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Srinivasan, Murali; Meyer, Simon; Mombelli, Andrea; Muller, Frauke

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Murali Srinivasan  
Simon Meyer  
Andrea Mombelli  
Frauke Müller

## Review Article

# Dental implants in the elderly population: a systematic review and meta-analysis

**Authors' affiliations:**

Murali Srinivasan, Frauke Müller, Division of Gerodontology and Removable Prosthodontics, University Clinics of Dental Medicine, University of Geneva, Geneva, Switzerland  
Simon Meyer, Andrea Mombelli, Division of Periodontology, University Clinics of Dental Medicine, University of Geneva, Geneva, Switzerland  
Frauke Müller, Service of Geriatrics, Department of Internal Medicine, Rehabilitation and Geriatrics, University Hospitals of Geneva, Thonex, Switzerland

**Corresponding author:**

Frauke Müller  
Division of Gerodontology and Removable Prosthodontics  
University Clinics of Dental Medicine  
University of Geneva  
19, Rue Barthélemy-Menn, CH-1205 Geneva  
Switzerland  
Tel.: +41 22 3794060  
Fax: +41 22 3794052  
e-mail: frauke.mueller@unige.ch

**Key words:** aged 65 years and over, dental implants, edentulous jaws, elderly patients, implant survival, meta-analysis, survival rate, systematic review

**Abstract**

**Objective:** This systematic review was conducted to evaluate the outcome of dental implant therapy in elderly patients ( $\geq 65$  years).

**Material and Methods:** Online database and hand searches were systematically performed to identify studies reporting on dental implants placed in the partially/completely edentulous jaws of elderly patients. Only prospective studies reporting on regular-diameter ( $\geq 3$  mm), micro-rough surface implants were included in this review. Two investigators performed the search and data extraction. An inter-investigator reliability was verified using kappa statistics ( $\kappa$ ). A meta-analysis was performed on implant survival rates, while the mean peri-implant marginal bone level changes (PI-MBL), technical/mechanical complications, and biological complications were reported descriptively.

**Results:** The systematic search yielded 2221 publications, of which 11 studies were included for statistical analyses. The calculated  $\kappa$  for the various parameters extracted was  $\kappa = 0.818$ –1.000. A meta-analysis was performed on the post-loading implant survival rates at 1, 3, 5, and 10 years. The random-effects model revealed an overall 1-year implant survival of 97.7% (95% CI: 95.8, 98.8;  $I^2 = 0.00\%$ ,  $P = 0.968$ ;  $n = 11$  studies). The model further revealed an overall implant survival of 96.3% (95% CI: 92.8, 98.1;  $I^2 = 0.00\%$ ,  $P = 0.618$ ;  $n = 6$  studies), 96.2% (95% CI: 93.0, 97.9;  $I^2 = 0.00\%$ ,  $P = 0.850$ ;  $n = 7$  studies), and 91.2% (95% CI: 83.4, 95.6;  $I^2 = 0.00\%$ ,  $P = 0.381$ ;  $n = 3$  studies) for 3, 5, and 10 years, respectively. The reported 1-year average PI-MBL ranged between 0.1 and 0.3 mm, while the reported 5- and 10-year PI-MBL were 0.7 and 1.5 mm, respectively. Information obtained pertaining to the technical and biological complications in the included studies was inadequate for statistical analysis. The frequent technical/mechanical complications reported were abutment screw loosening, fracture of the overdenture prostheses, activation of retentive clips, ceramic chipping, and fractures. The common biological complication reported included peri-implant mucositis, mucosal enlargement, bone loss, pain, and implant loss.

**Conclusions:** This review provides robust evidence favoring dental implant therapy in elderly patients as a predictable long-term treatment option, in terms of implant survival, clinically acceptable PI-MBL changes, and minimal complications. Therefore, age alone should not be a limiting factor for dental implant therapy.

Global demographic trends project a world population of nine billion people by the year 2050, which is an estimated increase of 50 million annually. This trend is not just because of an increase in the birth rates but due to a multitude of other factors such as increased life expectancy, reduction in mortality, slow growth, and urbanization. It is estimated that in the United States alone, the elderly population ( $>65$  years) will double by the year 2050 (Ortman et al. 2014). Although the decline in the rates of edentulism in developed countries has been reported (Mojon et al. 2004; Müller et al.

2007), it will however not be eradicated, tooth loss will gradually appear at a later age and in an older segment. The elderly segment will inevitably start requiring complex and quality rehabilitation procedures including, but not restricted to, dental implant therapy.

Rehabilitation with dental implants is a highly successful therapeutic option for the partially/completely edentulous jaws, with predictable and long-term success rates (Chappuis et al. 2013). In fact, a mandibular two-implant overdenture therapy is considered a first-choice standard of care in the

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rehabilitation of completely edentulous patients (Feine et al. 2002; Thomason et al. 2009). Implant-supported prostheses have proven to improve mastication (van Kampen et al. 2004) and the associated oral health-related quality of life (OHRQoL) (Emami et al. 2009). In the very old dependent edentulous patients, implant overdentures (IODs) have shown to increase the maximum voluntary bite force and the masseter muscle thickness, thus signifying a benefit of IODs even in later life (Müller et al. 2013). In the past, implant therapy has been mostly used in a younger adult segment, but current demographic trends suggest that the candidates for implant therapy, at the present and in the future, would primarily be in the older strata. This older segment would inevitably be the patient pool for routine and complex implant rehabilitation procedures. Yet, in the literature, scientific evidence is lacking pertaining to implant therapy in the elderly population. Few studies existing in the literature were purposefully designed for the geriatric age group undergoing dental implant therapy (Müller et al. 2013; Becker et al. 2015; Hoeksema et al. 2015). However, most published studies including elderly participants do also comprise of younger adults within the same study groups, hence deeming it impossible to ascertain a true treatment effect exclusive to the elderly patient segment. Little is known on the long-term influence of age on dental implant therapy, in the old and the very old patients. Information related to the effects like implant survival, complications (technical/mechanical or biological), and prosthodontic maintenance needs and patient satisfaction (subjective and objective) in the elderly population is scarce or inexistent.

Hence, the dedicated aim of this systematic review was to evaluate the outcome of dental implant therapy in the elderly population aged 65 years or over. The null hypothesis set for this review was that in the elderly population undergoing dental implant therapy, there is no difference in the post-loading implant survival rates between the partially and completely edentulous jaws. The population intervention/exposure comparison outcome (PICO) focus question set for this systematic review was: "In the elderly geriatric patients, what are the survival-, technical complication-, and biological complication- rates when comparing dental implant therapy between the partially and completely edentulous jaws?"

## Material and methods

### Protocol and registration

This systematic review was performed and reported as prescribed by the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines (Moher et al. 2010). The protocol followed in this systematic review is similar to the design used in previously published systematic reviews (Schimmel et al. 2014; Srinivasan et al. 2016).

### Eligibility criteria

The predefined set of inclusion and exclusion criteria for this systematic review are enumerated in Table 1.

### Information sources

All prospectively designed human studies reporting on dental implant therapy in the elderly population ( $\geq 65$  years) were searched in online electronic databases (PubMed, Embase, CENTRAL, and Web of Science). Relevant publications which were not accessible online were hand-searched. Other sources such as online search engines (Google, Yahoo, etc.), online research community websites (<https://www.researchgate.net/>), reference cross-checks, and personal contacts with authors were all accessed for generating a maximum pool of relevant studies. No further search was performed after the last executed update, which was on January 14, 2016.

### Search strategy

The search strategy was designed and set up by experts in database searches (FM and AM) and the two investigators (MS and SM). The two investigators performed the searches based on the identified medical subject headings (MeSH) search terms as dictated by the search design and strategy. The terms were then applied using the appropriate Boolean operators, "OR" or "AND," to perform the search in the databases. The complete set of search terms used, and the filters set, while performing the searches in the above-mentioned databases are described in Table 1.

### Study selection

No restrictions were applied relating to the type of studies included, which included all studies with a prospective design (randomized controlled trials [RCTs], prospective cohort studies, prospective case-control studies, and prospective case series). The investigators (MS and SM) initially swept through the search results by a thorough title and abstract screening. After the initial sweep,

the shortlisted studies were included for a full-text analysis only after a mutual agreement between the two investigators. Disagreements, if present, were resolved by a consensus meeting with the senior authors (AM and FM). The final list was mutually agreed upon by the two investigators before data extraction. If multiple publications reporting on the same cohort from the same author existed, then only the most recent publication was included in the review.

### Data collection process

Data extraction was performed independently and was reciprocally blinded. Both investigators (MS and SM) used Microsoft® Excel spreadsheets (Microsoft Excel 2016 for Macintosh/Windows, version 16.0, Microsoft Corporation, Redmond, WA, USA) for tabulating the extracted information. When in doubt, concerning the extracted data, the corresponding authors were contacted by email for confirmation.

### Data items

The following parameters were extracted from the included studies: authors' names, year of publication, study design, loading protocol, implant system, observation period, number of patients included in the study, mean age, number of implants placed, survived, and failed, number of patient and implant drop-outs, dental state of the jaw rehabilitated (partially or completely edentulous), the type of prosthetic rehabilitation (fixed or removable prostheses), mean peri-implant marginal bone level changes (PI-MBL), biological complications, technical/mechanical complications, and the reported implant survival rates.

### Missing data

Missing relevant information from the included studies was procured by a direct email contact with the corresponding author. Email reminders were sent to the authors in case of a nonresponse. Further emails were sent if the received information required further clarity. A nonresponse from the author would ultimately lead to the exclusion of the study, when necessary information was lacking.

### Risk of bias and quality assessment of the included studies

Risk of bias was assessed in the included RCTs using the Cochrane Collaboration's tool (Higgins et al. 2011), while the Newcastle-Ottawa Scales (NOS) were used for prospective cohort and case-control studies (Wells et al. 2014).

**Table 1.** Inclusion criteria, information sources, search terms, and search strategy

Focus question	In elderly geriatric patients, what are the survival-, technical complication-, and biological complication- rates when comparing dental implant therapy between the partially and completely edentulous jaws?	
Criteria	Inclusion criteria	<ul style="list-style-type: none"> <li>• Dental implants placed in the completely and partially edentulous human patients</li> <li>• Implant-supported fixed and removable prostheses</li> <li>• Must specify the study design, number of patients, number of implants placed and failed, time of loading, and number of dropouts</li> <li>• Implants type: two-piece, micro-rough surface, solid screws, pure Ti and Ti-alloyed implants</li> <li>• Patients must have been clinically examined during recall</li> </ul>
	Exclusion criteria	<ul style="list-style-type: none"> <li>• Age &lt;65 years</li> <li>• Post-loading follow-up &lt;12 months</li> <li>• Implants placed in irradiated patients or in augmented bone</li> <li>• Implants with HA-coated surfaces</li> <li>• Patients diagnosed with medication-related osteonecrosis of the jaw (MRONJ)</li> <li>• Implant diameter less than 3 mm</li> <li>• Sample size of less than 10 cases</li> <li>• Retrospective studies</li> </ul>
Information sources	Electronic databases	PubMed, Embase, the Cochrane Central Register of Controlled Trials (CENTRAL), and the Web of Science
	Journals	Peer-reviewed dental journals available in PubMed, Embase, CENTRAL, and Web of Science databases
	Others	Online search engines (Google, Yahoo, etc.), online research community websites ( <a href="https://www.researchgate.net/">https://www.researchgate.net/</a> ), reference crosschecks, personal communication with authors, etc.
Search Terms	Population	#1 – (Jaw, edentulous [MeSH]) OR (mouth, edentulous [MeSH]) OR (humans [MeSH]) OR (dental prosthesis, implant supported [MeSH]) OR (Overdentures [MeSH]) OR (Jaw, Edentulous [MeSH]) OR (Removable dental prostheses [MeSH]) OR (fixed dental prostheses [MeSH]) OR (Elderly patient [MeSH]) OR (elderly adults [MeSH]) OR (80+ aged [MeSH]) OR (65+ Aged [MeSH]) OR (older patient [MeSH]) OR (Octogenarians [MeSH]) OR (Aged patients [MeSH]) OR (implant supported fixed dental prostheses [all fields]) OR (implant supported overdentures [all fields]) OR (Removable dental prostheses* [all fields]) OR (Overdentures [all fields]) OR (Implant supported Overdentures [all fields]) OR (Implant assisted Overdentures [all fields]) OR (edentulous ridge [all fields])
	Intervention or exposure	#2 – ((dental implantation, endosseous [MeSH]) OR (dental implants [MeSH]) OR (dental implantation* [all fields]) OR (dental implant [all fields]) OR (implants [all fields]))
	Comparison	#3 – ((Partially edentulous [MeSH]) OR (Fully edentulous [MeSH]) OR (Completely edentulous [MeSH]) OR (Partially edentulous maxilla [MeSH]) OR (Fully edentulous maxilla [MeSH]) OR (Completely edentulous maxilla [MeSH]) OR (Partially edentulous mandible [MeSH]) OR (Fully edentulous mandible [MeSH]) OR (Completely edentulous mandible [MeSH]))
	Outcome	#4 – ((Survival [MeSH]) OR (survival rate [MeSH]) OR (survival analysis [MeSH]) OR (implant survival [MeSH]) OR (dental implant survival rate [MeSH]) OR (periimplantitis [MeSH]) OR (periimplant mucositis [MeSH]) OR (peri-implant mucositis [MeSH]) OR (treatment failure [MeSH]) OR (prevalence [MeSH]) OR (mandibular implants failure rate [MeSH]) OR (maxillary implants failure rate [MeSH]) OR (success rate [MeSH]) OR (failure rate [MeSH]) OR (crestal bone loss [MeSH]) OR (periimplant bone loss [MeSH]) OR (bone loss [MeSH]) OR (periodontal conditions [MeSH]) OR (peri-implant conditions [MeSH]) OR (implant success rates [MeSH]) OR (implant failure rates [MeSH]) OR (dental implant success rate [all fields]) OR (dental implant failure rates [all fields]) OR (biological complications [all fields]))
Filters	Language	#5 – ((English [lang]) OR (French [lang]) OR (German [lang]))
	Species	Human
	Ages	Minimum age 65 years (at the time of implant placement)
	Journal categories	Dental journals
Search Builder	Search combination	#1 AND #2 AND #3 AND #4 AND #5
Search dates	January 1980 to January 14, 2016	Last search date was January 14, 2016. No further search was performed after the mentioned date

### Summary measures

The primary outcome measure set for this review was the implant survival rate, as set in previously published reviews (Schimmel et al. 2014; Srinivasan et al. 2014, 2016). This review adopted the criteria for defining implant survival/success proposed by Buser and coworkers (Buser et al. 1990). The loading protocols defined in this review are as described in a previous review (Esposito et al. 2007). Secondary outcome measures included the mean PI-MBL, biological, and technical/mechanical complications.

### Synthesis of results

An inter-investigator reliability was assessed using kappa ( $\kappa$ ) statistics. The meta-analysis was performed for the included studies on the post-loading implant survival rates at 1, 3, 5, and 10 years. Confidence intervals were set to 95% (95% CI), and implant survival rates (SR %) were calculated for each study using the comprehensive meta-analysis software, version 3.0 (Biostat, Englewood, NJ, USA). A random-effects model was used to calculate the weighted means across the studies (DerSimonian & Laird 1986). *I*-squared statistics

( $I^2$ -statistics) was used to assess the heterogeneity across the included studies.

### Risk of publication bias and additional analyses

A risk of publication bias was assessed across the studies using a funnel plot (Sterne & Egger 2001). A sensitivity analysis was carried out wherein the implant survival rate was recalculated considering the dropout implants as failures (Srinivasan et al. 2016). Additional descriptive analysis was performed to report the PI-MBL and biological and technical/mechanical complications.

## Results

### Study selection

The details of the search and selection processes are described in the PRISMA flow diagram (Moher et al. 2010; Fig. 1). The systematic database search yielded a total of 2221 eligible studies (PubMed = 1115; Embase = 394; CENTRAL = 58; Web of Science = 654). From this total, 1850 studies were eliminated after an initial title and abstract screening, thus identifying a total of 371 studies for full-text analysis; 157 studies were shortlisted for inclusion in the review. However, most studies did not have a true elderly cohort and the intervention groups in the studies also consisted of patients who were below 65 years. Hence, 157 emails were sent to the corresponding authors, requesting them for details pertaining only to the elderly population (65 years and above). After receiving the responses from the authors, reference cross-checks and hand searches were performed; 18 studies were shortlisted for a final evaluation. To carefully avoid publication bias, many studies were excluded because they reported on the same cohort from different time points. The various reasons for exclusion of the studies during the various stages of the systematic search process are shown in Fig. 1. A reapplication of the

inclusion and exclusion criteria was performed to this final list resulting in a further elimination of seven studies, because six of these publications had a sample size of less than 10 elderly patients and one was a double publication (Glauser et al. 2005, 2007; Crespi et al. 2008, 2014; Schropp & Isidor 2008; Degidi et al. 2010; Grandi et al. 2014). Finally, a total of 11 methodologically sound publications were included in this review for statistical analyses (Ormianer & Palti 2006; Strietzel & Reichart 2007; Laviv et al. 2010; Cakarar et al. 2011; Covani et al. 2012; de Carvalho et al. 2013; Müller et al. 2013; Bressan & Lops 2014; Becker et al. 2015; Hoeksema et al. 2015; Rossi et al. 2015).

### Study characteristics

The included list of publications for analyses comprised of two RCTs (Müller et al. 2013; Rossi et al. 2015), one prospective cohort study (Covani et al. 2012), one prospective case-control study (Laviv et al. 2010), one prospective comparative study (Hoeksema et al. 2015), and six prospective case series (Ormianer & Palti 2006; Strietzel & Reichart 2007; Cakarar et al. 2011; de Carvalho et al. 2013; Bressan & Lops 2014; Becker et al. 2015). All of the 11 included studies could be analyzed for a 1-year post-loading implant survival, while six of them could be analyzed

for a 3-year post-loading implant survival (Ormianer & Palti 2006; Strietzel & Reichart 2007; Laviv et al. 2010; Covani et al. 2012; de Carvalho et al. 2013; Rossi et al. 2015). Seven studies provided data enabling a 7-year post-loading implant survival (Ormianer & Palti 2006; Strietzel & Reichart 2007; Laviv et al. 2010; Covani et al. 2012; de Carvalho et al. 2013; Hoeksema et al. 2015; Rossi et al. 2015) analysis. From the list of 11 studies, only three studies could be analyzed for a 10-year observation period (Covani et al. 2012; de Carvalho et al. 2013; Hoeksema et al. 2015).

Four studies reported on the rehabilitation of the completely edentulous jaw with implant-supported fixed (ISFP) or implant-supported removable prostheses (ISRP) (Cakarar et al. 2011; Müller et al. 2013; Bressan & Lops 2014; Hoeksema et al. 2015), four reported on partially edentulous jaws with ISFP (Laviv et al. 2010; Covani et al. 2012; de Carvalho et al. 2013; Rossi et al. 2015), two reported on rehabilitations in both the partially and completely edentulous jaws (Ormianer & Palti 2006; Strietzel & Reichart 2007), and in one study, neither the jaw type nor the type of rehabilitation was specified (Becker et al. 2015).

Information pertaining to the PI-MBL was available in only two of the included studies (Becker et al. 2015; Hoeksema et al. 2015); biological and technical/mechanical complications were reported in nine studies (Ormianer & Palti 2006; Strietzel & Reichart 2007; Laviv et al. 2010; Cakarar et al. 2011; Covani et al. 2012; de Carvalho et al. 2013; Bressan & Lops 2014; Hoeksema et al. 2015; Rossi et al. 2015). All the information extracted from the published articles and from email correspondences is presented in Tables 2 and 3.

### Risk of bias/quality assessment of the included studies

The RCTs, cohort studies, and case-control studies included in this review could only be considered as prospective case series. Therefore, neither the Cochrane tool nor the NOS could be applied to assess the risk of bias and quality of the studies.

### Synthesis of results

Inter-investigator agreement

The overall  $\kappa$  scores calculated for the various parameters extracted by the two investigators ranged between 0.818 and 1.000, hence indicating an excellent degree of inter-investigator agreement.

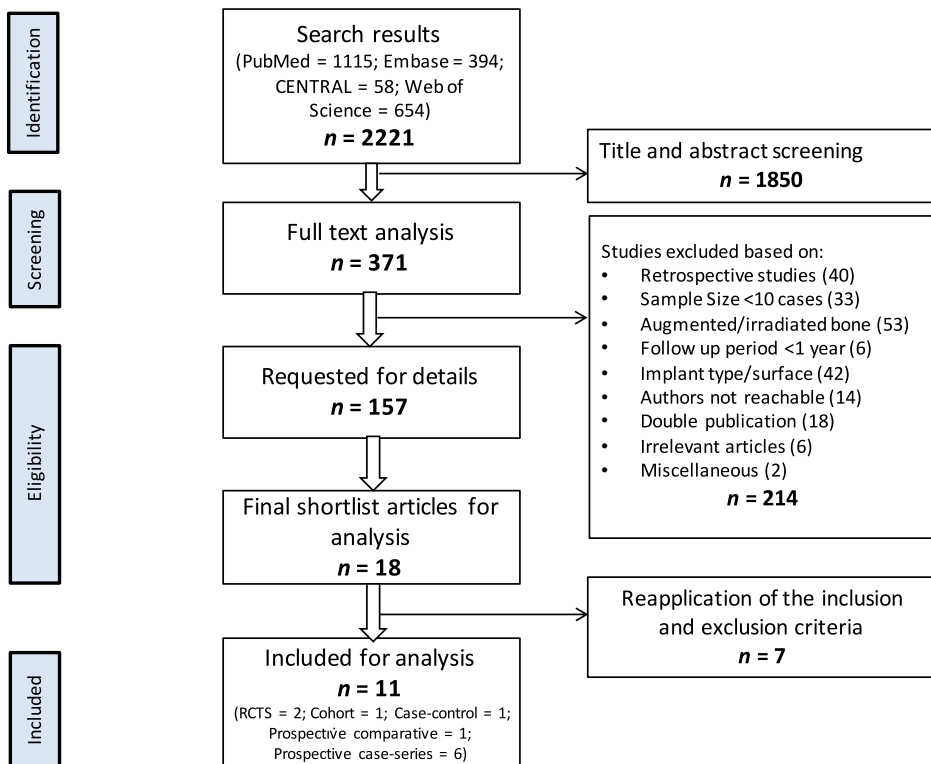


Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) flow diagram showing the entire identification and inclusion process. n, number; RCTs, randomized controlled trials.



**Table 2. Included prospective studies and RCTs reporting on dental implant therapy in elderly patients (65 years and above)**

Study (First author)	Year	Loading protocol	Implant system	Observation period in months	Number of patients	Mean age in years	Number of implants placed	Number of implant dropouts	Number of implants survived* (failed)	Calculated implant survival rate (SR%):†	Edentulous state of the jaw rehabilitated	Prosthesis type
Becker‡	2015	Not specified	Nobel Biocare	12	31	84.0 (σ = 15) 83.0 (σ = 16)	59‡	0	57 (2)‡	96.6‡	Not specified	Not specified
Bressan	2014	Immediate	Ankylos	24	19	≥65	76	0	76 (0)	100	Completely edentulous	Complete fixed prostheses on 4 implants
Cakarer	2011	Conventional	Astra Tech, Straumann, Nobel, Frialit, Swiss Plus, Biohorizons, BioLok	Up to 60	16	75.56	42	0	41 (1)	97.6	Completely edentulous	2- IODs
Covani	2012	Conventional	Premium, Sweden and Martina	120	20	67.5	31	2	25 (4)	86.2	Partially edentulous	Single Crowns
de Carvalho	2013	Immediate	Nobel Biocare, Lifecore, Biomet 3i, Globtek	12-180	30	≥65	60	0	57 (3)	95.0	Partially edentulous	Single crowns
Hoeksema Laviv	2015 2010	Conventional Immediate	Straumann Zimmer, Biomet 3i, Dentsply Friadent, Spline, Alpha-Bio	120 Up to 60	11 19	70.0 69.5	22 54	10 0	11 (1) 52 (2)	91.7 96.3	Completely edentulous Partially edentulous	2-IODs Single crowns
Müller Ormianer	2013 2006	Conventional Immediate	Straumann Zimmer	12 60	16 14	85.0 ≥65	32 80	4 8	28 (0) 71 (1)	100 98.6	Completely edentulous Partially and completely edentulous	2-IODs Fixed and removable prostheses
Rossi Strietzel	2015 2007	Early Not specified	Straumann Camlog	60 55.2	10 20	≥65 69.0	10 57	0 4	10 (0) 52 (1)	100 98.1	Partially edentulous Partially and completely edentulous	Single crowns Fixed and removable prostheses

RCTs, randomized controlled trials; σ, men; σ, women; ≥65, exact mean age was not provided, but the mean age of cohort was confirmed by the authors as 65 years and above.

\*Includes implant dropouts.

†Calculated as per the raw data supplied by the authors and not considering implant dropouts as failures.

‡Data extracted and reported for 1-year only and excluding machined surface implants.

Meta-analysis of the included studies  
 A meta-analysis was performed on the post-loading implant survival rates at various time points (1, 3, 5, and 10 years). The random-effects model revealed an overall 1-year post-loading implant survival of 97.7% (95% CI: 95.8, 98.8;  $I^2 = 0.00\%$ ,  $P = 0.968$ ;  $n = 11$  studies; Fig. 2). Six studies provided data for a 3-year analysis, and the model revealed an overall post-loading implant survival of 96.3% (95% CI: 92.8, 98.1;  $I^2 = 0.00\%$ ,  $P = 0.618$ ;  $n = 6$  studies), and is shown in Fig. 3. Five-year post-loading implant survival was found to be 96.2% (95% CI: 93.0, 97.9;  $I^2 = 0.00\%$ ,  $P = 0.850$ ;  $n = 7$  studies; Fig. 4), while the 10-year survival was found to be 91.2% (95% CI: 83.4, 95.6;  $I^2 = 0.00\%$ ,  $P = 0.381$ ;  $n = 3$  studies) as revealed in the forest plot (Fig. 5).

Descriptive analysis of the mean PI-MBL changes, biological and technical/mechanical complications  
 The reported 1-year mean PI-MBL ranged between 0.1 and 0.3 mm (Becker et al. 2015; Hoeksema et al. 2015), while the reported 5- and 10-year PI-MBL were 0.7 and 1.5 mm, respectively (Hoeksema et al. 2015).

Information obtained pertaining to the technical/mechanical and biological complications in the included studies was inadequate for statistical analysis and is reported descriptively in Table 3. The frequent technical/mechanical complications reported were abutment screw loosening ( $n = 1$ ), fracture of the over-denture prostheses ( $n = 1$ ), activation of retentive clips ( $n = 1$ ), ceramic chipping ( $n = 3$ ), and ceramic fractures ( $n = 2$ ). The common biological complication frequently encountered included peri-implant mucositis ( $n = 2$ ), mucosal enlargement ( $n = 1$ ), bone loss ( $n = 7$ ), pain ( $n = 1$ ), and implant loss ( $n = 2$ ).

**Additional analyses**

Sensitivity analyses were performed for implant survival rates at 1, 3, 5, and 10 years while considering dropout implants as failures. The sensitivity analyses revealed a reduction in the 1-year implant survival rate dropping down to 95.6% (95% CI: 92.1, 97.5;  $I^2 = 29.49\%$ ,  $P = 0.165$ ;  $n = 11$  studies; Fig. 6), while the 3-year survival rate dropped down to 91.7% (95% CI: 87.6, 94.5;  $I^2 = 0.00\%$ ,  $P = 0.465$ ;  $n = 6$  studies; Fig. 7). The 5-year implant survival reduced to 91.2% (95% CI: 87.4, 94.0;  $I^2 = 0.00\%$ ,  $P = 0.656$ ;  $n = 7$  studies; Fig. 8), and the 10-year implant survival was 80.5% (95% CI: 45.5, 95.3;  $I^2 = 88.11\%$ ,  $P = 0.000$ ;  $n = 9$  studies; Fig. 9).

**Table 3. Marginal peri-implant bone level changes and technical and biological complications reported by the included prospective studies and randomized controlled trials (RCTs)**

Study (First author)	Year	Peri-implant marginal bone level (PI-MBL) changes in millimeters (mm)	Technical/mechanical complications (n, number of events)	Biological complications (n, number of events)
Becker	2015	0.1	Not available	Not available
Bressan	2014	Not available	n = 0	n = 2 Two cases of peri-implant mucositis (successfully treated with interceptive supportive therapy)
Cakarer	2011	Not available	n = 2 One fracture of overdenture prosthesis One need of clips activation	n = 1 Mucosal enlargement in a patient with ball attachment
Covani	2012	Not available	n = 2 One ceramic chipping One screw loosening	n = 0
de Carvalho	2013	Not available	n = 1; Not specified whether it was a technical/biological/mechanical complication	
Laviv	2010	Not available	n = 0	n = 7 Not specified in details, but reported as inflammation, redness, mobility, and pain
Hoeksema	2015	Baseline-1 year = 0.3 Baseline-5 years = 0.7 Baseline-10 years = 1.5	n = 0	n = 1 Infection and implant had to be removed
Ormianer	2006	Not available	n = 4 Two porcelain fractures Two porcelain chipping	n = 3 Bone loss of 1 mm observed on three implants at 5 years
Rossi	2015	Not available	n = 0	n = 0
Strietzel	2007	Not available	n = 1 Prosthetic complication (not specified) in one patient with two implants	n = 6 Four patients with vertical bone loss exceeding 1/3 of implant length One implant loss One patient with pain and discomfort
Müller	2013	Not available	Not available	Not available

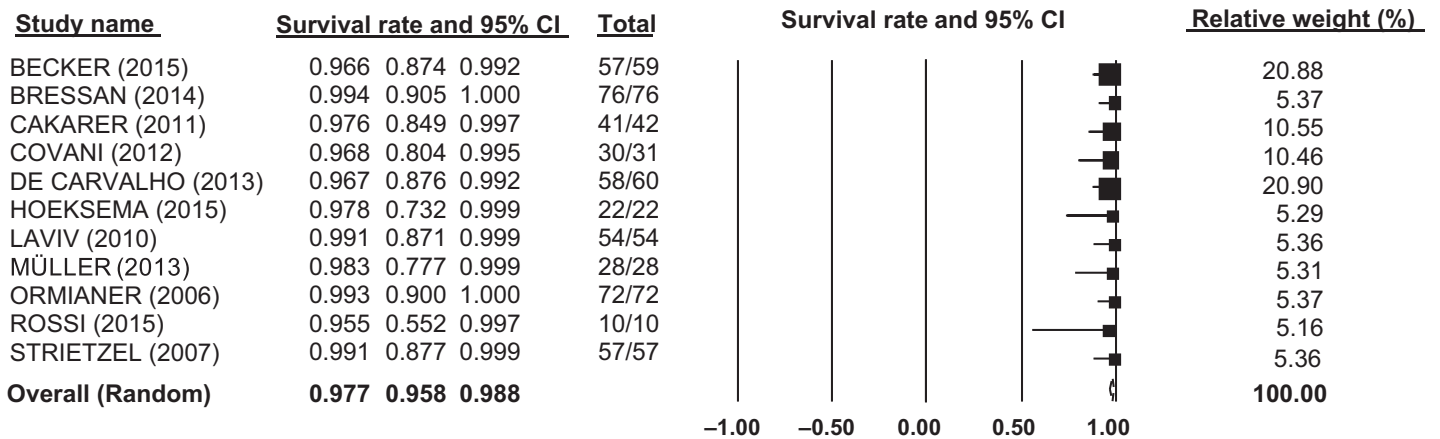


Fig. 2. Forest plot showing the 1-year post-loading implant survival rate. CI, confidence interval.

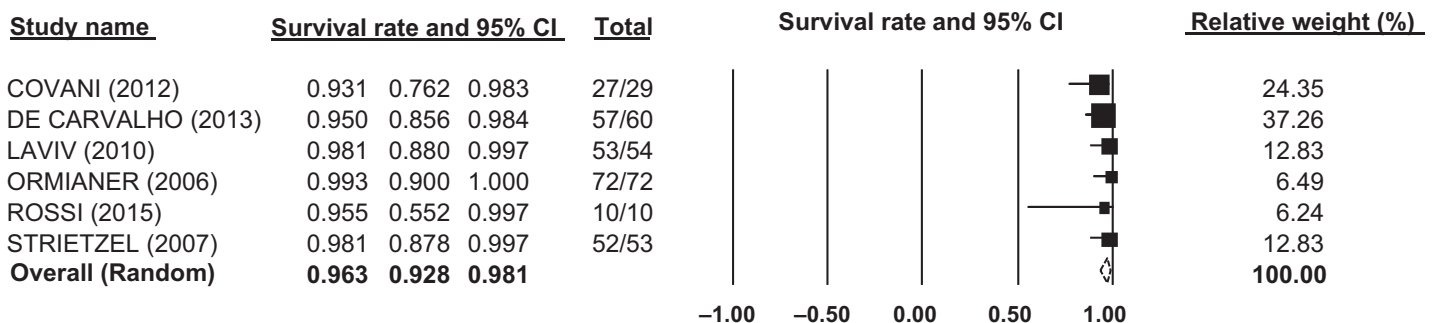


Fig. 3. Forest plot showing the 3-year post-loading implant survival rate. CI, confidence interval.

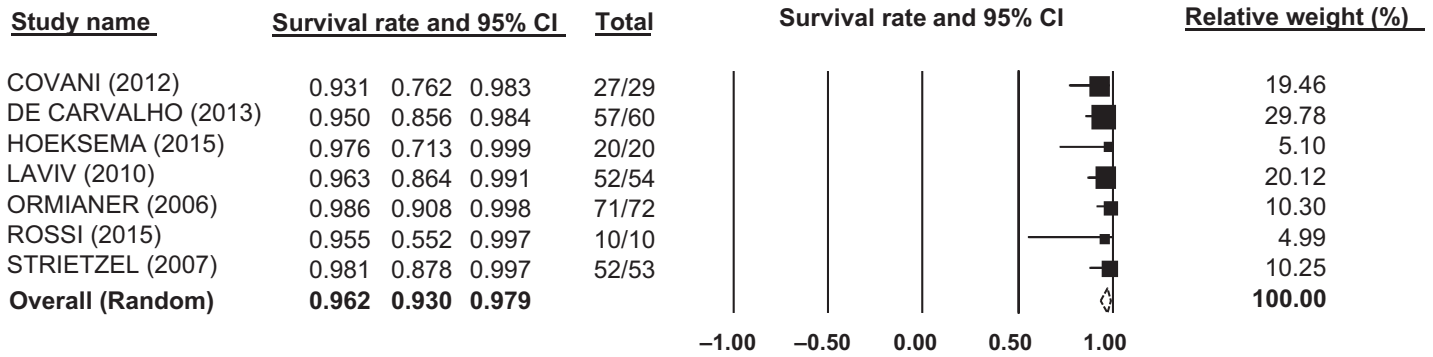


Fig. 4. Forest plot showing the 5-year post-loading implant survival rate. CI, confidence interval.

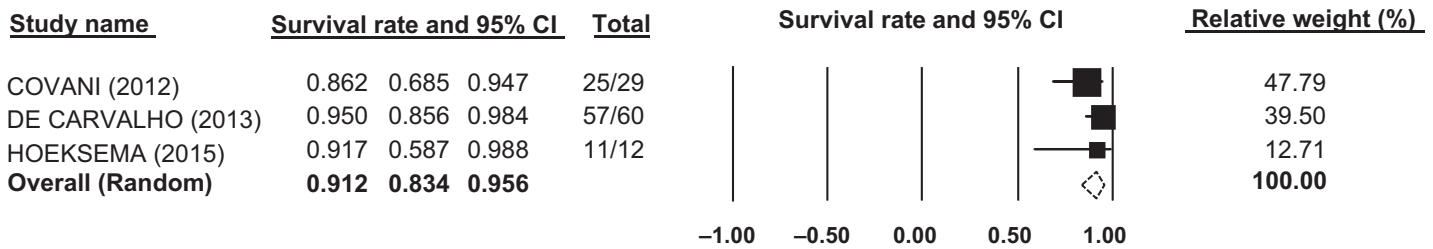


Fig. 5. Forest plot showing the 10-year post-loading implant survival rate. CI, confidence interval.

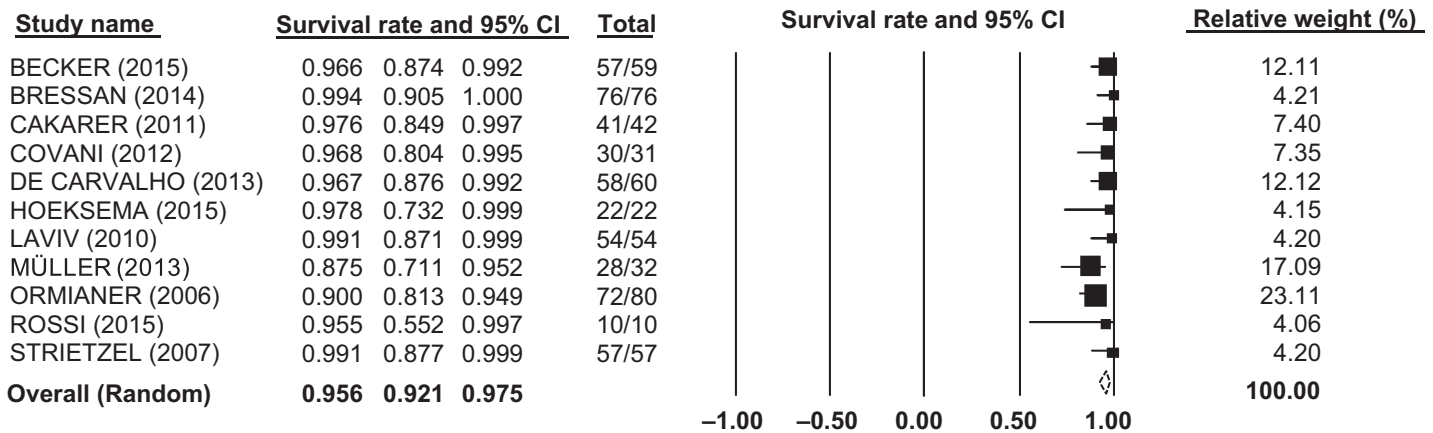


Fig. 6. Sensitivity analysis showing the 1-year implant survival rate where implant dropouts were considered as failures. CI, confidence interval.

A funnel plot was used to rule out any publication bias (Fig. 10).

### Discussion

The protocol followed in this systematic review was in accordance with the guidelines prescribed by PRISMA, and the review was conducted in a manner similar to previously published reviews (Schimmel et al. 2014; Srinivasan et al. 2016). Although the methodology executed can be considered robust, a few limitations may have existed. This study delivers a meta-analysis of prospectively designed studies that included two RCTs, one cohort study, one comparative study, and

six prospective case series. However, the included RCTs and cohort studies could not be considered as such, because their tested interventions and study objectives did not conform to our focus question. Therefore, they were recruited as prospective case series, solely, for the purpose of this review. However, in terms of strength, the included studies were methodologically of superior quality conducted by well-known and senior researchers. Meta-analysis of RCTs is often graded the highest level of scientific evidence (Glenny et al. 2008). This review was unable to identify RCTs with similar objectives as our framed PICO question, because there were none. Hence, the conclusions drawn

from the results of this meta-analysis, although credible, should be cautiously interpreted. Furthermore, our deliberate exclusion of retrospective studies could have influenced the number of studies included, but this was deemed necessary so that only studies with low bias and high methodological quality would be included in this review (Schimmel et al. 2014; Srinivasan et al. 2016).

During the search and identification process, we found that numerous studies reporting on dental implant therapy had an elderly cohort, but within the cohort group there also existed participants below the age of 65 years. The inclusion criteria for this review required a minimum age of 65 years



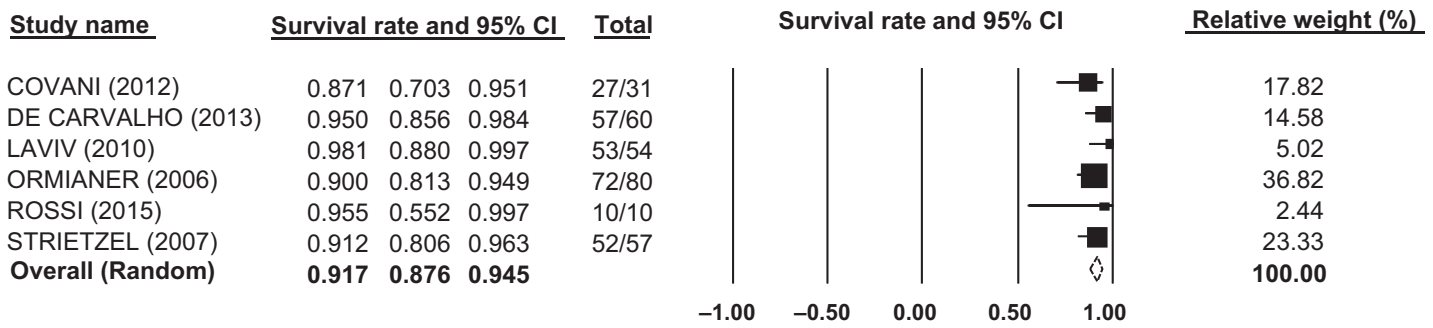


Fig. 7. Sensitivity analysis showing the 3-year implant survival rate where implant dropouts were considered as failures. CI, confidence interval.

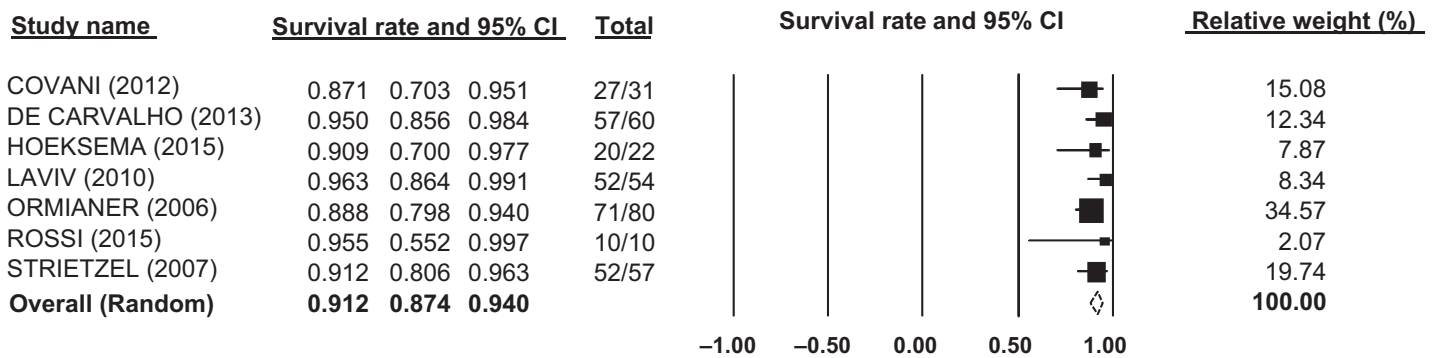


Fig. 8. Sensitivity analysis showing the 5-year implant survival rate where implant dropouts were considered as failures. CI, confidence interval.

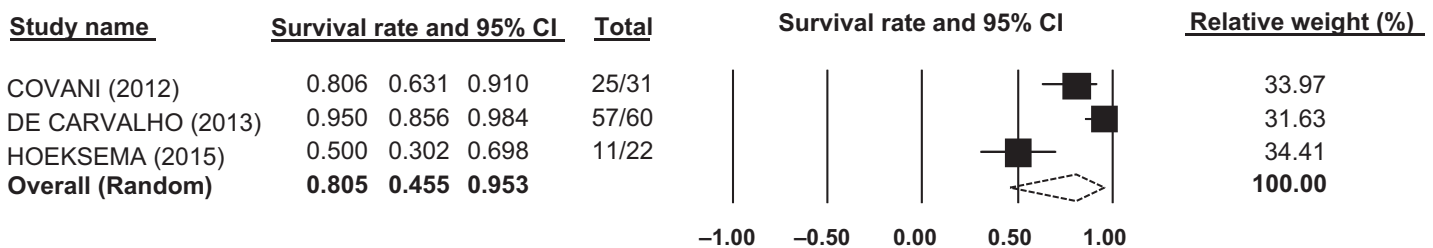


Fig. 9. Sensitivity analysis showing the 10-year implant survival rate where implant dropouts were considered as failures. CI, confidence interval.

and over; hence, it was necessary to either eliminate those studies from the review or request the respective corresponding authors for raw data pertaining to participants aged 65 years and over. Therefore, email requests were sent to the corresponding authors requesting for unpublished raw data from their studies pertaining to the elderly cohort. This unusual approach requested additional sub-analyses from the authors, and at this point we would like to acknowledge the willingness of some authors to invest time and effort to help with this review. Still, after contact with the authors, many studies were further excluded because of either sample size of less than 10 elderly participants, or nonresponse, or implant surface, etc. Only two of our included studies were exclusively on the geriatric population and had participants aged over 65 years (Müller et al. 2013;

Becker et al. 2015). For all the other included studies, authors had to be contacted for details. From the 11 finally retained studies, nine were based on these additional analyses, without which this review would have not been possible. The study published by Becker et al. (2015) provided 7-year outcomes of dental implant therapy in the elderly population (Becker et al. 2015). However, the implant pool in this study also consisted of machined implants. The exact time point of dropouts of these machined surface implants was not available; hence, the review only considered the 1-year outcomes from this study, as it was possible to precisely exclude the machined surface implant number for this period.

The results of the meta-analysis revealed a pooled overall 1-year post-loading implant survival of 97.7%, while the overall 3- and 5-

year implant survival rates were calculated as 96.3% and 96.2%, respectively; and a 10-year implant survival rate of 91.2%. These implant survival rates in the elderly population are comparable to the survival rates published in the literature (Kowar et al. 2014). A recently published retrospective study reported for an elderly cohort (aged 65–89 years) an implant-based survival rate of 95.39% over an observation period of up to 17 years (Park et al. 2016). Becker et al. (2015) reported an implant survival rate of 94.6% in the elderly population (aged 66–93 years) in an observation period of 7 years (Becker et al. 2015).

In the 11 included studies, four studies reported on completely edentulous jaws (Cakarar et al. 2011; Müller et al. 2013; Bressan & Lops 2014; Hoeksema et al. 2015) and four reported on partially edentulous jaws

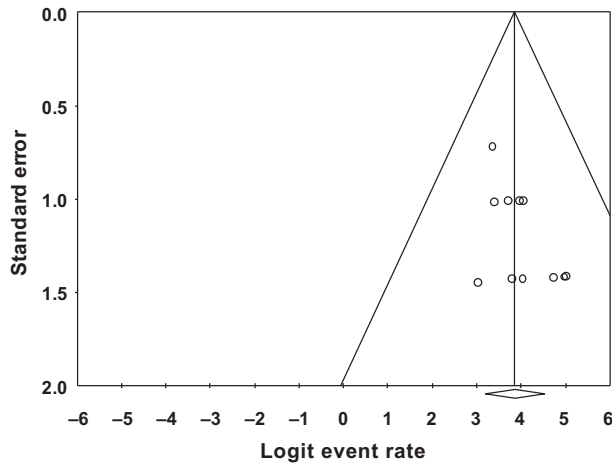


Fig. 10. Funnel plot of the included studies showing no publication bias.

(Laviv et al. 2010; Covani et al. 2012; de Carvalho et al. 2013; Rossi et al. 2015), while two studies reported on both partially and completely edentulous jaws (Ormianer & Palti 2006; Strietzel & Reichart 2007) and one study did not specify (Becker et al. 2015). The random-effects model did not reveal a significant difference, between the studies, in the overall effects for the 1-year ( $P = 0.968$ ,  $I^2 = 0.00\%$ ), 3-year ( $P = 0.618$ ,  $I^2 = 0.00\%$ ), 5-year ( $P = 0.850$ ,  $I^2 = 0.00\%$ ), and 10-year ( $P = 0.381$ ,  $I^2 = 0.00\%$ ) survival rates, with the  $I^2$ -statistics revealing no heterogeneity. Therefore, the findings of this review do not reject the null hypotheses. Despite the limited body of evidence, the results suggest that in elderly population undergoing dental implant therapy, there is no difference in the post-loading implant survival rates between the partially and completely edentulous jaws.

The review further revealed changes in an annual PI-MBL between 0.1 and 0.3 mm (Becker et al. 2015; Hoeksema et al. 2015), while the reported 5- and 10-year PI-MBL were 0.7 and 1.5 mm, respectively (Hoeksema et al. 2015). These are similar to the reported mean annual bone level changes of  $0.17 \pm 0.71$  mm in the elderly population (Park et al. 2016).

The question of implant treatment in elderly patients is not only of increasing importance in terms of volume of the elderly segment in the population, but is also pertinent with regards to an “inclusion society” which supports the participation of vulnerable groups like handicapped or elders in the social life of a society. Old and very old

persons should have the opportunity to benefit from the achievements in dentistry, just as younger persons do. Particularly for complete denture wearers, the benefits of implant placement are well documented in the literature. On the other hand, there may be biological risks related to aging which present a risk of osseointegration. With age, the bone metabolism slows down and the immune defense weakens. Often physiological aging is accompanied by chronic diseases and functional decline. Polypharmacy may cause xerostomia, thus rendering the oral mucosa sensitive. Oral biofilm is often poorly removed when vision, tactile sensitivity, and dexterity diminish in the elderly. When chronic diseases and functional disability dominate daily life, elderly patients’ priorities may drift away from oral health, and in general, a more “accepting” attitude toward functional impairment is adopted. The reaction of the peri-implant tissues to oral biofilm was recently demonstrated in elderly persons (Meyer et al. 2016). This experimental gingivitis/mucositis trial, with intrapatient comparison, revealed that although there was less plaque accumulation on the implants, the inflammatory response to a cessation of oral hygiene measures for 21 days was stronger on the peri-implant mucosa than on the gingiva of natural teeth. Finally, denture handling may be compromised by a weakened hand force and low dexterity. For elderly persons, denture management may be particularly difficult when sophisticated attachment systems are used. Along with functional and cognitive

impairment, they will increasingly depend on help from carers for the activities of daily living. Unfortunately, the nursing staff is often not well trained for the handling of implant dentures and the corresponding oral hygiene gestures. Hence, the success criteria for implants in dependent elders have to be revisited (Müller & Schimmel 2016). Given the preceding aspects, a close monitoring of elderly implant patients is recommended to monitor their performance and reduce the degree of technical complexity along with functional decline and morbidity.

## Conclusion

This systematic review provides robust evidence favoring dental implant therapy in elderly edentulous patients as a predictable long-term treatment option in terms of high implant survival rates, clinically acceptable PI-MBL changes, and minimal complications. Therefore, age alone need not be considered a factor in effectuating dental implant therapy, and implants should be a recommended treatment option in the rehabilitation of elderly edentulous patients in order to help improve their oral function and quality of life.

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## Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Appendix S1.** PRISMA 2009 Checklist.