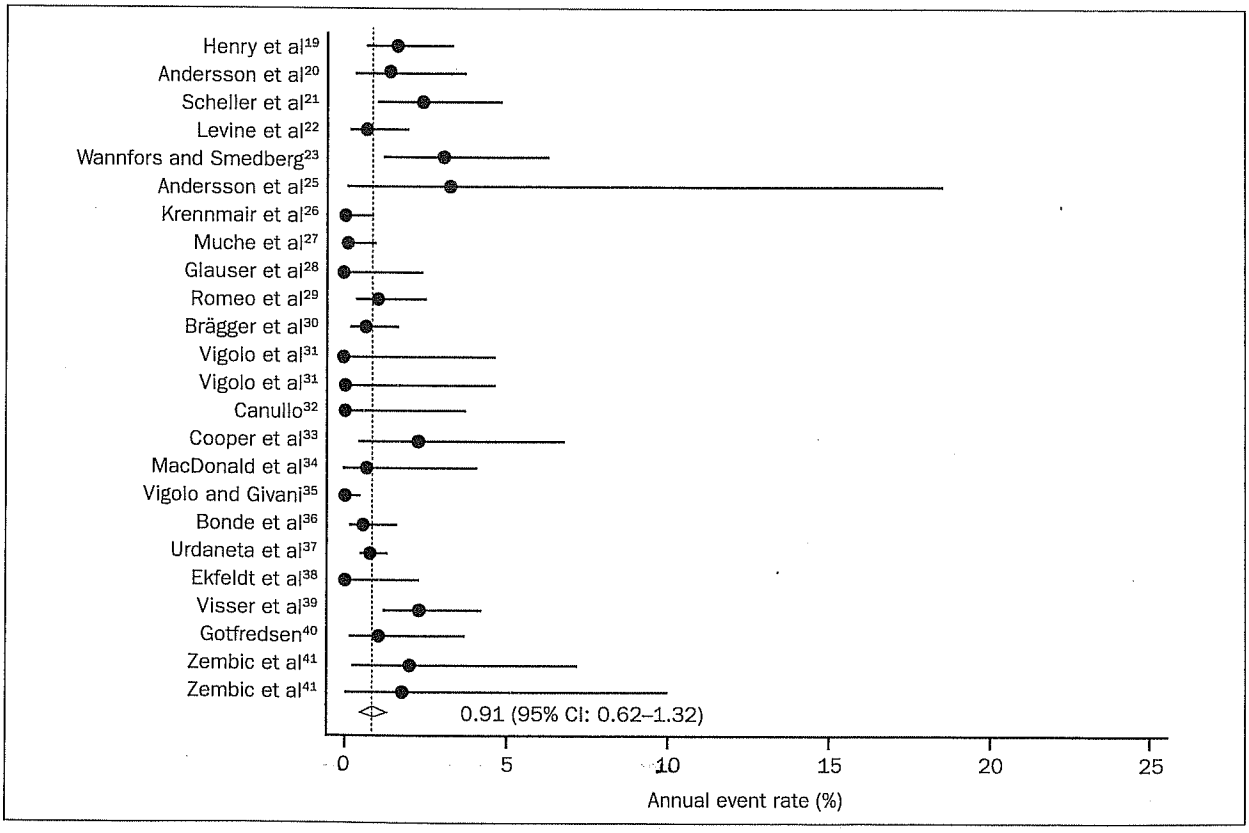

Fig 4 Annual prosthesis failure rates (per 100 years).

Table 5 Technical Complications Occurring in Abutments and Prostheses

Study	Year of publication	Total no. of abutments/ prostheses	Abutment fractures	Misfit	Screw fractures	Abutment screw loosening	Chipping	Crown loosening
Avivi-Arber and Zarb[18]	1996	42	NR	NR	2	NR	5	1
Henry et al[19]	1996	96	0	NR	1	28	NR	13
Andersson et al[20]	1998	55	NR	1	NR	1	NR	NR
Scheller et al[21]	1998	65	NR	NR	NR	4	7	3
Levine et al[22]	1999	157	0	NR	0	4	NR	18
Wannfors and Smedberg[23]	1999	76	NR	8	NR	14	2	NR
Bianco et al[24]	2000	229	NR	9	NR	22	3	13
Andersson et al[25]	2001	10	2	NR	0	0	0	0
Andersson et al[25]	2001	10	0	NR	0	0	0	0
Krennmair et al[26]	2002	146	0	NR	0	5	1	12
Muche et al[27]	2003	205	0	NR	1	8	2	NR
Glauser et al[28]	2004	36	0	NR	NR	2	3	NR
Romeo et al[29]	2004	121	NR	NR	0	0	2	4
Brägger et al[30]	2005	69	0	NR	0	2	3	1
Vigolo et al[31]	2006	20	0	NR	0	0	0	0
Vigolo et al[31]	2006	20	0	NR	0	0	0	0
Canullo[32]	2007	30	0	0	0	0	1	0
Cooper et al[33]	2007	43	0	NR	0	0	3	2
MacDonald et al[34]	2009	17	0	NR	0	3	0	3
Vigolo and Givani[35]	2009	182	NR	NR	0	0	0	0
Bonde et al[36]	2010	52	0	NR	0	3	3	3
Urdaneta et al[37]	2010	326	3	NR	NR	NR	18	18
Ekfeldt et al[38]	2011	40	1	1	0	NR	NR	0
Visser et al[39]	2011	92	NR	1	NR	1	1	NR
Gotfredsen[40]	2012	19	0	NR	0	2	2	2
Zembic et al[41]	2013*	18	0	0	0	0	0	0
Zembic et al[41]	2013*	10	0	0	0	0	3	0

*Available ahead of print in 2012. Total summary estimate (95% CI, random-effects Poisson regression) for technical complications: 2.5 (1.8–3.6); estimated 5-year failure rate for technical complications: 11.8% (8.5–16.3). NR, not reported.

were described with regard to the soft tissue.[19,20,31,36,38] With regard to hard tissue, peri-implantitis (n = 14), pocket probing depths ≥ 5 mm (n = 1), and bone loss of more than 2 mm was mentioned in nine studies.[19–21,24,30,34,38–40] A peri-implant abscess was a rare event and found only in one study.[40]

The estimated 5-year rate for biologic complications was 6.4% (95% CI: 3.3% to 12.0%). The biologic failure rate per 100 abutment years ranged from 0.7% to 2.6% (Fig 6). The incidence of biologic events was almost twice as high for ceramic abutments compared to metal abutments (10.4%; 95% CI: 1.9% to 46.7% vs. 6.1%; 95% CI: 3.1% to 12.0%) (Table 6 and Fig 6). Even though, there was no significant difference ($P > .05$) between metal and ceramic abutments.

The rate of biologic complications was found to be two times (rate ratio = 2.0, 95%; CI: 0.4 to 8.9) higher for implants with external implant-abutment connection than with internal implant-abutment connection. This difference did not reach statistical significance ($P > .05$).

Esthetic Complications

Esthetic outcomes were reported in several studies in a nonstandardized way. Whereas some studies used questionnaires for patients to rate the esthetic outcome, other studies evaluated the esthetic outcome of the crowns by dentists and patients subjectively.[20,23,26,38–40] In addition, some studies evaluated the papilla height and/or peri-implant mucosal color.[34,42]

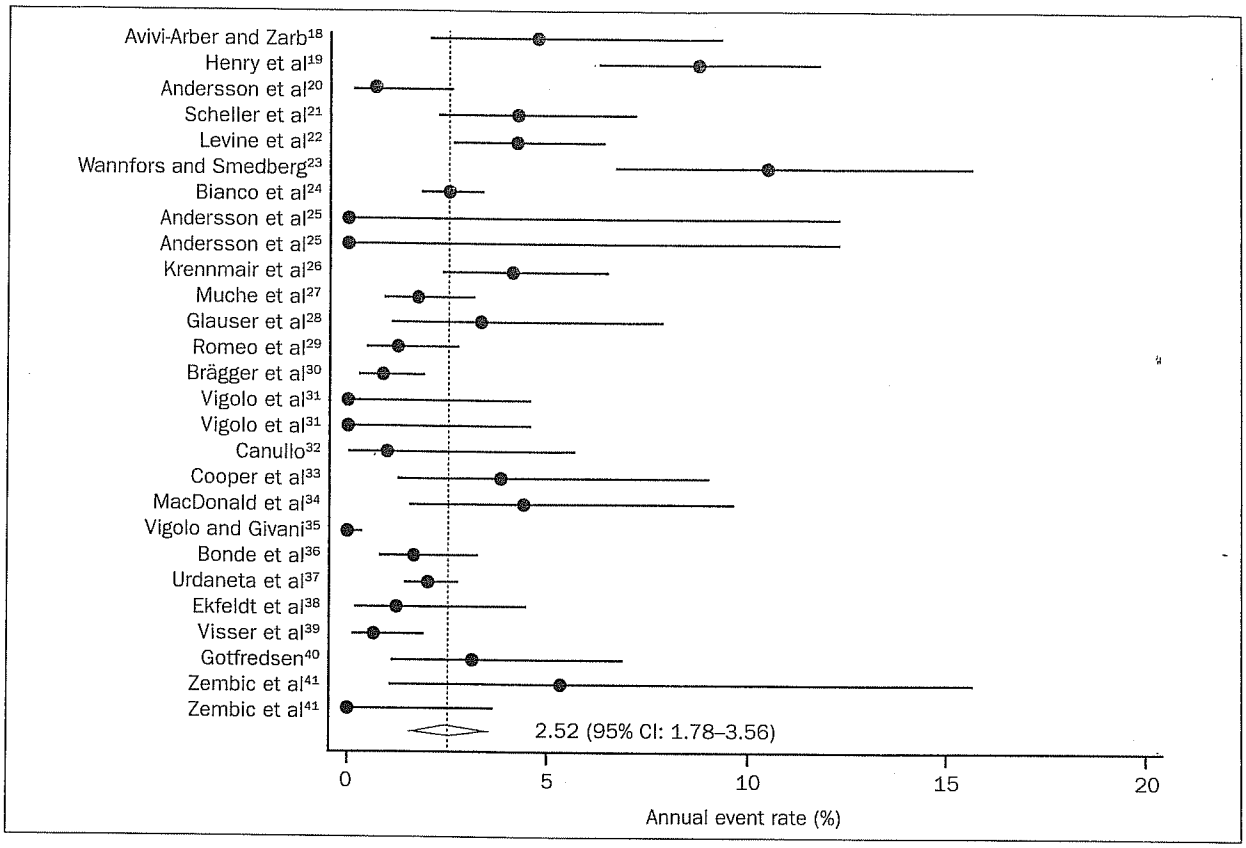

Fig 5 Annual rates for technical complications at ceramic and metal abutments (per 100 years).

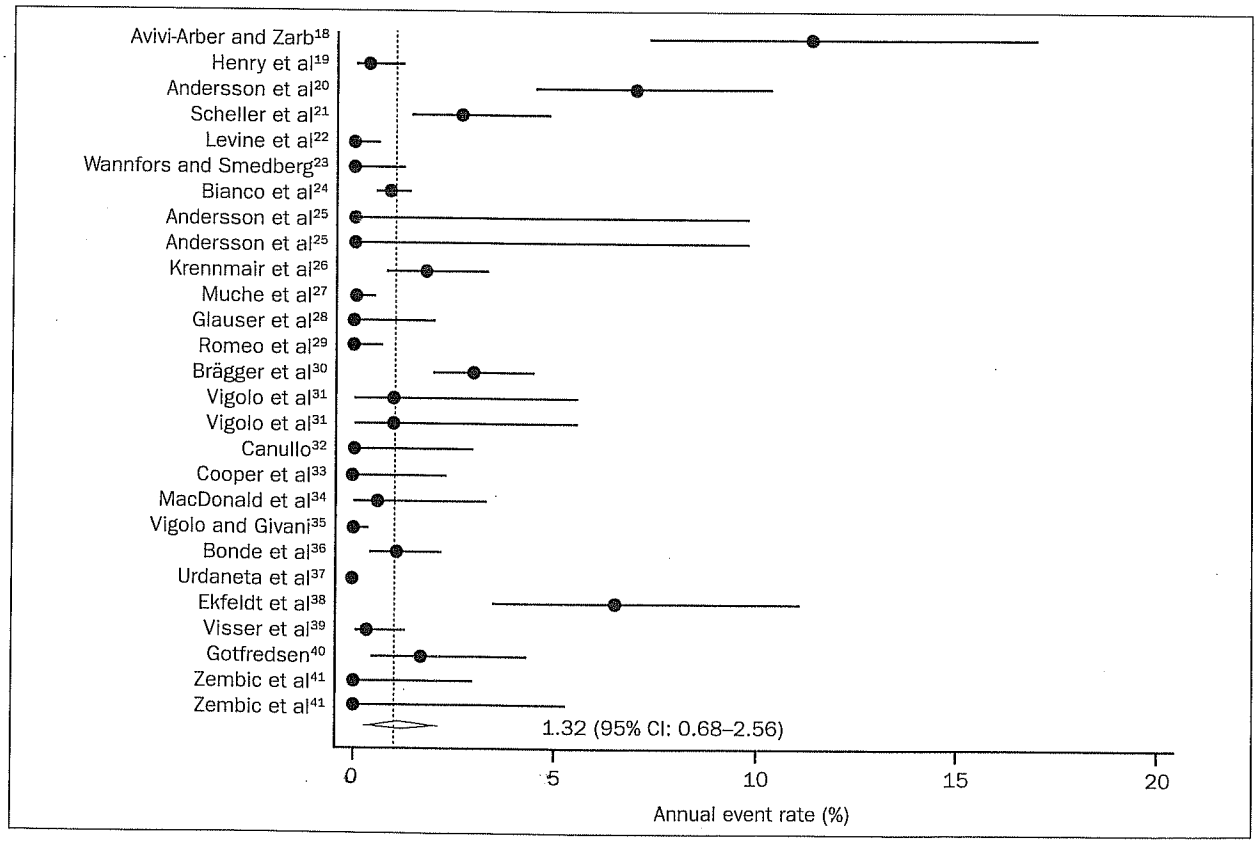

Fig 6 Annual rates for biologic complications at ceramic and metal abutments (per 100 years).

Table 6 No. of Biological and Esthetic Complications at Abutments/Prostheses and Estimated 5-Year Failure Rrate

Study	Year of publication	Total no. of abutments/ prostheses	Bone loss (> 2 mm)	Soft tissue complication	Recession	Biologic complications	Esthetic complications
Avivi-Arber and Zarb[18]	1996	42	NR	7	5	12	NR
Henry et al[19]	1996	96	1	NR	NR	1	NR
Andersson et al[20]	1998	55	11	1	NR	12	0
Scheller et al[21]	1998	65	4-8	5	NR	0	1
Levine et al[22]	1999	157	4	NR	NR	4	NR
Wannfors and Smedberg[23]	1999	76	0	NR	NR	NR	7
Bianco et al[24]	2000	229	6	2	2	10	5
Andersson et al[25]	2001	10	0	0	0	0	0
Andersson et al[25]	2001	10	0	0	0	0	0
Krennmair et al[26]	2002	146	0	1	4	5	4
Muche et al[27]	2003	205	NR	NR	NR	NR	NR
Glauser et al[28]	2004	36	0	0	NR	0	NR
Romeo et al[29]	2004	121	NR	NR	NR	NR	NR
Brägger et al[30]	2005	69	13	NR	NR	13	NR
Vigolo et al[31]	2006	20	0	0	0	1	NR
Vigolo et al[31]	2006	20	0	0	0	1	NR
Canullo[32]	2007	30	NR	0	NR	0	NR
Cooper et al[33]	2007	43	0	0	0	0	NR
MacDonald et al[34]	2009	17	1	NR	NR	0	NR
Vigolo and Givani[35]	2009	182	0	NR	NR	NR	NR
Bonde et al[36]	2010	52	0	NR	NR	7	NR
Urdaneta et al[37]	2010	326	NR	NR	NR	NR	NR
Ekfeldt et al[38]	2011	40	3	NR	1	9	0
Visser et al[39]	2011	92	NR	NR	1	1	4
Gotfredsen[40]	2012	19	1	1	NR	2	NR
Zembic et al[41]	2013*	18	0	0	0	0	0
Zembic et al[41]	2013*	10	0	0	0	0	0

*Available ahead of print in 2012. Total summary estimate (95% CI, random-effects Poisson regression) for biologic complications: 1.32 (0.68–2.56); total summary estimate (95% CI, random-effects Poisson regression) for esthetic complications: 0.19 (0.08–0.47); estimated 5-year failure rate for biologic complications: 6.4% (3.3–12.0); estimated 5-year failure rate for esthetic complications: 0.94% (0.38–2.30). NR, not reported.

The overall estimated 5-year esthetic complication rate for single-implant prostheses was 0.9% (95% CI: 0.4% to 2.3%) (Fig 7). Esthetic problems occurred in 1.0% (95% CI: 0.4% to 2.5%) of all implant prostheses supported by metal abutments. No esthetic complications were reported in the five studies using ceramic abutments. The instrumented color analysis of mucosal tissues found a tissue color change both for metal and ceramic abutments.[13,41] However, no perceivable difference between titanium and zirconia abutments was visually observed when the thickness of the mucosa exceeded 2 mm.

The rate of negative esthetic events was found to be 1.3 times higher (rate ratio = 1.3; 95% CI: 0.2 to 8.1, $P > .05$) at prostheses with external implant-abutment connection than with internal. This difference did not reach statistical significance.

DISCUSSION

The 5-year survival rate of single implant abutments was 98%. Thus, both ceramic and metal abutments survived at a rate of more than 95% at 5 years.

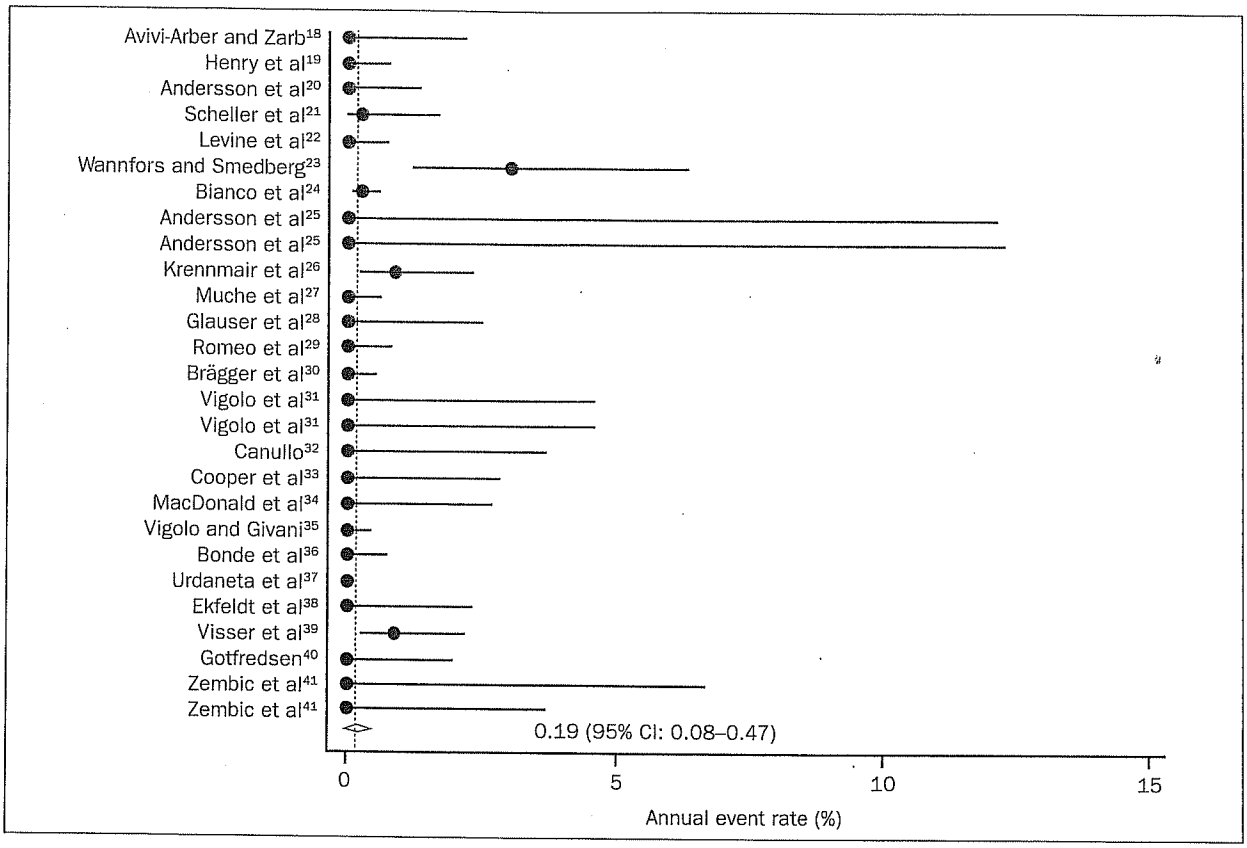

Fig 7 Annual rates for esthetic complications at ceramic and metal abutments (per 100 years).

The most common complications at 5 years were technical complications (11.8%), followed by biologic complications (6.4%). Esthetic complications were fewest and occurred in 0.9% at 5 years.

Implant Survival

The overall 5-year implant survival rate of single implants amounted to 96.9% based on this systematic review. This result is in accordance with the results of two systematic reviews on single implants reporting 5-year survival rates of 96.4% and 97.2%, respectively.[12,13] With today's optimized implant surfaces and configurations, most of the implant failures are likely to occur before loading.[12] Thus, not many failures are expected to happen at 5 years of clinical function. This might explain the positive implant survival rates found in the existing studies.

Abutment Survival

The present results correspond to the results of a previous systematic review on implant abutments, also reporting an estimated 5-year abutment survival rate of 98%.[13] Most of the evaluated abutments were metal abutments (n = 2,052). From the 134 ceramic abutments, mainly zirconia abutments were evaluated (124 zirconia, 10 alumina abutments). In total, six abutments fractured, one externally connected zirconia abutment, two externally connected alumina abutments, and three titanium abutments being internally connected to Bicon implants.[25,37,38]

Alumina abutments were the first generation of ceramic abutments. Previous studies demonstrated a failure rate between 1.9% and 7% after 1 to 5 years of clinical use.[25,43,44] In the above-mentioned RCT alumina abutments were compared with the "gold standard" titanium and showed a lower survival rate of 93% compared to 100% for titanium abutments.[25] This explains the introduction of a stronger substitute material.

The subsequently developed high-strength ceramic zirconia showed superior mechanical properties with much higher bending strength and fracture toughness compared to alumina.[45] Thus, a superior clinical behavior for zirconia might be expected and zirconia might even serve as an alternative to metal in various indications. However, clinical studies on zirconia abutments are scarce (only four studies in this review). When zirconia and titanium abutments were compared in a RCT, the survival rate for both materials was 100% after 5 years of function.[41] Other studies with a shorter follow-up confirm these positive results for zirconia abutments.[28,32,46–48]

Two internally connected zirconia abutments fractured within 2 months in a retrospective study.[38] Among several factors influencing the stability of zirconia abutments, the abutment wall thickness is discussed as being critical.[49] A minimum abutment wall thickness of 0.5 mm was recommended for zirconia abutments, especially when using CAD/CAM techniques.[50] The fractured abutment consisted of an internal insert of titanium to adapt to the implant.[38] The abutment wall thickness might have been insufficient, which might have caused the fractures after a short period of only 2 months.

No clinical long-term data are available for zirconia abutments. Taking the nature of ceramics into account, one might assume fatigue fractures over time.[51] On the other hand, the fatigue performance of zirconia is likely increased through its behavior called "transformation toughening" which causes a resistance to crack growth compared to other polycrystalline ceramics.[52] This might explain the positive clinical results for zirconia abutments thus far.

Metal abutments are still considered the "gold standard" due to high survival rates and excellent physical properties.[20] When gold and titanium abutments were compared in a RCT there were no significant differences with regard to survival and peri-implant bone and soft tissue parameters after 4 years of clinical service.[31]

Three internally connected titanium abutments fractured in one study.[37] These abutments are constructed for specially configured locking-taper implants (Bicon) containing a thin neck part, which might be prone to fracture. Furthermore, the crown-to-implant ratio is increased in this implant-abutment configuration, which might increase the stress at the weakest point, ie, the thin abutment neck part, and thus contribute to its fracture.

Usually, fractures of metal abutment are a rare event and were estimated to occur in only 0.07% at 5 years.[13] The only additional fractures were limited to one specific implant system (Bicon implants).[37]

It has to be taken into account that the number of observed metal abutments (n = 2,052) was much higher than of ceramic abutments (n = 134). On one hand, this might explain why no significant difference between the outcomes of ceramic and metal abutments was calculated. On the other hand, the results have to be interpreted with caution. It may be recommended that the application of ceramic abutments should be selective and not generalized for every situation.

There was no difference in the occurrence of abutment failures for implants with internal compared to external implant-abutment connection. In contrast, a tendency towards less risk for fracture was observed with abutments having an internal implant-abutment connection in the previous review.[13]

Technical Complications

The most common technical complication found was abutment screw loosening (4.6%), mostly observed with metal abutments. This finding is in agreement with several other studies.[12,13,53,54] The high rate for abutment screw loosening in the present study might partly be explained by one study, which reported 29.1% of screw loosenings and used the first generation of Brånemark gold abutment screws, known for this problem.[19] The majority of the abutment screws loosened in externally connected abutments ($n_1 = 85$) compared to internally connected ones (n = 14). The tendency of less screw loosening at internal implant-abutment connections is supported by other studies.[13,55,56] A recent systematic review on abutment screw loosening for single-implant restorations did not find a difference with internally compared to externally connected implants.[57] The authors concluded that abutments screw loosening is irrespective of the implant-abutment geometry and occurs rarely, provided that a proper antirotational torque is applied.[57]

The second most common technical complication was crown loosening (4.3%). Metal abutments supported all loosened crowns. The cement used was not evaluated. Since in some parts of the world there is a preference for the use of provisional cement for implant prostheses, one might speculate that a high rate of crown loosening is plausible.

The chipping rate of veneering ceramics (2.7%) in the present study was less than reported in previous systematic reviews (4%) at 5 years.[12,13]

Biologic and Esthetic Complications

There is a lack of classification for the report of biologic complications. Consequently, negative events were reported in a non-standardized way and comparison of the studies was impeded. There was a trend for a higher incidence of biologic complications with ceramic abutments (10.4%) compared to metal abutments (6.1%), but without statistical significance. This finding is rather unusual. Animal studies demonstrated a comparable soft tissue integration of alumina, zirconia, and titanium.[58–60] Other studies found even fewer inflammatory cells in the epithelium around zirconia than titanium and gold, and finally less bacterial adhesion at zirconia clinically.[61–64]

Another systematic review indicated a similar soft tissue complication rate of 7.1% after 5 years.[12] Even though the proportion of biologic complications at externally connected abutments was found to be 1.7 times that of internally connected abutments, the type of connection did not have a significant influence on the estimated rate of biologic complications ($P > .05$).

In contrast to the results of a previous review, the incidence of recession in the present study was higher

at metal abutments.[13] The reason for this observation remains unclear. The present review indicated no esthetic failures with prostheses on ceramic abutments. This finding is in accordance with a previous review and RCT where less soft tissue discoloration was found for ceramic abutments.[13,54]

There is a large heterogeneity among the studies concerning the evaluation of the esthetics, due to a lack of standardization. The scientific value of the estimated 5-year esthetic complication rate is rather low. Standardized esthetic parameters, such as the pink and white esthetic score[65,66] are thus strongly advisable and should be applied more often in future studies on implant prostheses.

CONCLUSIONS

The present meta-analysis on single implant prostheses presents high survival rates of single implants, abutments and prostheses after 5 years of function.

There are no performance differences in technical or biologic outcomes for ceramic and metal abutments. The only significant finding pertaining to esthetics was a difference in tissue color with both metal and ceramic abutments, which was greater for metal abutments up to 2 mm mucosal thickness.

Similarly, no differences were found for either external or internal implant-abutment connections. The incidence of technical complications is higher than for either esthetic or biologic complications.

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CAD/CAM Technology for Implant Abutments, Crowns, and Superstructures

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Purpose: *The aim of this systematic review was to compare implant prostheses fabricated by computer-assisted design and computer-assisted manufacturing (CAD/CAM) with conventionally fabricated implant prostheses when assessing esthetics, complications (biologic and mechanical), patient satisfaction, and economic factors.* ***Materials and Methods:*** *Electronic searches for clinical studies focusing on long-term follow-up were performed using the PubMed and Ovid search engines. Concentrating on the restorative aspect of the CAD/CAM technology applicable to implant dentistry, pertinent literature was divided into articles related to implant abutments, crowns, and frameworks.* ***Results:*** *A total of 18 articles satisfied the inclusion criteria. Two articles reported on CAD/CAM crowns, six on abutments, and 10 on implant-supported CAD/CAM frameworks. The mean survival rate for CAD/CAM crowns was 98.85% and for CAD/CAM abutments 100%. The mean survival rate for CAD/CAM frameworks was 95.98%.* ***Conclusion:*** *Based on the current literature, CAD/CAM fabricated crowns, abutments, and frameworks demonstrate survival rates comparable to conventionally fabricated prostheses. Implant survival appears unaffected by fabrication technique. Since this technology encompasses several manufacturing variations, a new definition might be necessary to accurately define the processes under which the CAD/CAM restorations are fabricated. "Complete CAD/CAM product" where no or minimal manual intervention is employed could be a possible term.* Int J Oral Maxillofac Implants 2014;29(suppl):117–136. doi: 10.11607/jomi.2014suppl.g2.3

Key words: *abutment, CAD/CAM, crown, dental prosthesis implant-supported, implant-supported framework, implant superstructure*

Computer-assisted design (CAD) and computer-assisted manufacturing (CAM) have been gaining increased use in implant dentistry over the past 10 years. Continuous improvements to CAD/CAM technology have started to challenge the technique of fabricating implant-supported prostheses and abutments using conventional methods. Fundamental to considering the routine use of these techniques for the fabrication of implant-supported prostheses (ISP) in every clinical situation is the premise that the outcomes are improved when compared to traditional fabrication techniques.

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The purpose of this systematic review was to answer the focus question: "How do CAD/CAM implant-supported prostheses in patients with missing teeth, who have one or more dental implants, perform compared with conventionally fabricated prostheses, when assessing esthetics, complications (biologic and mechanical), patient satisfaction, and economic factors?"

MATERIALS AND METHODS

Focus Question

Framing of the research question was undertaken using the PICO strategy.[1,2] The focus question was constructed based on the four PICO elements: Population, Intervention, Comparison, and Outcome. Following development of the focus question by the authors, it was accepted and confirmed by consensus within the working group.

Search Strategy

A systematic and comprehensive search of the literature was conducted (Table 1). The search was started in August 2012 and completed in January 2013. Electronic databases (Medline) were searched using the MeSH

Table 1 Systematic Search Strategy

Focus question:	**How do CAD/CAM implant prostheses in patients with missing teeth who have one or more dental implants perform comparable to conventionally fabricated implant prostheses when assessing esthetics, complications (biologic and mechanical), patient satisfaction, and economic factors.**
Search strategy	
Population	#1 (partially dentulous) OR (partially edentulous) OR (edentulous)
Intervention or exposure	#2 (Computer-Aided Design [MeSH]) AND (Dental Prosthesis, Implant-Supported) [MeSH] #3 (Computer-Aided Design [MeSH]) AND (Dental Implant-Abutment Design [MeSH]) #4 (Computer-Aided Design [MeSH]) AND (Dental Implants [MeSH]) AND crown #5 (Computer-Aided Design [MeSH]) AND (Dental Implants [MeSH]) AND denture #6 (Computer-Aided Design [MeSH]) AND (Dental Implants [MeSH]) AND prosthesis #7 (Computer-Aided Design [MeSH]) AND (Dental Implants [MeSH]) AND reconstruction #8 (Computer-Aided Design [MeSH]) AND (Dental Implants [MeSH]) AND restoration #9 (Computer-Aided Design [MeSH]) AND (Dental Implants [MeSH]) AND superstructure #10 CAD CAM (keywords and select subject Heading) + Dental Prosthesis, implant supported (keywords and select subject Heading) #11 CAD CAM (keywords and select subject Heading) + Dental Abutment (keywords and select subject Heading) #12 CAD CAM + dental implant + crown #13 CAD CAM + dental implant + dentures #14 CAD CAM + dental implant + dental restoration
Comparison	#15 ((conventional techniques) OR (cast techniques) OR (stock abutments) OR (prefabricated abutments))
Outcome	#16 ((complications) OR (precision) OR (patient satisfaction) OR (esthetics))
Search combination	#1 AND #2 (or #3, #4, #5, #6, #7, #8, #9) AND #15 AND #16 #10 (or #11, #12, #13, #14) AND #15 AND #16
Database search	
Electronic	PubMed, Ovid
Journals	Peer reviewed journal
Selection criteria	
Inclusion criteria	All levels of the hierarchy of evidence except for expert opinion and case reports Studies with 10 case series or more Clinical observational or experimental studies reporting a minimum of 12 mo follow-up Studies with CAD/CAM techniques designed for implant use or/as directed by implant manufacturer
Exclusion criteria	Case reports and case series Clinical experimental studies with less than 1 y follow-up Laboratory studies Non-prosthetic publications Papers with no abstract available Finite element analyses Studies with non-endosseous root form implants Not dentally related articles and review or commentary articles

terms: "Computer-Aided Design" [MeSH] AND "Dental Prosthesis, Implant-Supported" [MeSH] (201 results) and "Computer-Aided Design" [MeSH] AND "Dental Implant-Abutment Design"[MeSH] (10 results).

The search was expanded using MeSH terms including keyword (prosthesis, crown, denture, reconstruction, restoration, and superstructure): "Computer-Aided Design" [MeSH] AND "Dental Implants" [MeSH] AND "crown" (25 results); "Computer-Aided Design" [MeSH] AND "Dental Implants" [MeSH] AND "denture" (86 results); "Computer-Aided Design" [MeSH] AND "Dental Implants" [MeSH] AND "prosthesis" (220 results); "Computer-Aided Design"[MeSH] AND "Dental Implants" [MeSH] AND "reconstruction" (18 results); "Computer-Aided Design" [MeSH] AND "Dental Implants" [MeSH] AND "restoration" (74 results); "Computer-Aided Design" [MeSH] AND "Dental Implants" [MeSH] AND "superstructure" (6 results).

All results were filtered for human studies and English language, yielding a total of 642 articles.

In addition, an Ovid search was carried out for the headings: "CAD CAM (key words and select subject heading) + Dental Prosthesis, implant supported (key words and select subject heading)" (207 results) and

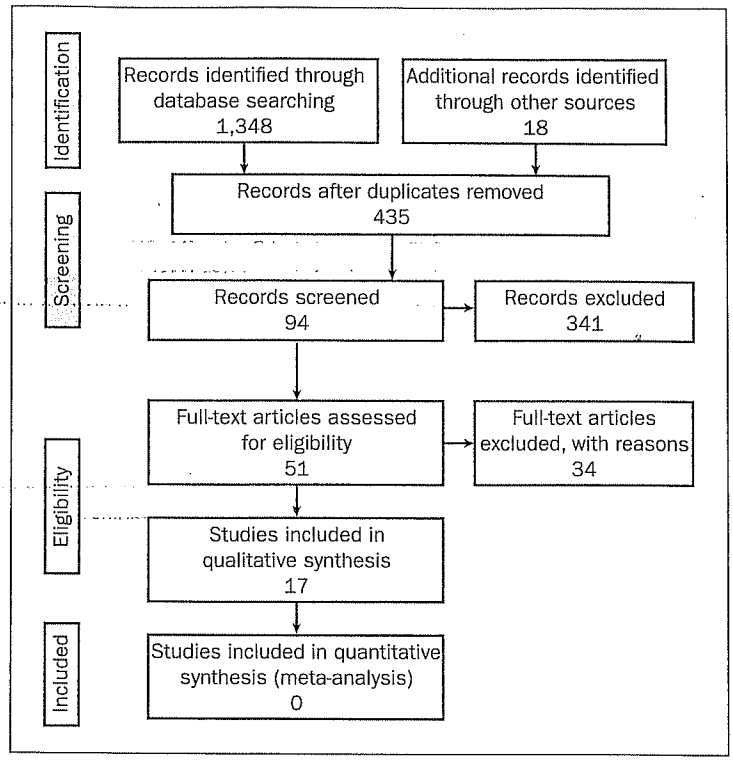

Fig 1 Literature search and selection of articles.

"CAD CAM (key words and select subject heading) + Dental Abutment (key words and select subject heading)" (236 results). The search was further expanded using the key words: "CAD CAM + dental implant + crown" (66 results); "CAD CAM + dental implant + dentures" (96 results); "CAD CAM + dental implant + dental restoration" (101 results).

A total of 706 articles were identified. Relevant journals were hand-searched to identify additional articles. The bibliographies of selected papers and published review articles on the topic were also scanned for relevant publications. All searches resulted in a total of 1,348 articles, which were collected in the reference manager software Endnote X4 (Thomson Reuters). All duplicates were electronically discarded and 435 articles were considered for review.

Selection and Exclusion Criteria

All levels of evidence, except for expert opinion, were considered to provide a comprehensive search of the literature. The articles excluded from full-text analysis were:

- Individual case reports
- Case series with less than 10 cases
- Clinical experimental studies with less than 1 year follow-up
- Laboratory studies
- Non-prosthetic publications
- Papers with no abstract available
- Finite element analyses
- Studies on non-endosseous root-form implants
- Articles not related to dentistry
- Review or commentary articles

In addition, the CAD/CAM technology discussed in the article must have been designed for implant use and carried out in accordance to the implant manufacturer's recommendations. The authors screened all 435 articles independently. They then met to review any disagreement on articles inclusion, which was resolved through discussion. After screening, 51 articles were identified as appropriate for full-text review. However, 7 of these were systematic review articles. A total of 17 articles were then selected for data extraction (Fig 1).

Quality Assessment

A quality assessment of each included publication was undertaken. For randomized control trials and controlled clinical trials, the Cochrane Collaboration's tool for assessing risk of bias was utilized.[3] Nonrandomized controlled studies were assessed for quality using the Newcastle-Ottawa Scale.[4]

Assessment Scale for Observational Studies

Results and conclusions from the included studies and the relevant data were extracted and tabulated. The results were then presented and conclusions drawn.

Table 2 Selected CAD/CAM Crown Articles

Study	Year published	No. of patients	No. of crowns	Retention method	Material	Cumulative survival rate	Implant type
Hosseini et al[5]	2011	36	75	All cement-retained	Ti and Zr abutments; Procera Zirconica core crowns (CAD/CAM)	100%	Astra Tech
Henriksson and Jemt[6]	2003	20	24	13 cement-retained, 11 screw-retained	Procera Alumina Oxide	100%	Nobel Biocare

Table 3 Selected CAD/CAM Abutment Articles

Study	Year published	Patients	Abutments	Material	CAD/CAM system	Cumulative survival rate
Zarone et al[11]	2005	44*	58	Aluminum Oxide†	Procera, Nobel Biocare	98.3% (one patient lost to follow-up)
Zembic et al[8]	2009	22	40	20 Zr 20 Ti	Procera, Nobel Biocare	100%
Canullo[10]	2007	25	30	Zr bonded to Ti†	ZirconZahn	100%
Furze et al[12]	2012	10	10	Zr	Straumann Cares	100%
Sailer et al[7]	2009	22	40	20 Zr, 20 Ti	Procera, Nobel Biocare	100%
Zembic et al[9]	2012	22	40	20 Zr, 20 Ti	Procera, Nobel Biocare	88.9% Zr 90% Ti

*Report included some crowns on natural teeth, but disclosed abutment numbers.
†CAD design reported, scanned wax body used.
NR = not reported.

Table 4 Study and Patient Characteristics of the Reviewed CAD/CAM Crown and CAD/CAM Abutment Studies

Study	Year of publication	Journal	Study design	CAD/CAM system	Restoration type	Patients
Crowns						
Hosseini et al[5]	2011	EJOI	RCT	Procera	Single crown	36
Henriksson and Jemt[6]	2003	IJP	Prospective clinical report	Procera	Single crown	20
Abutments						
Zarone et al[11]	2005	CIDRR	Retrospective review	Procera	Single crown	86
Zembic et al[8]	2009	COIR	RCT	Procera	Single crown	22
Canullo[10]	2007	IJP	Prospective	ZirconZahn	Single crown	25
Furze et al[12]	2012	QUINT	Consecutive case series	Straumann Cares	Single crown	10
Sailer et al[7]	2009	COIR	RCT	Procera	Single crown	22
Zembic et al[9]	2012	COIR	RCT	Procera	Single crown	22

NR = not reported; FDPs = fixed dental prostheses; RCT = randomized-controlled clinical trial; IJP = *The International Journal of Prosthodontics*; EJOI = *European Journal Oral Implantology*; CIDRR = *Clinical Implant Dentistry & Related Research*; COIR = *Clinical Oral Implants Research*; QUINT = *Quintessence International*.

Peer Review

Prior to the consensus conference, each manuscript in the working group was submitted to the *International Journal of Oral and Maxillofacial Implants* for peer review. Corrections, amendments, and revisions were then completed. Once accepted for publication by the editor of the journal, the review papers provided the basis for the formulation of consensus statements and treatment recommendations within each working group.

RESULTS

The studies included that reported on crowns are presented in Table 2. The studies included that reported on abutments are presented in Table 3. The patient characteristics of the reviewed studies are presented in Table 4.

Follow-up (mo)	CAD/CAM system	Patients dropped out
Mean 13.5 (11–22)	Procera (Nobel Biocare)	0/30
12	Procera (Nobel Biocare)	1

Implant type	Mean follow-up (mo)	Patients dropped out
Straumann, Brånemark	48	NR
Brånemark RP	36	4
TSA Implantdent	40	NR
Straumann Bone Level	12	0
Brånemark RP	12.6	2
Brånemark RP	67.2	4

Age range (y)	Mean age (y)	Setting	Patients dropped out
19-57	28.1	University	0
18-62	29	Private practice	1
18-62	NR	University	NR
NR	41.3	NR	2
25-70	52.3	Private Practice	NR
26-61	45.1	Private practice	0
NR	41.3	NR	2
NR	41.3	NR	4

CAD/CAM Crowns

Only two studies were identified: one randomized controlled trial (RCT)[5] and a prospective clinical report.[6] Fifty patients were treated with a total of 99 implants supporting single crowns in patients with an age ranging from 19 to 60.1 years of age. The mean age of the patient population was 28 years of age for the study by Hosseini et al[5] and 45.1 years of age for the study by Henriksson and Jemt.[6] The mean survival rate of the crowns was 98.85%. The implant survival rate was unaffected by the crown fabrication technique. The failure rates and survival of implants supporting CAD/CAM crowns are summarized in Table 5. The failure rates, survival rates, and complications rates for CAD/CAM crowns[7–12] are presented in Tables 6 and 7.

Hosseini et al[5] evaluated the biologic, technical, and esthetic outcomes of implant-supported single crowns (ISSC) treating single tooth agenesis in the premolar region. Thirty-eight zirconia abutments and crowns (test group) were compared to 37 metal abutments and metal ceramic crowns (control group). In the test group, 38 zirconia abutments (ZrDesign, Astra Tech) supported all-ceramic crowns fabricated using CAD/CAM milled zirconia copings and layered with HeraCeram zirconia veneering porcelain. KaVo zirconia copings (Ivoclar Vivadent) were used in 27 of 38 cases, and Procera zirconia copings (Nobel Biocare) were used in 11 of 38 cases. In the control group, 37 metal abutments were used to support metal ceramic crowns. In 35 of these cases, TiDesign (Astra Tech) titanium abutments were used and 2 cases used a gold alloy Cast-to abutment (Astra Tech) modified using conventional fabrication techniques. No implant failures were recorded and no difference in mean marginal bone loss was seen between the test and control groups. Two technical complications (2 of 37) were reported, both from the control group. No technical complications were reported for the test group. The esthetic outcomes were evaluated using both patient-reported VAS scores and professionally reported esthetic outcomes employing the Copenhagen Index Score (CIS). No significant difference in esthetic parameters was reported when comparing the test and control group for patient-reported outcomes. However, the professionally reported color match was significantly better for the all-ceramic crowns ($P = .031$). No difference was seen in mucosal discoloration between the all-ceramic crown group and the metal-ceramic crown group. Mucosal inflammation was reported in 7 of 10 (16.3%) of all-ceramic crowns, and 3 of 10 (7%) of metal-ceramic crowns.

Henriksson and Jemt[6] evaluated the clinical performance of customized ceramic single-implant Procera abutments in combination with two different crown types. This prospective clinical study evaluated 20 patients consecutively treated for single-unit implant restorations in the maxillary anterior region. Customized Procera alumina oxide abutments were fabricated for the 24 implants. In 13 cases, the crowns were fabricated using Procera techniques and cemented onto the abutment using zinc phosphate cement. In 11 cases, porcelain was fused directly onto the abutment to provide a direct screw-retained restoration with a screw access hole on the palatal surface.

Table 5 Failure Rates and Survival of Implants Supporting CAD/CAM Crowns and Abutments

Study	Year of publication	Restoration type	Loading	Implants	Mean follow-up time (mo)
Crowns					
Hosseini et al[5]	2011	Single crown	Delayed	75	13.5
Henriksson and Jemt[6]	2003	Single crown	Delayed	24	12
Abutments					
Zarone et al[11]	2005	Single crown	Delayed	58	48
Zembic et al[8]	2009	Single crown	Delayed	40	36
Canullo[10]	2007	Single crown	Delayed	30	40
Furze et al[12]	2012	Single crown	Delayed	10	12
Sailer et al[7]	2009	Single crown	Delayed	40	12.6
Zembic et al[9]	2012	Single crown	Delayed	40	67.2

ZR = zirconia group; Ti = titanium group.

Table 6 Failure Rates and Survival of CAD/CAM Crowns and Abutments

Study	Year of publication	Restoration type	Loading	Total restorations	Restorations lost to follow-up
Crowns					
Hosseini et al[5]	2011	Single crown	Delayed	75 AC = 38 MC = 37	0
Henriksson and Jemt[6]	2003	Single crown	Delayed	24	1
Abutments					
Zarone et al[11]	2005	Single crown	Delayed	58	1
Zembic et al[8]	2009	Single crown	Delayed	40 AC = 20 MC = 20	11 AC = 1 MC = 10
Canullo[10]	2007	Single crown	Delayed	30	NR
Furze et al[12]	2012	Single crown	Delayed	10	0
Sailer et al[7]	2009	Single crown	Delayed	40 AC = 20 MC = 20	9 AC = 1 MC = 8
Zembic et al[9]	2012	Single crown	Delayed	40 AC = 20 MC = 20	11 AC = 1 MC = 10

AC = all-ceramic group, MC = metal-ceramic group, NR = not reported.
*Implant but not restoration failure

Nineteen patients were examined at the 1-year recall, with all implants stable. One ceramic abutment fractured in the laboratory and was remade before clinical placement. All crowns in both groups were stable during the 12-month period. One patient in the cement crown group experienced a buccal fistula (1 of 13) and a further two cement-retained crowns (2 of 13) experienced buccal recession for an estimated annual biologic complication rate of 12.5%.

No studies reported any data regarding CAD/CAM implant prostheses or conventional prostheses in terms of cost effectiveness.

CAD/CAM Abutments

The six studies that met inclusion criteria for data extraction on CAD/CAM dental implant abutments are shown in Table 3. These comprise three RCTs, which describe the same patient cohort at 12, 36, and 67 months[7–9]; one prospective clinical report[10]; one retrospective case report[11]; and one case series.[12] A further case report by Vafiadis[13] had to be excluded due to lack of detail regarding patient recruitment and treatment details. A total of 101 patients were treated with a total of 138 CAD/CAM implant abutments to support single-crown restorations. The patients' ages

Implant failures	Estimated annual failure rate	Cumulative survival rate
0	0%	100%
0	0%	100%
0	0%	100%
0	0%	100%
0	0%	100%
0	0%	100%
0	0%	100%
3	1.30%	88.9% Zr 90% Ti

Mean follow-up time (mo)	Restoration failures	Total restoration exposures	Estimated annual failure rate
13.5	1, MC group, remade	75	MC: 2.6% AC: 0%
12	0	23	0%
48	1	57	0.80%
36	0	29	0%
40	0	30	0%
12	0	10	0%
12	0	31	0%
67.2	3*	28*	0%

ranged from 18 to 70 years with the mean ages of each study group ranging from 41.3 to 52.3 years. Three different CAD/CAM systems were used to fabricate the abutments for the included studies; Procera technique (Nobel Biocare) was used in 4 studies,[7–9,11] Straumann Cares for one study,[12] and Zirconzahn for one study.[10] No abutment complications, including screw loosening or fracture, were reported for any of the publications reviewed. The CAD/CAM abutment survival rate is 100%. The survival rate of the crowns supported by CAD/CAM abutments is 99.8%. The failure rates and survival of implants supporting CAD/CAM abutments are summarized in Table 5. Tables 6 and 7 detail the failure rates, complication rates, and survival rates for CAD/CAM fabricated implant abutments. While no technical complications were reported for the CAD/CAM abutments, most studies reported a low incidence of veneering porcelain chipping (0% to 3% estimated annual chipping rate) from the crown on the abutment.

The papers by Sailer et al and Zembic et al[7–9] evaluated the survival and complication rate of customized zirconia and titanium abutments in a randomized controlled clinical trial. Twenty-two consecutively recruited patients were included in this study that evaluated 40 fixed implant-supported crowns replacing missing canines, premolars, and molars. Patients were randomly assigned to a test or control group. The test group consisted of 20 customized Procera zirconia abutments to support all-ceramic crowns. The control group of 20 single-tooth implant replacements received customized Procera titanium abutments for the support of metal-ceramic crowns. All patients received a regular platform (RP) Nobel Biocare implant installed according to standard surgical protocol. The all-ceramic crowns were fabricated from glass ceramic or two high-strength ceramics, alumina or zirconia. Metal-ceramic crowns were fabricated for the titanium abutments. Clinical examinations were made at baseline, 6, 12, and 36 months with four patients lost to follow-up at the 36-month review. Implants in the test group replaced crowns in 2 canines, 11 premolars, and 5 molars. All implants showed a 100% survival rate for both implant groups. No technical complications were seen in either group for the abutments with the survival rate being 100% for both groups.

Zembic et al[9] reported that between the 3- and 5-year reviews, two patients lost three implants due to loss of integration. These were supporting 2 of 20 zirconia abutments and 1 of 20 titanium abutments. In spite of these three implant failures, biologic complications associated with CAD/CAM abutments were rare. Plaque and bleeding scores were low, and bone levels were reported as stable at follow-up. At 12 months' review, Sailer et al[7] reported that the mean bleeding on probing (BOP) was more often observed around the implant crowns than teeth and zirconia abutments had a higher mean BOP than titanium (60% vs 30%). However, at the 3-year review these changes were no longer reported[8] and this remained the same at the 5-year review.[9] Only one case was reported showing facial tissue recession at the CAD/CAM zirconia abutment.[12]

Canullo[10] studied the efficacy of a zirconia abutment cemented to an antirotational titanium component attached to the implant in a prospective clinical report. Twenty-five patients requiring 30 single-implant–supported crowns were selected for the

Table 7 Complications for CAD/CAM Crowns and Abutments

Study	Year of publication	Type of restoration	Total restorations	Mean follow-up time (mo)	Estimated annual rate of screw loosening	Estimated annual rate of abutment fracture
Crowns						
Hosseini et al[5]	2011	Single crown	75 AC = 38 MC = 37	13.5	0	0
Henriksson and Jemt[6]	2003	Single crown	24	12	0	0
Abutments						
Zarone et al[11]	2005	Single crown	58	48	0	0
Zembic et al[8]	2009	Single crown	40 AC = 20 MC = 20	36	0	0
Canullo[10]	2007	Single crown	30	40	0	0
Furze et al[12]	2012	Single crown	10	12	0	0
Sailer et al[7]	2009	Single crown	40 AC = 20 MC = 20	12	0	0
Zembic et al[9]	2012	Single crown	40 AC = 20 MC = 20	67.2	0	0

MC = metal-ceramic crown group; AC = all-ceramic crown group; BOP = bleeding on probing.

study. The abutments were designed such that for one group, zirconia contacted the implant shoulder and in the other group, the titanium structure contacted the implant shoulder. No abutment screws fractured and no screw loosening occurred. The survival rate was 100%. One crown demonstrated marginal porcelain chipping at the 1-year follow-up. Periodontal and gingival indices showed healthy tissue at both natural tooth and implant sites.

In a retrospective evaluation of 86 patients treated with CAD/CAM fabricated restorations, Zarone et al[11] evaluated the performance of Procera all-ceramic maxillary anterior restorations over a period of 48 months. The crowns were fabricated on both natural teeth (28/86) and implant-supported abutments (58/86). Both non-submerged (Institut Straumann, Waldenberg) and submerged (Nobel Biocare) implants were restored. Alumina oxide Procera abutments where fabricated for the submerged implants and titanium abutments for the non-submerged ones. The implants were restored with crowns fabricated using Procera aluminum oxide copings, which were machined and finished with layering porcelain by the dental technician in the laboratory. All restorations were cement retained using a hybrid glass ionomer cement (RelyX, 3M ESPE). One implant-supported restoration failed during the follow-up, but it is not stated which implant type and how the implant failed. One implant crown exhibited porcelain fracture at the incisal edge of the veneering porcelain. Although marginal adaption was reported to be very good, the other indices evaluated (Plaque, Gingival, BOP, and patient satisfaction) while showing generally very high scores, were not distinguished between implant and natural teeth. No abutment complications were reported.

Furze et al[12] evaluated the clinical and esthetic outcomes of 10 consecutive single-tooth implant restorations in the anterior maxilla. Ten Straumann SLActive bone-level implants were used to replace six central incisors, one lateral incisor, two canines, and one premolar. Implants were restored with provisional prostheses customized to the mucosa before restoration with CAD/CAM zirconia abutments (Straumann Cares) and zirconium-based all-ceramic crowns (Straumann Cares). Pink and white esthetic scores (PES and WES) were made after 12 months of loading. The only reported complication was fracture of the provisional restoration. The mean PES score was 7.9 and mean WES was 7.

No studies reported any data regarding CAD/CAM implant prostheses or conventional prostheses in terms of cost effectiveness.

CAD/CAM Frameworks

Nine studies were included under the search of clinical trials of CAD/CAM frameworks. These comprised one RCT,[14] six prospective,[15–20] and two retrospective

Total veneer chipping/fracture	Estimated annual rate of veneer chipping/fracture	Total loss retention	Estimated annual loss retention	Biologic complications	Estimated annual rate of biologic complication
1 chip, MC group	2.4% MC 0% AC	1, MC group	2.4% MC 0% AC	7/10 inflammation, AC group; 3/10, MC group	11.80% 16.3% AC 7% MC
0	0%	0	0%	1 fistula, 2 buccal recession	12.50%
1 chip, 1 fracture	0.80%	0	0%	0	0%
2 chip, MC group	3% MC 0% AC	0	0%	0, but greater mean BOP at implants	0%
1 chip	1%	0	0%	0	0%
0	0%	0	0%	1, facial recession	10%
2 chip, MC group	3% MC 0% AC	0	0%	0 (BOP similar for teeth and implants)	0%
2 chip, MC group	3% MC 0% AC	0	0%	0, but greater mean BOP at implants and 3 implant failures	1.30%

clinical reports[21,22] published between 2005 and 2012. The study and patient characteristics are summarized in Table 8.

The implant-supported prostheses were fabricated using CAD/CAM technology to mill the framework from either titanium or zirconia. Three different manufacturing companies were involved in the production of the frames: Decim (Denzir), Nobel Biocare (Procera), and Es-Healthcare.

Eight clinical investigations used CAD/CAM technology to restore completely edentulous patients with full-arch fixed partial dentures (FDPs). In six studies, both the maxilla and the mandible received a full-arch rehabilitation.[15,17,18,20–22] The Engquist et al[16] study restored only mandibular arches and the Katsoulis et al[19] restored only maxillary arches. Only one study reported the application of CAD/CAM framework technology in partially edentulous patients.[14] In this study, FDPs were used to restore both maxillary and mandibular edentulous spaces.

The loading time of the prostheses varied significantly in all these investigations. Three studies described immediate loading protocols of CAD/CAM frameworks.[17,18,20] Four reported on conventional loading[14,15,19,21] and one reported on both immediate and conventional loading.[22] Finally, Engquist et al[16] applied immediate, early, and conventional loading protocols. The definitions of the terms relating to timing of restoration used were: immediate loading (less than 1 week), early loading (at 24 days), and conventional loading (12 weeks or later), and they are all based on the 2007 Cochrane Review.[23]

Larsson et al[14] performed a randomized prospective clinical trial during which two different ceramic systems, Denzir (DZ) and In-Ceram Zirconia (InZ), were compared in partially edentulous patients. Eighteen patients were treated with a total of 25 implant-supported reconstructions ranging in size from two to five units. They were reviewed after 60 months (5 years). In the CAD/CAM arm of the study, nine patients received 13 FDPs with frameworks made out of yttria-stabilized tetragonal zirconia polycrystal material (DZ). Seven of the nine patients (69%) in the DZ group showed chip-off fractures, whereas two out of nine patients (17%) in the InZ group showed such fractures. More specifically, 16 units (52%) in the DZ group and 3 units (9%) in the InZ group were affected. Three of the 16 fractures (19%) in the DZ group were judged to be adhesive between the framework and veneering porcelain. None of the fractures in the InZ group were adhesive, all being cohesive in nature within the layering porcelain. Although the CAD/CAM frameworks did not present any complications, the DZ system exhibited an unacceptable amount of veneering porcelain fractures. Since these complications were superficial, the study reported 100% survival rate for the restorations of both

Table 3 Study and Patient Characteristics of the Reviewed CAD/CAM Framework Studies

Study	Year of publication	Journal	Study design	CAD/CAM system	Restoration type	Arch loaded
Larsson et al[14]	2010	IJP	RCT	Denzir, Decim	partial FDPs (2-5 units)	Mandible and maxilla
Engquist et al[16]	2005	CIDRR	Prospective cohort	Procera, Nobel Biocare	Full-arch FDPs	Mandible
Komiyama et al[18]	2008	COIR	Prospective	Procera, Nobel Biocare	Full-arch FDPs	Mandible and maxilla
Ortorp and Jemt[15]	2012	CIDRR	Prospective control	Procera, Nobel Biocare	Full-arch FDPs	Mandible and maxilla
Sanna et al[17]	2007	JPD	Prospective cohort	Procera, Nobel Biocare	Full-arch FDPs	Mandible and maxilla
Tahmaseb et al[20]	2012	IJOMI	Prospective	Es-Healthcare	Full-arch FDPs	Mandible and maxilla
Katsoulis et al[19]	2011	IJOMI	Prospective controlled cohort	Procera, Nobel Biocare	Full-arch FDPs	Maxilla
Papaspyridakos and Lal[22]	2013	COIR	Retrospective	Procera, Nobel Biocare	Full-arch FDPs	Mandible and maxilla
Malo et al (1)[21]	2012	JP	Retrospective	Procera, Nobel Biocare	Full-arch FDPs	Mandible and maxilla
Malo et al (2)[21]	2012	JP	Retrospective	Procera, Nobel Biocare	Full-arch FDPs	Mandible and maxilla

NR = not reported; FDPs = fixed dental prostheses; RTC = randomized-controlled clinical trial; IJP = *The International Journal of Prosthodontics*; CIDRR = *Clinical Implant Dentistry and Related Research*; COIR = *Clinical Oral Implant Research*; JDP = *The Journal of Prosthetic Dentistry*; IJOMI = *The International Journal of Oral & Maxillofacial Implants*; JP = *Journal of Prosthodontics*.

groups after 5 years. The differences in the success rates from baseline to the 5-year follow-up were statistically significant for the two groups at both the FDP level (31% DZ vs 83% InZ) ($P < .05$) and the unit level (48% DZ vs 91% InZ) ($P < .001$).

Ortorp et al,[15] in their prospective control study, evaluated and compared the clinical and radiographic performance of implant-supported prostheses during 10 years of function. Patients were randomly assigned to the test or control group. The test frameworks (n = 67) were constructed using a computer numeric-controlled (CNC) titanium technique (All-in-One Procera, Nobel Biocare) while the control group frameworks (n = 62) were cast from gold alloy. Acrylic resin teeth were processed to each metal framework. This university-based study (The Brånemark Clinic, Gotenberg, Sweden) originally included 126 edentulous patients. After 10 years, there were 52 patients lost to follow-up, of which 29 belonged to the test group (36 remaining patients). At the implant level the overall 10-year implant cumulative survival rate (CSR) was 95.0% and 97.9% for the test and control groups, respectively. The titanium framework group had five framework incidents out of which three were recorded as "survival and modified" since the modification shortened the prosthesis span. In the remaining two cases, the first prosthesis was lost due to failure of the supporting six implants after 2 years of function, and the second one fractured after 9 years in function. As a result the 10-year prosthesis CSR was 89.0% for the test group and 94.4% for the control group ($P > .05$). In addition, there were three incidents of prosthesis loosening in the test group. These were all from the same case. Thirty-five incidents of acrylic chipping in 19 cases were reported from the test group. Eight of these incidents from seven cases were uncomplicated while the remaining 27 incidents from 12 cases required removal and management in the dental laboratory. There were no significant differences in bone loss around the implants between the two groups. The mean marginal bone loss after 10 years was 0.7 mm (SD = 0.77) and 0.6 mm (SD = 0.57) in the test and control groups, respectively ($P > .05$).

In the Engquist et al[16] prospective cohort study, the results of early loading in the edentulous mandible were evaluated and compared with delayed loading, for both one- and two-stage implant surgery protocols. One hundred and eight patients each received four Brånemark (Nobel Biocare) implants. A total of 432 implants were placed to support 108 prostheses that were followed for up to 36 months. The superstructure used for all patients was a titanium frame (Procera All-in-One, Nobel Biocare) combined with acrylic teeth. The frameworks were milled from a titanium block in a computer-steered three-dimensional milling machine. Due to the vertical placement of the four implants, the bridges were constructed with cantilevers having two teeth on each side. Nine patients were lost to follow-up and of the 418 remaining implants, 24 failed due to loss of integration. As a result 98 cases were surviving at the 3-year period. Prosthetic outcomes were not

Loading type	Patients	Age range (y)	Mean age (y)	Setting	Drop out (% of patients/ cases lost to follow-up)
Delayed	9	37–70	NR	Malmö University Hospital, Sweden	0%
Delayed + early + Immediate	108	25–75	64.9	University Hospital, Linkoping, Sweden & Vrinnevi Hospital, Norrkoping, Sweden	9.25% (10 patients/cases)
Immediate	26 (excluding 5 carbon frames)	42–90	71.5	University Karolinska Institutet, Huddinge Sweden	NR
Delayed	65	49–85	66.8	Brånemark Clinic, Göteborg, Sweden	44.6% (29 patients/cases)
Immediate	30	38–74	56	University Hospital Leuven, Belgium	13.3% (4 patients/cases)
Immediate	35	NR	NR	University of Amsterdam School of Dentistry, ACTA, Amsterdam, The Netherlands	0%
Delayed	13	52-78	63.3	University of Bern, Switzerland	0%
13 delayed and 3 immediate	14	35-71	58	Columbia University, New York, USA	0%
Delayed	52	38-81	59.5	Private Center: Malo Clinic Lisbon, Portugal	11% (12 patients/cases)
	56	34-82	57.6	Private Center: Malo Clinic Lisbon, Portugal	

reported, and the study concentrated on implant survival and marginal bone loss. The survival rate of the early-loaded implants did not significantly differ from that of implants inserted with the conventional two-stage procedure. Survival rates of the implants showed a tendency toward better results with the two-stage technique, but the differences were not significant. The mean marginal bone loss from fixture insertion to the 3-year examination was significantly lower with early loading than with the conventional two-stage technique (range 1.24 to 1.68 mm). Finally, the survival rates and marginal bone changes of the one-piece implants did not differ from those of the two-piece implants.

Komiyama et al[18] reported on the treatment of 29 edentulous patients, 9 women and 20 men, using the Nobel Guide immediate loading Teeth-in-an-Hour protocol. In this prospective clinical investigation, 176 Brånemark MKIII TiUnite (Nobel Biocare) implants were placed in 31 edentulous jaws. Twenty-six edentulous jaws were restored with prostheses fabricated from machined titanium frameworks supporting acrylic resin teeth and 5 edentulous jaws used carbon fiber reinforced resin prostheses. All cases were followed up to 1 year and thereafter annually for up to 44 months. Upon delivery the authors experienced abutment/prosthesis misfit in five cases, and there was extensive occlusal adjustment in three cases. This resulted in prosthesis disconnection in two cases for retreatment. At the implant level, 157 of 176 implants (89%) survived over 44 months (92% in maxilla and 84% in mandible). Nineteen implants (11%) were removed within 18 months of implant installation, with 10 of 124 from the maxilla and 9/52 from the mandible. At the prosthesis level, 26 of 31 prostheses were surviving at 44 months (84%); 19 of 21 in the maxilla (90%) and 7 of 10 in mandible (70%). Superstructure failure occurred in five patients (17%); two due to fixture loss, two due to prosthesis misfit, and one due to a combination of both complications. These superstructures were removed within the first 6 months.

In a prospective cohort study Sanna et al[17] evaluated 30 consecutive patients, who were treated with a full-arch implant-retained reconstruction, in either the maxillary or mandibular arch. Two hundred and twelve TiUnite Brånemark implants (Nobel Biocare) were placed (Department of Periodontology at the University Hospital in Leuven) and 30 edentulous arches were restored following an immediate loading protocol. All patients received a prefabricated CAD/CAM framework veneered with acrylic resin teeth. Four patients were lost to follow-up (29 implants) although they were contacted to confirm that their prostheses remained in function. Twenty-six patients with 183 implants were followed for a mean time of 2.2 years. Overall 9 out of 183 implants were lost (4.9%), 8 of which were from a smoking group. The CSR after 5 years was 91.5%. Digital panoramic radiographs were taken at annual recalls and were used to evaluate bone loss. The mean bone loss was 2.6 mm (± 1.6 mm) for the smoker group and 1.2 mm (± 0.8 mm) for the nonsmoker group. There was no report for any prosthetic complications or prosthetic survival rates.

Tahmaseb et al[20] evaluated the immediate loading of 40 full-arch cases in both the mandibular and maxillary jaw in a prospective study. The definitive fixed full-arch restorations were fabricated prior to surgery using CAD/CAM technology. A total of 35 patients, including 20 edentulous maxillae, 10 edentulous mandibles, and 5 patients with edentulism in both arches were treated with 240 Straumann Standard Tissue level implants (Straumann). A total of 40 superstructures were made out of a prefabricated CAD/CAM framework (Es-Healthcare), which was veneered with resin and connected directly to the implants without using Straumann abutments. All patients were followed for at least 1 year with a range of 12 to 36 months. All metal frameworks (n = 40) showed a clinically passive fit at the time of surgery and no adjustments were needed. Thirty-nine finished superstructures (97.5%) showed satisfactory occlusion and only one case required significant occlusal adjustment. Of the 240 inserted implants, 229 (95.4%) survived after 12 months, with 146 (93.6%) and 83 (98.8%) implants in the maxillary and mandibular arches, respectively. Four implants in one patient failed 6 months post-surgery and as a result the superstructure was lost as well (1 of 40 arches). No other additional prosthetic complications were reported at the 1-year follow-up period.

Katsoulis et al[19] in a prospective controlled cohort study compared the outcomes of three different treatment modalities in the maxilla: overdentures with conventional soldered gold bars (Dolder bars), overdentures with CAM-fabricated titanium bars, and fixed prostheses with CAM-fabricated titanium frameworks. Forty-one patients were treated in the study. Thirteen patients received between four to six implants to support a CAD/CAM implant–supported fixed prosthesis that was conventionally loaded. The titanium frameworks were fabricated using Procera and veneered with acrylic resin denture teeth (Candulor). The frameworks were screw-retained at the implant level and followed for 2 years. At the end of the follow-up period there were no fractures reported (100% survival rate) and there was no need for re-tightening of occlusal screws. There were 14 repair incidents reported (five acrylic resin denture base fractures, eight teeth fractures, one redesign of prosthesis). In addition, there were 11 prosthesis adaptation incidents (one sore spot, three prosthesis relinings, five occlusal corrections, one excessive tooth wear, and one discoloration of acrylic resin teeth). Furthermore, there were no implant failures reported for the fixed CAD/CAM group, yielding a 100% implant survival rate. Finally, the Oral Health Impact Profile (OHIP) was used to investigate the patients' oral health–related quality of life (QoL). The OHIP confirmed high satisfaction, but QoL appeared to be slightly higher with fixed CAD/CAM prostheses.

Malo et al,[21] in a retrospective study with mean follow-up of 5 years (range: 9 months to 10 years), compared milled titanium frameworks, restoring edentulous patients using a delayed loading protocol, with two different all-ceramic crown systems. In the first group (development group), a CAD/CAM fabricated Procera titanium frame had Duceram (Ducera Dental) veneering porcelain used to replicate the gingival tissue replacement. Multiple individual crowns were fabricated and luted to the framework. The crowns were made out of Alumina copings (Nobel Biocare), and Alkceram porcelain (Ducera Dental). A total of 66 full arches (both maxilla and mandible) were restored and followed for a mean of 6.5 years (range: 9 to 127 months). In the second group (routine group), similar titanium Procera frameworks and a gingival replacement veneering material of PalaXpress Ultra (Heraeus Kulzer) was used to replicate the gingival tissues. Individual crowns were made out of zirconia copings (Nobel Biocare) and Nobel Rondo Zirconia Ceramic (Nobel Biocare) porcelain. Fifty-nine arches were restored (both maxilla and mandible) and followed for a mean of 3.8 years (range: 12 to 67 months). A total of 634 Nobel Speedy Brånemark (Nobel Biocare) implants were placed. The cumulative survival rates for the implant-supported fixed prostheses were 92.4% for the alumina crown group at 10 years and 100% at 5 years (overall 96%) for the zirconia crown group. The authors reported six lost frameworks (including one that was lost due to the implant failure) for the first group and none for the second. Veneer chipping occurred in 36 and 14 cases, respectively, for the development and routine groups.

Papaspyridakos and Lal[22] in their retrospective cohort study evaluated 14 patients who were restored with screw-retained implant-supported superstructures. Thirteen edentulous arches were treated with conventional loading protocols and three with an immediate loading protocol. Ten cases were in the mandibular jaw and six were in the maxillary jaw. The frameworks were zirconia frameworks made with Procera CAD/CAM. Veneering porcelain was applied to the framework. Out of the 16 edentulous arches, 14 received one-piece restoration and 2 received a segmented two-piece fixed restoration. The mean clinical follow-up period was 36 months (3 years). One hundred and three Tiunite implants were placed, distributed as 57 implants in the mandible and 46 implants in the maxilla. There were five to six implants placed to support mandibular prostheses and six to eight to support the maxillary prostheses. No screw loosening was observed throughout the follow-up period. The prostheses in 11 of 16 arches were structurally sound, whereas porcelain veneer chipping/fracture was observed in five prostheses (four patients), yielding a ceramic chipping rate of 31.25% at the prosthesis level. Great

patient satisfaction with function and esthetics was recorded for all patients both at baseline and recall.

Statistical analysis was thus based on nine studies, with one reporting on partial FDPs with CAD/CAM-fabricated zirconia frameworks veneered with porcelain,[14] eight reporting on implant-supported full-arch FDPs with CAD/CAM-fabricated titanium frameworks (seven with acrylic teeth and one with porcelain veneering),[15–21] and one reporting on implant-supported full-arch FDPs with CAD/CAM-fabricated zirconia frameworks veneered with porcelain.[22]

No studies reported any data regarding CAD/CAM implant prostheses or conventional prostheses in terms of cost effectiveness.

DISCUSSION

This literature search revealed a total of 17 studies which used CAD/CAM techniques to restore implants. The first observation that needs to be made is that in most investigations the primary goal of the authors was not the assessment of the actual CAD/CAM prosthesis. Instead, in several cases there was a focus on the surgical aspect of the treatment. As a result, acquiring the relevant prosthetic data was challenging and in some cases not possible since there was no prosthetic outcome reported.

In addition, the selected studies evaluated a variety of factors such as the fit of the prosthesis, bone loss, and numerous complications using different assessment techniques or parameters. For this reason, the comparison of the presented data would not be accurate or even feasible in certain occasions. Parameters that could be easily reported and compared were the survival rate of the implants that supported the prostheses and the survival rate of the actual prostheses. This data could be easily determined in most of the investigations. Any technical complications could be reported but not included in the analysis.

The purpose of this systematic review was to compare the clinical outcomes of restorations that were fabricated using CAD/CAM technology with the ones that were fabricated conventionally. Two recent systematic reviews[24,25] have assessed and reported the survival and complication rates of implant-supported restorations for both single crowns and FDPs, respectively, for a mean observation period of at least 5 years.

Crowns

The use of all-ceramic CAD/CAM restorations in the short term appears to provide acceptable clinical outcomes. The difference in materials used for ceramic core fabrication, choice of ceramic veneering porcelain and crown retention between the studies makes direct comparison between studies difficult. Hosseini et al[5] in their randomized controlled trial restored single missing teeth in the maxillary or mandibular premolar region. All implants survived and no mobility was recorded. No significant differences were seen between all-ceramic (AC) and metal-ceramic (MC) crowns for Plaque or Bleeding Indices. Mean marginal bone loss was not significantly different. Inflammatory reactions were seen at the 1-year examination for seven AC crowns and three MC crowns. The inflammatory reactions were believed to be due to poor marginal adaption with five of seven AC crowns showing poorer marginal adaption than the MC crowns (one of three). No abutment complications were seen and porcelain chipping was seen in one MC crown. Patient-reported VAS score did not report differences in outcomes from the AC versus MC crowns; however, professionally reported color matching was found to be significantly better in the AC crowns. No difference was seen between MC and AC crowns for crown morphology or papilla index, and the frequency of mucosal discoloration was unchanged for both types. None of the studies were able to employ a pure CAD/CAM technique (devoid of human intervention) for the crown fabrication. Currently, to achieve optimal esthetic outcomes, coloration, staining, or layering of a core is needed to appropriately match natural tooth color. The CAD/CAM technique was used for the core fabrication, onto which layering porcelain was applied. Henriksson and Jemt[6] reported one abutment fracture in the laboratory during crown fabrication in their prospective clinical evaluation; however, all crowns in both groups were stable during the 12-month period. One patient in the cement crown group experienced a buccal fistula and a further two experienced buccal recession. The recession exposed the cement-abutment joint. While comparable outcomes were seen with both techniques, the issue of recession and increased bone loss on two implants in the cement-retained group possibly point toward a trend that the direct screw-retained group may yield better outcomes with less risk of tissue-related complications.

The studies of Zarone et al[11] and Furze et al[12] also employed high strength ceramic cores, of different material, which appear to have been fabricated using CAD/CAM processes. Unfortunately, the description of the process for crown fabrication was not detailed enough to be certain of the CAD/CAM process, and thus were excluded from the CAD/CAM crown section. These studies reported overall low complication rates and good esthetics. It was interesting that in the publication by Furze et al[12] the clinician wished to reject the color of one crown but the patient did not feel it necessary. This reduced the mean WES score by 0.2. Newer generation color- and translucency-graded ceramic blocks

are becoming available for use in CAD/CAM milling machines, which may reduce the need for routine manual intervention in achieving optimal coloration of the anterior restoration.

Abutments

Very few technical complications were reported with the CAD/CAM abutments from the studies reviewed. This indicates that in the short- to medium-term, CAD/CAM abutments demonstrate acceptable clinical performance with no reported incidence of screw loosening or abutment fracture of either ceramic or metallic materials. Zembic et al[8] reported many of the test group ceramic abutments (16 of 18 cases) were in posterior areas of the mouth subjected to high masticatory load with no technical complications reported. However, the rate of veneering porcelain fracture from the prostheses upon the abutments is still comparable to other reviews. The rate of porcelain chipping for the cohort did reduce dramatically from 16.7% in the metal-ceramic group in the first 12 months[7] to 0% at the 3-year review.[8] The majority of the crowns were cement-retained. A modest number of abutments, totaling 11 at the 3-year review and mostly titanium,[10] were lost to follow-up. The study by Zarone et al[11] had one crown chipping and one fracture, which was in the incisal edge region.

The study by Ekfeldt et al[26] evaluated the clinical outcome of custom-made zirconia abutments for implant-supported single-tooth restorations. Unfortunately, this study was excluded since during the first follow-up (1 year), the implant-supported restorations (185 single-tooth implant restorations placed in 130 patients) were evaluated retrospectively using only patient records. This action could involve a possible bias in the values presented since the evaluation did not include an actual clinical examination. During the second follow-up of this cohort (greater than 3 years), only 37% of the original 130 patients were invited for a clinical examination. Out of these patients, only 25 (40 restorations) could be examined, which means that 105 were lost to follow-up. The paper was thus considered to be highly biased and was therefore not included in the data analysis.

The latest generation CAD/CAM techniques are utilizing newer technologies, which allow the clinician or technician to fully customize the abutment contour to match carefully the clinical situation[12] after tissue customization with provisional restorations. Of further interest is the ability of the abutment material choice to influence the mucosal color and have a negative affect on the final esthetic outcome. Zembic et al[8] reported that both the zirconia and titanium abutments induced a visible color change in the mucosa when compared with natural teeth. No difference in mean mucosal thickness was seen when comparing abutment type. The average thickness of the mucosa over the abutments (1.8 ± 0.7 mm) was slightly higher than the gingival thickness overlying natural teeth (1.5 ± 0.9 mm). However, the tissue thickness was reduced over the zirconia abutments from 2.1 to 1.9 mm and the tissue thickness increased from 1.3 to 1.5 mm over teeth in the follow-up period from 12 to 36 months. This may be as a result of the technique used to measure the overlying tissue thickness. This is different than the data published by Bressan et al,[27] who reported less change with zirconia abutments. Unfortunately, the publication of Bressan et al[27] was excluded from the review as the abutments were only installed for a period of 10 minutes prior to color evaluation. The mucosal thickness overlying the abutments in the cases presented by Zembic et al[8] was less than that reported by Bressan et al[27] and this could explain the differences seen, as could the different measurement techniques. However, they did not seek to classify the tissue thickness and measurements were made using different techniques, which may also explain the difference in spectrophotometric evaluation. Only one publication reviewed the esthetic outcome using the objective PES/WES scale.[12] More widespread use of these objective evaluation scales will enable better comparison of the studies.

One of the true advantages of the latest generation CAD/CAM techniques is the ability for the clinician or technician to fully customize the abutment contour without the need for human intervention. The distinction between these generational technology changes should be considered by clinicians when evaluating these techniques. One of the limitations of this technology, which is progressing at a rapid rate, is that direct comparisons of "old" and "new" generation technologies become difficult. For the purposes of this review, the design of the abutment needed to include some computer-aided design process, if not exclusively CAD/CAM produced. Scanning of a manually-produced wax pattern could be argued to be non–computer-aided design, as the majority of the design is not performed in the digital environment. Vanlioglu et al[28] describes a technique for manually-aided design (MAD) and/or manually-aided manufacturing technique (MAM) of abutments. Often, similar materials for abutment production as those employed in CAD/CAM strategies are used for this technique. Two papers were excluded from evaluation due to the employment of a MAD/MAM technique used to produce abutments.[28,29] Additionally, any hand modification to the abutment after return from the laboratory where digitally design and production occurs breaks the chain of "purity" of CAD/CAM production. Zafiropoulos et al[30] was also excluded, as this study required multiple manual

interventions to achieve the abutment outcome. These manual interventions may cloud the true accuracy of the CAD/CAM systems at precision output of a product for clinical use.

The review conducted by Jung et al[24] reported a total of 46 studies that met the inclusion criteria and a mean follow-up of at least 5 years. This can serve as a comparison for these techniques. Based on the meta-analysis, survival of implants supporting SCs at 5 years amounted to 97.2% (95% CI: 96.3% to 97.9%), and at 10 years to 95.2% (95% CI: 91.8% to 97.2%). While three late implant failures were reported in one publication between the 3- and 5-year review, no other papers reported implant failure for a mean cumulative survival rate of 98.3%. It is unlikely that these failures were a result of the CAD/CAM technology.

The survival of implant-supported SCs was 96.3% (95% CI: 94.2% to 97.6%) after 5 years and 89.4% (95% CI: 82.8% to 93.6%) after 10 years. While only two papers were found which met inclusion for crowns fabricated with a CAD/CAM technique, the mean survival rate of 98.85% for these two studies is comparable. The survival rate of CAD/CAM abutments was 100% indicating good success of this technology, with the crowns supported by CAD/CAM abutments having a mean survival rate of 99.8%.

For biologic complications, a 5-year cumulative soft tissue complication rate of 7.1% (95% CI: 4.4% to 11.3%) and a cumulative complication rate for implants with bone loss > 2 mm of 5.2% (95% CI: 3.1% to 8.6%) were calculated. Technical complications reached a cumulative incidence of 8.8% (95% CI: 5.1% to 15.0%) for screw-loosening, 4.1% (95% CI: 2.2% to 7.5%) for loss of retention, and 3.5% (95% CI: 2.4% to 5.2%) for fracture of the veneering material after 5 years. The cumulative 5-year esthetic complication rate amounted to 7.1% (95% CI: 3.6% to 13.6%). The mean cumulative complication rate for CAD/CAM crowns based on only two studies was 0%. Compared to the control group for Hosseini et al,[5] which had a technical complication rate for metal-ceramic restoration similar to Jung et al's 4.8% compared to 3.8%, no technical complications were observed for abutments fabricated with CAD/CAM technology. The crowns supported by these appeared to suffer technical complications with similar frequency to that reported by Jung et al.[24] The mean rate of biologic complications for the CAD/CAM techniques was almost twice as high when compared to that reported previously (14.4% vs 7.1%), however, the use of CAD/CAM abutments did not approach this previously reported rate (2.5% vs 7.1%).

Frameworks

There were two articles that were initially considered but excluded from statistical calculation. Both of these studies warrant discussion. Pieri et al[31] reported a 1-year follow-up of 26 patients that received a full-arch CAD/CAM-fabricated FDP. However, patients had a temporary prosthesis for the first few months, and the definitive CAD/CAM composite resin restoration was then delivered 4 to 5 months after surgery. This would imply that the follow-up time would apply only for the implants placed and not the final prosthesis. Since the time followed was less than 1 year, the study was excluded. In the second excluded study, by Yong and Moy,[32] there were 14 arches restored with an immediate loading protocol. Patients received either carbon fiber frameworks with acrylic teeth or acrylic denture teeth on a milled titanium frame (Procera Implant Bridge, Nobel Biocare). The mean follow-up period was 26.6 months. Unfortunately, the exact number of titanium-milled cases was not reported and the complications presented included both treatment modalities. Since it was not possible to distinguish the outcomes of the CAD/CAM prosthesis, the study was excluded.

During the analysis of the CAD/CAM data for frameworks, the terminology needs to be addressed again. It seems that the techniques used to produce CAD/CAM frames vary significantly between the different investigations. A technique that seems to be very prominent is the scanning of a framework, usually fabricated out of resin, composite, or wax. Jemt at al[33] first introduced the concept in 1999 as a CNC milling technique. It was an innovative protocol under which a titanium framework could be fabricated. Following a clinically acceptable tooth try-in, "a resin pattern was made to reproduce the design of the final titanium framework. This resin pattern was then placed in a laser scanner to feed information on the contour of the framework into a computer. Following measurement of the positions of the implant replicas in the master cast, a block of grade 2 titanium was milled in a CNC milling machine with 5 degrees of freedom. An identical copy of the resin pattern was achieved in one piece of titanium". Several authors in their clinical investigations have used this protocol with some minor modifications.[15,16,19,21,22]

Since then, dental technology and adjunctive computer techniques have advanced, and the software and the available materials have also improved significantly. As a result, there is now the option of completely designing the CAD/CAM parts virtually using a computer and not by scanning a prototype. This virtual protocol is encountered in most of the immediate loading cases where the final prosthesis is designed prior to the implant placement. There were three studies that followed this model in the present review.[17,18,20] The existing dental technology allows clinical information to be fed into computer software as digital data by scanning an actual implant master cast or even by taking a digital intra-oral impression of the clinical situation.

Table 9 Failure Rates and Survival of CAD/CAM Frameworks Supporting Implants

Study	Year of publication	Restoration type	Implant Placement	Implants	Type of implants
Larsson and Vult von Steyern[14]	2010	Partial FDP (2–5 units)	Delayed	NR	Astra Tech standard or ST
Engquist et al[16]	2005	Full-arch FDP	Delayed	432	Brånemark (Nobel Biocare)
Komiyama et al[18]	2008	Full-arch FDP	Delayed	176	Brånemark MKIII, TiUnite
Ortorp and Jemt[15]	2012	Full-arch FDP	Delayed	367	Brånemark (Nobel Biocare)
Sanna et al[17]	2007	Full-arch FDP	Delayed	183	Brånemark TiUnite (Nobel Biocare)
Tahmaseb et al[20]	2012	Full-arch FDP	Delayed	240	Straumann Standard Tissue Level
Katsoulis et al[19]	2011	Full-arch FDP	Delayed	74	Replace Select tapered (Nobel Biocare)
Papaspyridakos and Lal[22]	2013	Full-arch FDP	Delayed	103	Brånemark TiUnite (Nobel Biocare)
Malo et al (1)[21]	2012	Full-arch FDP	Delayed	634	Brånemark system, Nobel Speedy; (Nobel Biocare)
Malo et al (2)[21]	2012	Full-arch FDP	Delayed	634	Brånemark system, Nobel Speedy; (Nobel Biocare)

NR = not reported; FDPs = fixed dental prostheses;
*Mean follow-up time for combined studies: 60 (range, 9 months–10 years).

A digital wax-up is usually evaluated and the abutment or framework can then be designed virtually. This technique seems to follow the designation of CAD, computer-aided design, most closely.

For this reason, the authors feel that a distinction needs to be made between the products that require a pattern to be scanned, and the ones that can be fully designed using only a computer software program. A new definition of the dental CAD/CAM procedures would be beneficial to more accurately define the processes under which these restorations are manufactured. "Complete CAD/CAM product" vs "Partial CAD/CAM product" (product referring to abutment, mesostructures, frameworks, and prostheses) could be two terms that would provide a classification of the implant-supported prosthesis fabrication technique that more accurately reflects the processes used.

To compare the CAD/CAM literature with the conventional implant-supported frameworks, a scientific systematic review was assessed and analyzed. The search for this clinical investigation was conducted by Pjetursson et al[25] and reported a total 32 studies that met the inclusion criteria. A meta-analysis of these studies indicated an estimated survival of implants supporting fixed dental prostheses (FDPs) of 95.6% after 5 years and 93.1% after 10 years. When machined-surface implants were excluded from the analysis and only rough-surfaced implants included, the survival rate increased to 97.2% after 5 years. Under the selected CAD/CAM publications, there was a total of 2,209 rough-surfaced implants that were evaluated (excluding the paper by Larsson and Vult von Steyern,[14] which did not report the number of implants related to CAD/CAM prosthesis). The range of the survival rate for those implants varied between 89.2% and 100%. If only the studies that reported on a purely delayed loading protocol[15,16,21] (1,001 implants) were chosen, then the survival rate range becomes 95% to 100%. The failure rates and the survival of CAD/CAM supporting implants are summarized in Table 9.

For the Pjetursson et al[25] review, the survival rate of implant-supported FDPs was 95.4% after 5 years and 80.1% after 10 years of function. When the analysis was done exclusively for metal-ceramic FDPs and excluding gold-acrylic FDPs, the survival rate increased to 96.4% after 5 years and 93.9% after 10 years. Those values can be compared with the ones reported by the CAD/CAM publications. The total number of prostheses evaluated was 438, and the range of the prosthesis survival rate (excluding the Engquist et al[16] study that did not report on survival rates) was between 80.7% and 100% for a follow-up range of 2 to 5 years.[17–19,21] Concentrating on the studies that reported on a delayed loading protocol[14,15,19,21] for a total of 218 prostheses changes the survival rate range to 90.1% to 100% over a follow-up range of 3.5 from 6 years.[14,21] The failure rates and survival of the CAD/CAM frameworks are summarized in Table 10.

Under the Pjetursson et al[25] report only 66.4% of the patients were free of any complications after 5 years

Mean follow-up time (mo)	No. of implant failures	CSR	Mean marginal bone loss
60	NR	NR	NR
36	24	92.30%	1.24 mm (Group D) – 1.68 mm (Group B)
44	19	89.20%	
120	17 and 161 lost to follow-up	95%	0.7 mm (SD, 0.77)
26.4	9	95%	Smokers, 2.6 mm (± 1.6); nonsmokers, 1.2 mm (± 0.8)
12 months minimum (range: 12–36 mo)	11	95.40%	Radiographic analysis showed bone loss on 2 implants up to second thread, both in posterior augmented maxillae, 15 implants not measurable
24	0	100%	NR
36	0	100%	NR
78 (range: 9–127)*	Implants NR, failures in 2 patients	98.10%	NR
46 (range: 12–67)*	0	100%	NR

(biological and technical complications were present in 33.6% of cases). The most frequent complications over the 5-year observation period were fractures of the veneering material (13.5%), peri-implantitis and soft tissue complications (8.5%), loss of access hole restoration (5.4%), abutment or screw loosening (5.3%), and loss of retention of cemented FDPs (4.7%).

The evaluated CAD/CAM framework investigations presented great variations between them. Studies differed in the number of implants that supported the prostheses, the loading protocols, the presence or absence of cantilevers, the type of restorations present in the opposing arch, and the type of veneering material. These differences as well as the variations in the techniques used for CAD/CAM framework fabrication made direct comparison between studies impossible. Table 11 summarizes the data of the observed CAD/CAM framework complications. Not all authors reported on complications and even when that was done, the methodology of assessment varied significantly. As with conventional fabrication techniques, veneering material fractures were the most common complication to be encountered. A total of 104 incidents were recorded from a total of 221[15,19,21,22] prostheses. On several occasions the fracture took place in the same prosthesis, increasing the overall number of fracture incidents. A total of six screw-loosening incidents were reported out of 221 cases[15,19,21,22] and nine occlusal adjustments out of 79 cases.[18–20] Malo et al[21] was the only study which reported in detail soft tissue complications. Nineteen incidents of peri-implant pathology and 12 of soft tissue inflammation were recorded in total.

In summary, the use of CAD/CAM frameworks for implant-supported restorations appears to provide acceptable clinical outcomes. When a delayed loading protocol was followed, the implant survival values between CAD/CAM restorations and conventional implant-supported frameworks seemed to be similar. In the relatively short-term, (3.5 to 6 years follow-up) the survival of prostheses fabricated by CAD/CAM (delayed loading protocol) and conventional also presented comparable values.

CONCLUSION

CAD/CAM technology is currently available which can be used to predictably facilitate the restoration of dental implants from single-unit cases to complex full-arch reconstructions. The purpose of this systematic review was to compare the outcomes of CAD/CAM generated restorations and abutments to those generated using conventional techniques. For crowns, abutments, and frameworks, CAD/CAM technology is able to provide results which, based on the current literature, are comparable to that of conventional techniques for implant survival, prosthesis survival, technical, and biologic complications. The authors believe that with the advent of a wide variety of CAD/CAM techniques being

Table 10 Failure Rates and Survival of CAD/CAM Frameworks

Study	Year of publication	Restoration type	Material
Larsson and Vult von Steyern[14]	2010	partial FDP (2–5 units)	Zr frame (Denzir, Decim) veneered with Esprident Triceram (Dentaurum) porcelain
Engquist et al[16]	2005	Full-arch FDP	Tiframe (Procera All-in-One, Nobel Biocare) combined with acrylic teeth
Komiyama et al[18]	2008	Full-arch FDP	Ti frame (Procera Implant Bridge, Nobel Biocare) combined with acrylic teeth
Ortorp and Jemt[15]	2012	Full-arch FDP	Ti frame (Procera All-in-One, Nobel Biocare) combined with acrylic teeth
Sanna et al[17]	2007	Full-arch FDP	Ti frame (Procera All-in-One, Nobel Biocare) combined with acrylic teeth
Tahmaseb et al[20]	2012	Full-arch FDP	Ti frame (Es-Healthcare) combined with acrylic teeth
Katsoulis et al[19]	2011	Full-arch FDP	Ti frame (Procera, Nobel Biocare) combined with acrylic resin Candulor
Papaspyridakos and Lal[22]	2012	Full-arch FDP	Zr frame (Procera, Nobel Biocare) + veneering porcelain
Malo et al (1)[21]	2012	Full-arch FDP	Ti frame (Procera, Nobel Biocare), Alumina copings (Nobel Biocare), Allceram (Ducera Dental) + Duceram (Ducera Dental) veneering porcelain
Malo et al (2)[21]	2012	Full-arch FDP	Titanium frame (Procera, Nobel Biocare), Zirconia copings (Nobel Biocare), Nobel Rondo Zirconia Ceramic (Nobel Biocare), PalaXpress Ultra (Heraeus Kulzer)

NR = not reported.
*Mean follow-up time for combined studies: 60 (range, 9 months-10 years).

Table 11 Complications of CAD/CAM Frameworks

Study	Year of publication	Restoration type	Mean follow-up time (mo)	Occlusion	Passive fit
Larsson and Vult von Steyern[14]	2010	Partial FDP (2-5 units)	60	NR	
Engquist et al[16]	2005	Full-arch FDP	36	NR	
Komiyama et al[18]	2008	Full-arch FDP	44	3/31	misfit in 5 cases
Ortorp and Jemt[15]	2012	Full-arch FDP	120	NR	
Sanna et al[17]	2007	Full-arch FDP	26.4	NR	NR
Tahmaseb et al[20]	2012	Full-arch FDP	12 months minimum (range: 12–36 mo)	1/40 lab adjustment	100%
Katsoulis et al[19]	2011	Full-arch FDP	24	5 corrections	NR
Papaspyridakos and Lal[22]	2013	Full-arch FDP	36		
Malo et al (1)[21]	2012	Full-arch FDP	78 (range: 9–127)	NR	100%
Malo et al (2)[21]	2012	Full-arch FDP	46 (range: 12–67)	NR	100%

NR = not reported; FDPs: fixed dental prostheses.

presented in the literature, the following recommendations should be made:

1. Authors should carefully consider how to report their processes for future publications so readers are able to easily and accurately compare the true advantages of newer technology.
2. Two new definitions are recommended for dental CAD/CAM procedures. These would more accurately define the process under which these restorations are manufactured. "Complete CAD/CAM Product," (product referring to abutment, mesostructures, frameworks, and prostheses) where the entire design and manufacturing process is software-implemented and controlled.
3. "Partial CAD/CAM Product," where some design and manufacturing processes involve manual intervention.

Loading	Arch loaded	Restorations	Mean follow-up time (mo)	Restoration failures	CSR
Delayed	Mandible and maxilla	13	60	0	100%
Delayed + early + immediate	Mandible	108	36	NR	NR
Immediate	Mandible and maxilla	26 (5 carbon)	44	5	80.70%
Delayed	Mandible and maxilla	67	120	2 incidents in 2 cases	95.60%
Immediate	Mandible and maxilla	30	26.4	0 (phone contact in 4)	100%
Immediate	Mandible and maxilla	40	12 months minimum (range: 12–36 mo)	1 (due to implant failure)	97.50%
Delayed	Maxilla	13	24	0	100%
13 delayed and 3 immediate	Mandible and maxilla	16	36	0	100%
Delayed	Mandible and maxilla	66	78 (range: 9–127)*	5 + 1 (due to implant failure) = 6	90.10%
Delayed	Mandible and maxilla	59	46 (range: 12–67)*	0	100%

Screw loosening	Total no. of veneering material chipping/fracture	Other
	16 (52%)	NR
NR	NR	NR
NR	NR	NR
3 incidents in 1 prosthesis	35 incidents out of 19 cases	NR
NR	NR	NR
NR	NR	NR
0	14	Sore spots: 1, Relining: 3, Excessive tooth wear: 1, Discoloration of acrylic: 1
0	5 (4 patients), ceramic chipping rate of 31.25%	NR
2	36	
1	14	

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Consensus Statements and Recommended Clinical Procedures Regarding Restorative Materials and Techniques for Implant Dentistry

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INTRODUCTORY REMARKS

Computer-assisted design (CAD) and computer-assisted machining (CAM) have been increasingly used in implant dentistry over the past 10 years. The continuous improvement of these newer techniques by their developers has started to challenge traditional techniques of fabricating implant-supported prostheses. The premise that there is an improvement in outcome compared with traditional fabrication techniques is fundamental to the use of CAD/CAM. The systematic review by Kapos and Evans is focused on the performance of CAD/CAM prostheses when compared to conventionally manufactured prostheses.

Since most patients provided with oral implants are between 40 and 50 years of age, long-term survival rates for implants and prostheses are expected both from the clinician and the patient to ensure the longevity of the reconstruction. "Long-term" has been specified as a follow-up of at least 5 years. Thus, survival rates and the incidence of biologic, technical, and esthetic events should be based on mean observation periods of at least 5 years. However, implant survival rates are not the only essential consideration when advising the patient on different treatment options. Prosthetic and implant-abutment outcomes need to be considered as well. Different kinds of abutments are available with respect to material (metal and ceramic) and shape (prefabricated and customized, both with various internal designs). At this time, metal abutments are classified as the gold standard, although high-strength zirconia abutments are being utilized more widely and may be an adequate alternative to metal abutments for the clinical use. The systematic review by Zembic et al focuses on the survival rates of metal and ceramic abutments supporting single-implant crowns with a mean observation period of at least 3 years, as sufficient 5-year data were not available. In addition, the occurrence of negative biologic, technical, and esthetic events was evaluated for metal and ceramic abutments.

One of the important decisions in implant prosthodontics is the choice of the connection type of the final restoration to the implant via the screw-retained abutment. The restorative connection can be either screw- or cement-retained. With screw-retained restorations, an abutment or mesostructure may be separate

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to the restoration (two-piece) or combined as part of the fabrication procedure (one-piece). In general, both retention types have their advantages and limitations. Clinical and technical issues relevant in making the choice include ease of fabrication, precision, passivity of the framework, retention, occlusion, esthetics, accessibility, retrievability, complications, and costs. The focus of the review by Wittneben et al is on biologic and technical failures and complication rates observed with cement- and screw-retained fixed implant-supported reconstructions.

Disclosure

All the group members were asked to reveal any conflicts of interest that could potentially influence the outcomes of the consensus deliberations. No such conflicts were identified.

CAD/CAM TECHNOLOGY FOR IMPLANT ABUTMENTS, CROWNS, AND SUPERSTRUCTURES

General Comments

The aim of the first systematic review was to answer the focus question "How do CAD/CAM implant-supported prostheses in patients with missing teeth and one or more dental implants perform compared to conventionally fabricated implant-supported prostheses when assessing esthetics, complications (biologic and mechanical), patient satisfaction, and economic factors?" CAD/CAM technology that can be used to predictably facilitate the restoration of dental implants from single-unit cases to complex full-arch reconstructions is currently available. The techniques used to produce the CAD/CAM frames vary significantly between the different investigations. The first described techniques were based on resin patterns placed in a laser scanner to feed information on the contour of the framework into a computer. An identical copy of the resin pattern was then milled out of one piece of titanium. Currently, it is possible to design a complete virtual prosthesis using computer-generated CAD/CAM parts without scanning a physical prototype. For crowns, abutments, and frameworks, CAD/CAM technology is able to provide results that, based on the current literature, are comparable to that of conventional techniques when considering implant survival, prosthesis survival, and technical and biologic complications.

Consensus Statements

With respect to CAD/CAM technology for implant abutments, crowns, and superstructures, the following statements can be made:

- CAD/CAM technology has been successfully incorporated into implant dentistry.
- The clinical performance of implant-supported prostheses produced using CAD/CAM and conventional techniques is similar over the short term (mean: crowns, 1 year [1 to 1.1 years]; abutments, 3.5 years [1 to 5 years]; frameworks, 4 years [1 to 10 years]).
- The variability of CAD/CAM software and hardware used in fabricating implant-supported prostheses makes comparison difficult.
- The variability of outcome measures and material choices in investigations of CAD/CAM implant-supported prostheses makes comparison difficult.
- The short-term (mean, 3.5 years [1 to 5 years]) survival rate of individually customized CAD/CAM abutments is similar to that of conventionally fabricated or stock abutments.
- The short-term (mean, 4 years [1 to 10 years]) survival rate of individually customized CAD/CAM frameworks is similar to that of conventionally fabricated frameworks.

Treatment Guidelines

- The implementation of CAD/CAM technologies should lead to acceptable clinical outcomes.
- Continuous training for both the restorative dentist and technician is essential to successfully implement CAD/CAM techniques for the restoration of dental implants.
- There is continuous industry-controlled development in CAD/CAM devices, techniques, and materials. The dentist and technician should be aware that product hardware and software, as well as support, will change with generational advances.
- As the dentist remains responsible for treatment outcomes, it is recommended that he/she play an active role, together with the technician, to carefully control CAD/CAM processes and material selection.
- It is recommended that the dentist approve a virtual final prosthesis (virtual diagnostic wax-up) that dictates abutment/framework design.
- It is recognized that digitally derived prostheses can be remanufactured from stored data sets. It is recommended that digital data sets be stored/protected for this eventuality and that digital technology work platforms maintain programming compatibility/transparency.

Recommendations for Future Research

- Renew the definitions relating to CAD/CAM techniques:

  1. Complete CAD/CAM product (including abutment, mesostructures, frameworks, and prostheses): The entire design and manufacturing process is software implemented and controlled.
  2. Partial CAD/CAM product (including abutment, mesostructures, frameworks, and prostheses): Some design and manufacturing process steps involve manual intervention.

- Standardization of measured outcomes and study protocols for clinical investigations are recommended.
- Studies on economic impacts and patient-centered outcome measures for new technologies are recommended.

SURVIVAL RATE AND INCIDENCE OF COMPLICATIONS OF SINGLE IMPLANT–SUPPORTED FIXED RECONSTRUCTIONS

General Comments

Different kinds of implant abutments are available with respect to material (metal and ceramic) and shape (prefabricated and customized, both with various internal designs). Although metal abutments are classified as the gold standard, high-strength zirconia abutments are being utilized more widely. However, the available data in the literature only covers a limited time span. Therefore, the consensus statements and clinical recommendations are based on a review of the survival rates of metal and ceramic abutments supporting single-implant crowns with a mean observation period of at least 3 years.

Consensus Statements

- No differences were found between ceramic and metal abutments in clinical performance based upon esthetic, technical, or biologic outcomes.
- No differences were found between the clinical performance of metal abutments with external or internal connections, based upon esthetic, technical, or biologic outcomes (mean, 5 years [3 to 10 years]).
- The reported rate of technical complications is higher than either esthetic or biologic complications (mean, 5 years [3 to 10 years]).

Treatment Guidelines

- As many different types of zirconia with differing microstructures and performance are being introduced into implant dentistry, they should be obtained from a reputable/qualified manufacturer.
- For anterior and premolar prostheses, zirconia abutments may be indicated. However, they should not be ground, abraded, or adjusted by the clinician or technician following sintering, unless recommended by the manufacturer.
- Ceramic abutments should not replace metal ones for all indications. Preliminary findings reflect an inherent sensitivity of ceramics to design and processing problems; eg, stress concentration, thin walls, sintering, and residual machining flaws.
- The design of full ceramic abutments should not be based on metal abutment design to avoid stress concentrations or the development of unfavorable stresses.
- Caution is recommended in the clinical use of ceramic abutments in molar sites, as their behavior in these sites has not been sufficiently described.
- The performance of bonded titanium-zirconia implant abutments is not yet established. Thus, caution is recommended in the clinical use of such abutments due to insufficient data.

Recommendations for Future Research

More clinical research is needed for:

- Bonded titanium-zirconia abutments
- Studies on zirconia abutments (both anterior and posterior) longer than 5 years
- Internal versus external implant-abutment connections for both ceramic and metal abutments
- Instrumented and visual esthetic outcomes for ceramic versus metal abutments
- Single- versus multiple-unit prostheses

Minimum standardized data set on outcome measures for future research protocols:

1. Abutment material and fabrication methods
2. Restoration sites (anterior, posterior)
3. Failure type with descriptive information and photographs
4. Timing of failure
5. Gingival indices
6. Soft tissue esthetic outcome(s) with information about tissue thickness
7. Radiographic bone level changes
8. Screw failure

CLINICAL PERFORMANCE OF SCREW- VERSUS CEMENT-RETAINED IMPLANT-SUPPORTED FIXED RECONSTRUCTIONS

General Comments

The restorative connection to the implant or abutment can be either screw- or cement-retained. With screw-retained restorations, an abutment or a mesostructure may be separate from the restoration (two piece) or combined as part of the fabrication procedure (one piece). In general, both retention types (screw- and cement-retained) have their advantages and limitations. The consensus statements of this review focus on biologic and technical failures and complication rates observed with screw- and cement-retained implant-supported fixed reconstructions.

Consensus Statements

- High survival rates can be achieved with both cemented and screw-retained fixed implant-supported prostheses. Neither failure nor complication can be avoided by selecting a prosthesis retention type.
- Cemented all-ceramic prostheses have a higher failure rate than cemented metal-ceramic prostheses. However, no difference was found with screw-retained prostheses.
- Based upon the literature reviewed, the type of cement used does not influence the failure rate of cemented prostheses.
- Technical complications occurred (estimated annual event rate of up to 10%) with both cemented and screw-retained prostheses. In the pooled data, the cemented prostheses exhibited a higher rate of technical complication.
- Screw-retained prostheses exhibited a higher rate of ceramic chipping than cemented prostheses.
- Biological complications can be found (estimated annual event rate of up to 7%) with both cemented and screw-retained prostheses. Cemented prostheses exhibit a higher rate of fistula formation and suppuration.

Treatment Guidelines

Based on the data in this review, a universal recommendation cannot be made for either cementation or screw retention. However, in a clinical situation that offers a choice of prosthesis retention type, the following recommendations may be made:

Cement retention may be recommended:

- For short-span prostheses with margins at or above tissue level to simplify fabrication procedures
- To enhance esthetics when the screw access passes transocclusally or in cases of malposition of the implant
- When an intact occlusal surface is desirable
- To reduce initial treatment costs
- It is further recommended that the clinician understand that the procedures involved with cement retention for implant-supported crowns are not simple and should be carried out with great caution.

Screw retention may be recommended:

- In situations of minimal interarch space
- To avoid a cement margin and thus the possibility of cement residue (this may be particularly important if the prosthetic margin is placed submucosally, since it has been shown to be more difficult to completely remove cement residue from margins placed > 1.5 mm submucosally)
- When retrievability is of importance
- In the esthetic zone, to facilitate tissue contouring and conditioning in the transition zone (emergence profile)
- To facilitate screw retention, it is recommended that the implant be placed in a prosthetically driven position.

RECOMMENDATIONS FOR FUTURE RESEARCH

- Standardization of outcomes for clinical investigations is recommended.
- Improved protocols for chairside cementation should be developed.
- Combined prostheses retention types should be tested (eg, bonding base).
- Ceramic chipping occurs frequently. Reporting of ceramic chipping should include the severity and location of the chipping. This should also be related with patient-centered outcomes.
- Details of the restorative and technical procedures, which may influence prostheses survival, should be reported.
- Prosthetic factors, such as the material of the components used, should be reported in greater detail.