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REVIEW ARTICLE

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Effect of advanced age and/or systemic medical conditions on dental implant survival: A systematic review and meta-analysis

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Abstract

Objectives: This review evaluated implant survival in geriatric patients (≥75 years) and/or the impact of systemic medical conditions.

Materials and Methods: Systematic literature searches were performed to identify studies reporting on geriatric subjects with dental implants and on implant patients who had any of the seven most common systematic conditions among geriatric patients. Meta-analyses were performed on the postloading implant survival rates. The impact of systemic medical conditions and their respective treatment was qualitatively analyzed.

Results: A total of 6,893 studies were identified; of those, 60 studies were included. The fixed-effects model revealed an overall implant survival of 97.3% (95% CI: 94.3, 98.7; studies = 7) and 96.1% (95% CI: 87.3, 98.9; studies = 3), for 1 and 5 years, respectively. In patients with cardiovascular disease, implant survival may be similar or higher compared to healthy patients. High implant survival rates were reported for patients with Parkinson's disease or diabetes mellitus type II. In patients with cancer, implant survival is negatively affected, namely by radiotherapy. Patients with bone metastases receiving high-dose antiresorptive therapy (ART) carry a high risk for complications after implant surgery. Implant survival was reported to be high in patients receiving low-dose ART for treatment of osteoporosis. No evidence was found on implant survival in patients with dementia, respiratory diseases, liver cirrhosis, or osteoarthritis.

Conclusions: Implant prostheses in geriatric subjects are a predictable treatment option with a very high rate of implant survival. The functional and psychosocial benefits of such intervention should outweigh the associated risks to common medical conditions.

KEYWORDS

aging, Alzheimer's disease, bisphosphonates, cancer, cardiovascular disease, chronic obstructive pulmonary disease, cirrhosis of the liver, dementia, dental implants, depression, diabetes mellitus, geriatric, hypertensive heart disease, hyposalivation, ischemic heart disease, lower respiratory infections, medication-related osteonecrosis of the jaw, meta-analysis, neurocognitive impairment, osteoarthritis, Parkinson's disease, radiotherapy, respiratory diseases, stroke, systematic review

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1 | INTRODUCTION

Current demographic trends suggest that tooth loss now occurs in later life, and an increased number of patients will require tooth replacements at an advanced age (Hugoson et al., 2005; Stock, Jurges, Shen, Bozorgmehr & Listl, 2015). In Germany and Switzerland, more than 90% of patients aged ≥75 years have a fixed and/or removable dental prosthesis, and this age group has an increasing number of implant restorations, compared to 20 years ago (Jordan & Micheelis, 2016; Schneider, Zemp & Zitzmann, 2017). This trend was likewise reported in the Department of Oral Surgery and Stomatology at the University of Bern, School of Dental Medicine, where there is a marked increase since the year 2000 in implant surgeries in the age cohort of ≥70 years (Schimmel, Müller, Suter & Buser, 2017). It has to be borne in mind that the prevalence of systemic medical conditions and frailty increase with age, and this may influence implant survival.

Today's aged generation present new challenges in the field of implant dentistry. Old and very old patients, terms that are often used when referring to persons 75 years or older, often present with functional dependency, multimorbidity, and frailty. This may or may not present a risk for implant placement, maintenance, and ultimately survival.

The world health report on aging published by the World Health Organization (WHO) lists the most common chronic conditions in elders: cardiovascular disease (CVD) (including ischemic heart disease, stroke, and hypertensive heart disease), cancer, respiratory diseases (chronic obstructive pulmonary disease COPD, and lower respiratory infections), diabetes mellitus, cirrhosis of the liver, osteoarthritis, and conditions that involve neurocognitive impairment (unipolar depression, Alzheimer's disease, and other dementias) (WHO, 2015).

Additional risks may arise from the treatment of these medical conditions, including negative side effects. Polypharmacy as well as radiotherapy directed toward the salivary glands may cause symptoms of dry mouth. High-dose bisphosphonates prescribed for the treatment of cancer with bone metastases may present a risk for necrosis of the jaw. Lower dose bisphosphonates are prescribed for the treatment of osteoporosis, although it is not listed among the seven most prevalent chronic systemic diseases in elders.

Any of these conditions or treatments might be considered by the patient or clinician as absolute or relative contraindication for implant surgery/therapy. Risks may be related to the surgical procedure itself, osseointegration, soft tissue response, as well as the long-term survival of the implant (Bartold, Ivanovski & Darby, 2016; Bornstein, Cionca & Mombelli, 2009). Another pathway of failure may be more indirect, via neglected oral hygiene and improper implant maintenance. For example, patients with dementia are known to have lower motivation to perform regular and meticulous oral hygiene, in addition to diminished cognitive and manual skills to perform the adequate procedures (Brändli, 2012). Reduced motor skills are also well documented for patients with rheumatoid arthritis (Lawrence et al., 2008; Zhang et al., 2002) or stroke (Schimmel et al., 2011).

Implant success and survival are well documented for younger age cohorts (Schimmel, Srinivasan, Herrmann & Müller, 2014), but little is known about the effect of age on osseointegration and long-term implant survival (Srinivasan, Meyer, Mombelli & Müller, 2016). In a comprehensive review of biological, clinical, and sociological considerations, Bartold et al. (2016) acknowledge the influence of physiological aging on wound healing. However, the complex process that leads to osseointegration of titanium implants as well as the accompanying inflammatory response has been mainly studied in animals (Bartold et al., 2016). Bornstein et al. reviewed and discussed the available evidence in relation to medical conditions that may influence early and late implant failure (Bornstein, Cionca & Mombelli, 2015; Bornstein et al., 2009) and found a low level of evidence that indicates absolute or relative contraindications for implant surgery. Furthermore, little is known about the reactions of the peri-implant tissues to poor oral hygiene in geriatric patients (Holm-Pedersen, Agerbaek & Theilade, 1975; Meyer et al., 2017).

In the scope of this review, geriatric patients were defined as patients with an age of 75 years and above. The aim of this systematic review was to screen and pool the available evidence to establish:

1. The dental implant survival rate in geriatric patients.
2. The potential impacts of the most common systemic medical conditions (WHO, 2015) and their treatments on implant survival.

The focused question set for this systematic review was "In patients undergoing dental implant therapy, what is the effect of advanced age (≥75 years) and/or common systemic medical conditions on the implant survival, biological complication, and technical complication rates?"

2 | MATERIAL AND METHODS

2.1 | Protocol and registration

This systematic review and meta-analysis were conducted and reported according to the PRISMA guidelines (Moher et al., 2015). The review protocol was registered with PROSPERO: International prospective register of systematic reviews (PROSPERO 2016: CRD42016049617).

2.2 | Eligibility criteria

All human studies reporting on geriatric individuals (≥75 years) with dental implants that satisfied the listed predefined inclusion criteria (Table 1) were included in the first part of this systematic review, which analyzed implant survival. Therefore, outcomes in healthy aged people were also sought.

For the second part of this search, no age limit was applied, as a preliminary screening of the literature did not identify any studies in relation to the most common medical conditions in the elderly (WHO, 2015) if the exclusion criteria included those aged 75 years or older.

TABLE 1 PICO focus question, criteria for inclusion, sources of information, search terms, search strategy, search filters, and search dates

Focus question	**In patients undergoing dental implant therapy, what is the effect of advanced age (≥75 years) and/or common systemic medical conditions on the implant survival, biological complication, and technical complication, rates?**	
Criteria	Inclusion criteria	Dental implants placed in the completely and partially edentulous human participants
		Implant-supported fixed prostheses and implant-supported/retained removable prostheses
		Studies must specify the study design, number of participants, number of implants placed and failed, time of loading, and number of dropouts
		Implant type: solid screw-type implants
		Participants must have been clinically examined during recall
	Exclusion criteria	Age <75 years
		One-piece implants, Zygomatic implants, and pterygoid implants
		Postloading follow-up <12 months
		Narrow diameter implants or mini dental implants (implants with diameter <3 mm)
		Implants with turned or machined surface
Information sources	Electronic databases	MEDLINE (PubMed): https://www.ncbi.nlm.nih.gov/pubmed/; EMBASE: https://www.embase.com/#search; and Central Register of Controlled Trials (CENTRAL) in the Cochrane Library: http://www.cochranelibrary.com.
	Others	Popular online internet search engines (e.g., Google and Yahoo), research community websites on the internet (https://www.researchgate.net/), reference cross-checks, personal communications, and hand searches. Hand searches in dental journals were only performed for records not available electronically or without an electronic abstract
Search terms	Population	#1: (Elderly Adults) OR (Partially Edentulous) OR (Fully Edentulous) OR (Completely Edentulous) OR (Partially Edentulous Maxilla) OR (Fully Edentulous Maxilla) OR (Completely Edentulous Maxilla) OR (Partially Edentulous Mandible) OR (Fully Edentulous Mandible) OR (Completely Edentulous Mandible) OR (80 + Aged) OR (75 + Aged) OR (65 + Aged) OR (Older Patient) OR (Aged Patients)
	Intervention or exposure	#2: (dental implantation, endosseous) OR (dental implants) OR (dental prosthesis, implant supported) OR (Overdentures) OR (Removable dental prostheses) OR (fixed dental prostheses) OR (dental implantation*) OR (dental implant) OR (implants) OR (implant supported fixed dental prostheses) OR (implant supported overdentures) OR (Removable dental prostheses*) OR (Overdentures) OR (Implant supported Overdentures) OR (Implant assisted Overdentures)
	Comparison	#3: (Cardiovascular disease) OR (ischemic heart disease) OR (stroke) OR (hypertensive heart disease) OR (cancer) OR (neoplasia) OR (COPD) OR (lower respiratory infections) OR (respiratory diseases) OR (Diabetes mellitus) OR (Cirrhosis) OR (Osteoarthritis) OR (neurocognitive disorder) OR (unipolar depression) OR (Alzheimer's disease) OR (other dementias) OR (Polypharmacy) OR (Hyposalivation) OR (Dry Mouth) OR (Multi Morbidity)
	Outcome	#4: (Survival) OR (survival rate) OR (survival analysis) OR (implant survival) OR (dental implant survival rate) OR (peri implantitis) OR (periimplant mucositis) OR (peri-implant mucositis) OR (treatment failure) OR (prevalence) OR (mandibular implants failure rate) OR (maxillary implants failure rate) OR (success rate) OR (failure rate) OR (crestal bone loss) OR (periimplant bone loss) OR (bone loss) OR (periodontal conditions) OR (peri-implant conditions) OR (implant success rates) OR (implant failure rates) OR (dental implant success rate) OR (dental implant failure rates) OR (biological complications)
Filters	Language	Not applied
	Species	Humans [MeSH]
	Ages	Aged [MeSH]
	Journal categories	Dental journals

(Continues)

TABLE 1 (Continued)

Focus question	In patients undergoing dental implant therapy, what is the effect of advanced age (≥75 years) and/or common systemic medical conditions on the implant survival, biological complication, and technical complication, rates?	
Search queries run as performed in MEDLINE (PubMed)	Using search combination: #1 AND #2 AND #3 AND #4 AND Humans AND Aged = 1,207 (June 2017)†	†Detailed use of the various search terms and their combinations are presented in the Supporting Information Table
	Using search combination: #1 AND #2 AND #4 AND Humans AND Aged = 1,210 (June 2017)††	††Detailed use of the various search terms and their combinations are presented in the Supporting Information Table
	Specific Searches for systemic medical conditions and implants without any age filters (PubMed/ Medline) = 1,348 (June 2017)	1. Stroke AND Dental Implants AND Humans 2. Respiratory Diseases AND Dental Implants AND Humans 3. Cirrhosis AND Dental Implants AND Humans 4. Osteoarthritis AND Dental Implants AND Humans 5. Neuorcognitive Disorders AND Dental Implants AND Humans 6. Polypharmacy AND Dental Implants AND Humans 7. Hyposalivation OR Dry Mouth AND Dental Implants AND Humans 8. Multi morbidity AND Dental Implants AND Humans 9. Multimorbidity AND Dental Implants AND Humans 10. Cancer AND Dental Implants AND Humans 11. Cardiovascular Diseases AND Dental Implants and Humans
Search dates	January 1980–26/05/2017	Final confirmatory online search was performed on 9 June 2017. No further online searches were performed after this date

2.3 | Information sources

Three electronic databases were searched: MEDLINE (PubMed), EMBASE, and CENTRAL. Hand searches of dental journals were performed for records that were not accessible electronically or for those records without an electronic abstract available. Further searches resulting from reference cross-checks were performed to identify studies that were not discovered online. Further attempts to maximize the pool of relevant studies and avoid any erroneous exclusion involved posting queries on research community websites (https://www.researchgate.net/) and, personal communications sent to selected authors. The final update for all the electronic searches was performed on June 9, 2017.

2.4 | Search strategy

The search strategy was designed and set up by two experts in database searches (Table 1). An initial electronic search was performed by a single reviewer (MS). Then the search was repeated by a second reviewer (GMK) to confirm the number of discovered articles by the search strategy. The search terms employed were either medical subject headings (MeSH) terms or keywords classified under general (all fields) category. The search terms were then combined with an "OR," and PICO categories were combined using "AND" to create a final logic search query (Supporting Information Table).

2.5 | Study selection

All relevant studies were included in this review, if they fulfilled the inclusion criteria. A title and abstract screening was performed by two investigators independently (MS and GMK). A final list of studies was put forth for full-text analysis and data extraction, only after a mutual agreement between the two investigators; disagreements, if any, were resolved by means of a consensus discussion. In cases of identified studies reporting on the same cohort at different time points, only the most recent publication was included in the review.

2.6 | Data collection process

The investigators (MS and GMK) extracted data from the included studies independently and were reciprocally blinded. During data extraction, for any uncertainty involving the extracted variable, a consensus was always reached by both investigators before finalizing the extracted data. In cases of significant doubts, corresponding authors were contacted for confirmation of the extracted information. The data items extracted from the included studies are specified in Tables 2–9.

2.7 | Missing data

Information was requested by email from the corresponding authors of included studies for missing or unclear data. In case of a nonresponse, email reminders were sent. A nonresponse from the corresponding author ultimately resulted in the exclusion of the study from the review.

2.8 | Risk of bias and quality assessment of the included studies

The Cochrane collaboration's tool and the Newcastle-Ottawa scales were used for the assessment of the risk of bias and quality

TABLE 2 List of RCTs and prospective studies reporting on dental implant therapy in elderly patients (75 years and above)

Study (first author)	Publication year	Loading protocol	Implant system	Observation period (in months)	Number of patients (*n*)	Mean age (in years)	Total number of implants failed/ placed in the study period (*n*)	Number of patient (implants) dropouts during the study period (*n*)	Number of implants survived (total)	Calculated implant survival rate (SR%)	Edentulous state of the jaw rehabilitated	Prosthesis type
Becker	2016	Not specified	Nobel Biocare	12	31	83.0 (♀ = 16), 84.0 (♂ = 15)	2/59	0 (0)	57 (59)	96.61	Not specified	Not specified
Bressan	2014	Immediate	Ankylos	24	5	79.0	0/20	0 (0)	20 (20)	100.00	Completely edentulous	Complete fixed on 4 implants.
Cakarer	2011	Conventional	Astra-tech, Straumann, Nobel, Frialit, Swiss-Plus, Biohorizons, Bio-Lok	Up to 60	16	75.56	1/42	0 (0)	41 (42)	97.62	Completely edentulous	2-IOD
de Carvalho	2013	Immediate	Nobel Biocare, Lifecore, Biomet 3i, Globtek	12–180	45	75+	1/45	0 (0)	44 (45)	97.77	Partially edentulous	Fixed
Hoeksema	2015	Conventional	Straumann	120	7	75+	0/14	5 (10)	4 (4)	100	Completely edentulous	2-IOD
Maniewicz	2017	Early	Straumann	60	17	87.06	2/36	12 (24)	10 (11)	90.91	Completely edentulous	2-IOD
Müller	2015	Early	Straumann	60	18	75.33	0/36	8 (16)	20 (20)	100.00	Completely edentulous	2-IOD

Note. RCTs: randomized controlled trials.

[a]Calculated as per the raw data supplied by the author for the end of the study period while not considering implant dropouts as failures; ♂: men; ♀: women; 2-IOD: implant overdenture retained by two implants. [b]Reported for 1 year only (excluding machined surface implants); 75+: exact age was not provided, but the minimum age was confirmed by the authors as over 75 years.

TABLE 3 Peri-implant marginal bone loss (PI-MBL), technical, and biological complications reported by the included RCTs and prospective studies

Study (first author)	Publication year	PI-MBL in millimeters	Technical/mechanical complications (*n*)	Biological complications (*n*)	Calculated annual bone loss in millimeters
Becker	2016	0.1 (annual)	n.r.	n.r.	0.1
Bressan	2014	0.4 (over 2 years)	*n* = 0	*n* = 2 Peri-implant mucositis	0.2
Cakarer	2011	n.r.	*n* = 2 1 Prosthesis fracture 1 Clips activation	*n* = 1 Mucosal enlargement around ball attachment	n.a.
de Carvalho	2013	1.0 (over 5 years)	*n* = 0	*n* = 0	0.20
Hoeksema	2015	0.51 (at 1 year)	*n* = 0	*n* = 0	0.51 (first year postloading)
Maniewicz	2017	0.17 (annual)	n.r.	n.r.	0.17
Müller	2015	0.61 (over 5 years)	n.r.	n.r.	0.12

Note. *n*: number of events; n.r.: not reported; n.a.: not applicable; RCTs: randomized controlled trials.

assessment of the included RCTs and prospective cohort/case–control studies, respectively (Higgins & Green, 2011; Wells et al., 2014).

2.9 | Summary measures

2.9.1 | Primary outcome measure

The primary outcome measure in this review was calculated implant survival based on the reported number of implants placed and failed. This calculation provided the event rate in the first year postloading. Implants in dropout patients and in those patients not available for follow-up were censored. Implant survival rate was assessed in the context of patient age and medical status. Implant failure has been defined as loss or removal of implant for any reason, and the timing of the failure has been described for the purpose of this review as either early, delayed, or late (ten Bruggenkate, Asikainen, Foitzik, Krekeler & Sutter, 1998). The loading protocols described in this review have been adopted as per the definitions of a previously published review (Schimmel et al., 2014).

2.9.2 | Secondary and tertiary outcome measures

Mean annual peri-implant marginal bone loss (PI-MBL), biological complications and any associated technical and/or mechanical complications were set as secondary and tertiary outcome parameters.

2.10 | Synthesis of results

Kappa (κ) statistics were calculated to confirm the interinvestigator agreement for the various extracted parameters. A meta-analysis was performed on the included prospective studies for implant survival rates at 1 and 5 years postloading. The weighted means across the studies were calculated using a fixed-effects model. Heterogeneity across the included studies was assessed using the *I*-squared statistics (I^2 statistics). For the purpose of the meta-analyses, case reports or case series reporting on less than 10 patients were excluded as the inclusion of individual participant data (IPD) would require a different statistical approach (Stewart et al., 2015). The meta-analysis was performed using a meta-analysis software (CMA, version 3.0; Biostat, Englewood, NJ, USA), with confidence intervals set to 95% (95% CI).

2.11 | Risk of publication bias and additional analyses

The risk of publication bias was explored across the included studies using a funnel plot (Sterne & Egger, 2001). PI-MBL, biological complications, technical/mechanical complications, and implant survival related to the medical status of the patients were reported descriptively.

3 | RESULTS

3.1 | Study selection

The search queries identified a total of 6,893 studies from the three electronic databases. After an initial sweep to eliminate duplicates and articles not relevant to the focus question followed by title and abstract screening, a combined total of 680 studies were selected for full-text analysis. Initially, 46 relevant articles were shortlisted for inclusion in the review. After subsequent hand searches, reference cross-checks, and information from other sources and authors, an additional 16 articles were identified. Four authors provided novel subanalyses from their published cohorts to report only on patients aged 75 years or older (Antoun, Karouni, Abitbol, Zouiten & Jemt, 2017; Bressan & Lops, 2014; Hoeksema, Visser, Raghoebar, Vissink & Meijer, 2016; Ormianer & Palti, 2006). A final total of 62 relevant articles were included in the review for data extraction. The flow of the entire search and the article identification process is shown in Figure 1.

TABLE 4 Studies reporting on implant survival in patients with cardiovascular diseases

Study (first author)	Publication year	Study design	Investigated condition	Observation period (months)	Number of patients (*n*)	Mean age in years	Total number of implants placed in the study period (*n*)	Total number of implants failed in the study period (*n*)	Number of implants survived (total)	Calculated implant survival rate (SR%)[†]	Time of failure (months)
Alsaadi[a]	2008	Cross-sectional	Hypertension	n.r.	n.r.	56.2	119	2	117	98	1–6
			Nonhypertension	n.r.	n.r.	56.2	601	12	589	98.32	
			Cardiac problems	n.r.	n.r.	56.2	68	0	68	100	
			No cardiac problems	n.r.	n.r.	56.2	652	14	638	97.85	
Wu X[a]	2016	Cohort	Antihypertensive drugs	84	142	57.7	327	2	325	99.39	Up to 60
			No antihypertensive drugs	84	586	57.7	1,172	48	1,124	95.90	

Note. n: number; n.r.: not reported.

[a]Different study groups within the same study reported in separate rows.

3.2 | Study characteristics

3.2.1 | Studies included for meta-analysis

From the included final list of 62 publications, seven prospective studies reported exclusively on geriatric cohorts aged ≥75 years (Becker, Hujoel, Becker & Wohrle, 2016; Bressan & Lops, 2014; Cakarer, Can, Yaltirik & Keskin, 2011; de Carvalho, de Carvalho & Consani, 2013; Hoeksema et al., 2016; Maniewicz Wins et al., 2017; Müller et al., 2015) (Table 2). Among these, there was one RCT (Müller et al., 2015), one prospective controlled clinical trial (Hoeksema et al., 2016), and five prospective case series (Becker et al., 2016; Bressan & Lops, 2014; Cakarer et al., 2011; de Carvalho et al., 2013; Maniewicz Wins et al., 2017). These three prospective studies were included in the meta-analysis for 1-year postloading implant survival in a geriatric population, aged 75 years or older; while six of these studies also provided information for inclusion in the meta-analysis for the 5 year postloading implant survival (de Carvalho et al., 2013; Maniewicz Wins et al., 2017; Müller et al., 2015).

3.2.2 | Studies included for descriptive analysis

The remaining 53 studies reported on cohorts with the most common systemic medical conditions or their respective treatment and their effect on implant survival. The analyses included both, the individual medical conditions and their treatment effects. Although these studies report on all-age cohorts, they were still included in this review because no studies were identified for cohorts aged 75 years and over.

3.3 | Synthesis of results

3.3.1 | Inter-investigator agreement

The calculated κ-range was 0.637–1.000, and 0.800–1.000, for the different stages of the search process, and the various parameters of the extracted data, respectively, which is defined as good to almost perfect reliability between the two independent investigators (MS and GMK).

3.3.2 | Meta-analysis of the included studies: Implant survival in geriatric subjects

A meta-analysis was performed for the postloading implant survival rates calculated for observation periods at 1 year (Becker et al., 2016; Bressan & Lops, 2014; Cakarer et al., 2011; de Carvalho et al., 2013; Hoeksema et al., 2016; Maniewicz et al., 2017; Müller et al., 2015). The fixed-effects model revealed an overall 1-year postloading implant survival of 96.7% (95% CI: 94.3, 98.7; I^2 = 0.00%; n = 7 studies; Figure 2). Three studies provided information for a 5-year meta-analysis and revealed an overall postloading implant survival of 96.1% (95% CI: 87.3, 98.9; I^2 = 0.00%, Figure 3) (de Carvalho et al., 2013; Maniewicz et al., 2017; Müller et al., 2015). According to the funnel plot analysis, a possible publication bias across the studies included in the meta-analysis was explored and ruled out (Figure 4).

3.3.3 | Calculated annual peri-implant bone loss

The calculated annual peri-implant bone loss was reported to range from 0.1 mm annually (Becker et al., 2016) to 0.51 mm during the first year postloading (Hoeksema et al., 2016) for geriatric subjects aged ≥75 years (Table 3).

3.4 | Medical conditions and their treatment

3.4.1 | Cardiovascular disease (including ischemic heart disease, stroke, hypertensive heart disease)

Implant survival in relation to CVD or associated treatment was reported in two studies (Table 4). In particular, Wu et al. (2016) reported a higher survival rate of implants in patients treated with antihypertensive therapy. In contrast, Alsaadi, Quirynen, Komarek and van Steenberghe (2008) did not find an influence of hypertensive heart disease on implant survival.

3.4.2 | Cancer

Radiotherapy

The effects of radiotherapy for the treatment of cancer in the head and neck region on implant survival were included in this systematic review. Seventeen studies were identified which met the inclusion and exclusion criteria (Table 5) (Arcuri, Fridrich, Funk, Tabor & LaVelle, 1997; Bodard et al., 2011; Buddula et al., 2012; Cuesta-Gil et al., 2009; Eckert, Desjardins, Keller & Tolman, 1996; Ernst et al., 2016; Fenlon et al., 2012; Gander, Studer, Studer, Gratz & Bredell, 2014; Heberer, Kilic, Hossamo, Raguse & Nelson, 2011; Hessling et al., 2015; Korfage et al., 2014; Linsen, Martini & Stark, 2012; Mancha de la Plata et al., 2012; Mericske-Stern, Perren & Raveh, 1999; Pompa et al., 2015; Sammartino, Marenzi, Cioffi, Tete & Mortellaro, 2011). Most of the studies reported on implants placed after radiotherapy (Arcuri et al., 1997; Bodard et al., 2011; Ernst et al., 2016; Gander et al., 2014; Heberer et al., 2011; Hessling et al., 2015; Korfage et al., 2014; Linsen et al., 2012; Mancha de la Plata et al., 2012; Pompa et al., 2015; Sammartino et al., 2011). Only two studies also included patients with implants placed prior to radiotherapy (Hessling et al., 2015; Mericske-Stern et al., 1999).

Survival rates were reported to range between 57.1% for immediately placed implants into vascularized grafts with subsequent radiotherapy (Fenlon et al., 2012) and 97.9% (Heberer et al., 2011).

Most investigators reported a time lapse between radiotherapy and implant placement of more than 12 months; however, some utilized a shorter delay (Ernst et al., 2016; Heberer et al., 2011; Korfage et al., 2014; Sammartino et al., 2011).

Antiresorptive therapy

Patients with bone metastases, including breast and prostate cancer or those suffering from multiple myeloma often receive high-dose intravenous antiresorptive therapy (ART) that may be associated with medication-related osteonecrosis of the jaw (MRONJ) (Jacobsen et al., 2013; Kwon et al., 2014). A recent review supports the statement that dental implant treatment is contraindicated in these patients because of the greatly increased risk of MRONJ (Lazarovici et al., 2010).

In a different context, ART is a very common treatment for osteoporosis. The current systematic search identified 14 articles that provided information about the implant survival in patients treated with ART for osteoporosis and osteopenia (Table 6) (Bell & Bell, 2008; Fugazzotto, Lightfoot, Jaffin & Kumar, 2007; Goss, Bartold, Sambrook & Hawker, 2010; Grant, Amenedo, Freeman & Kraut, 2008; Griffiths, 2012; Jacobsen et al., 2013; Koka, Babu & Norell, 2010; Kwon et al., 2014; Lopez-Cedrun et al., 2013; Martin et al., 2010; Memon, Weltman & Katancik, 2012; Shabestari et al., 2010; Siebert, Jurkovic, Statelova & Strecha, 2015; Tallarico, Canullo, Xhanari & Meloni, 2016; Zahid, Wang & Cohen, 2011). Another two articles reported on mixed indications, including malignancies (Jacobsen et al., 2013; Kwon et al., 2014). In studies of osteoporotic patients managed with ART, reported implant survival rates were predominately high. The prevalence of MRONJ in these patient cohorts was rarely specified (Fugazzotto et al., 2007; Goss et al., 2010; Griffiths, 2012; Shabestari et al., 2010; Siebert et al., 2015; Zahid et al., 2011).

Hyposalivation

The effect of hyposalivation on implant survival was only reported for patients with Sjögren's syndrome, rather than in cancer patients with radiotherapy (Table 7) (de Mendonca Invernici et al., 2014; Korfage et al., 2016; Oczakir, Balmer & Mericske-Stern, 2005; Spinato, Soardi & Zane, 2010; Weinlander, Krennmair & Piehslinger, 2010). Survival rates were reported to be 100% (de Mendonca Invernici et al., 2014; Oczakir et al., 2005; Spinato et al., 2010; Weinlander et al., 2010), with the exception of a recent comparative study, which reported a small number of early implant failures (Korfage et al., 2016).

3.4.3 | Respiratory diseases (chronic obstructive pulmonary disease COPD and lower respiratory infections)

No articles reporting on implant survival in patients with COPD or other respiratory diseases were identified in the search.

3.4.4 | Diabetes mellitus

A number of recent prospective cohort studies reported on the survival of implants in adult patients with diabetes mellitus, mainly Type 2 (Table 8) (Aguilar-Salvatierra et al., 2016; Alsaadi et al., 2008; Dowell, Oates & Robinson, 2007; Erdogan et al., 2015; Eskow & Oates, 2017; Oates et al., 2014; Peled, Ardekian, Tagger-Green, Gutmacher & Machtei, 2003). Calculated survival rates were reported to range from 86.3% (24-month observation period) (Aguilar-Salvatierra et al., 2016) to 100% (12 months) (Oates et al., 2014). Poor control (Hb_{A1c} ≥ 8.0%) may have an influence.

TABLE 5 Studies reporting on implant survival in patients with cancer treated with radiotherapy in the neck and head region [In PDF format, this table is best viewed in two-page mode]

Study (first author)	Publication year	Study design	Radiation dose (Gy)	Time of placement	Observation period (in months)	Number of patients (*n*)
Arcuri	1997	Retro	56–65	>12 months post-Ra	12–60	4
Bodard	2011	Retro	n.r.	n.r.	27.5	23
Buddula	2012	Retro	50.2–67.5	41 months post-Ra (mean)	60.0	48
Cuesta-Gil	2009	Retro	50–60	pre-Ra or >12 months post-Ra	6–108	79
Eckert	1996	Retro	20–65	post-Ra	n.r.	21
Ernst	2016	Retro	55–72	6 months post-Ra	52.9	17
Fenlon	2012	CS	65	pre-Ra	n.r.	12
Gander	2014	Retro	56–76	42 months post-Ra (mean)	20.0	21
Heberer	2011	Pros	≤72	>6 months post-Ra	14.4	20
Hessling	2015	Retro	40	pre-Ra	<60	21
Hessling	2015	Retro	61–66	post-Ra	<60	28
Korfage	2014	Follow-up	n.r.	>6 months post-Ra	45.6	100
Linsen	2012	Retro	36–60	mean: 41.0 months post-Ra	60.0	34
Mancha de la Plata	2012	Retro	50–70	33.4 months post-Ra 23 pat pre-Ra	6–96 (mean 45)	30
Mericske-Stern	1999	Follow-up	50–74	pre-Ra	12–84	4
Pompa	2015	Retro	≤50	12 months post-Ra	Mean 22.9	12
Sammartino	2011	Pros	50	Mean 9.4 months post-Ra	<36.0	77

Note. n.r.: not reported; *n*: number; Retro: retrospective study; CS: case series; Pros: Prospective study; post-Ra: implant postradiotherapy; pre-Ra: placement preradiotherapy; Early: before implant loading; Late: after implant loading; SR: calculated survival rate.

TABLE 6 Studies reporting on implant survival in patients treated with antiresorptive drugs because of osteoporosis and/or cancer treatment [In PDF format, this table is best viewed in two-page mode]

Study (publication year)	Study design	Route	Indication for ART	Duration of ART before/no onset of MRONJ (months)
Bell (2008)	Retro	Oral	n.r.	No onset (ART 6-132)
Fugazzotto (2007)	Retro	Oral	n.r.	No onset (ART: mean: 39.6)
Goss (2010)	CS	Oral	Osteoporosis	MRONJ in 10 weeks to 120
Grant (2008)	CS	Oral	Osteoporosis	No onset (ART: mean: 38)
Griffiths (2012)	RCT	Oral	n.r.	None with ART
Jacobsen (2013)	CS	Oral + IV	Malignancy (*n* = 9)/ osteoporosis (*n* = 5)	MRONJ in 38–50 months after implant placement
Koka (2010)	Retro	Oral	Osteoporosis/Osteopenia	No onset (ART 72)
Kwon (2014)	CS	Oral + IV	Osteoporosis/multiple myeloma	MRONJ in 3-82
Lopéz-Cedrún (2013)	Retro	Oral	Osteoporosis/Polymyalgia/ rheumatic	MRONJ in 6-120
Martin (2010)	Retro	Oral	Osteoporosis	No onset
Memon (2012)	Retro	Oral	Osteoporosis	No onset (ART: 0–36+)
Shabestari (2010)	Retro	Oral	Osteoporosis	No onset (ART before placement: 0–60; ART after placement: 0–36)
Siebert (2015)	Pros	IV	Osteoporosis	No onset (ART: mean: 36)
Tallarico (2015)	Pros	Oral	Osteoporosis	No onset (ART: mean: 36)
Zahid (2011)	Retro	Oral	Osteoporosis	No onset (ART 18-192)

Note. n.r.: not reported; Retro: retrospective study; RCT: randomized clinical trial; CS: case series; Pros: prospective study; ART: antiresorptive therapy; Route: route of administration; IV: intravenous administration; Early: before implant loading; Late: after implant loading; SR: calculated survival rate.

TABLE 5 (additional columns)

Mean age (in years)	Total number of implants placed in the study period (*n*)	Total number of implants failed in the study period (*n*)	Number of implants survived (*n*)	Calculated implant survival rate (SR%)	Time of failure (months)
51	18	1	17	94.4	n.r.
n.r.	75	n.r.	n.r.	80.0	n.r.
60.2	271	33	238	87.8	n.r.
52	395	75	320	81.0	n.r.
n.r.	111	9	102	91.9	n.r.
n.r.	88	3	85	96.6	2 in 12, 1 in 48
n.r.	35	15	20	57.1	<6
64.15	84	12	72	85.7	2–18
61.1	97	2	95	97.94	Early
55	95	2	93	97.89	2 in 24
55	128	6	122	95.3	1 in 24, 5 in 60
55.7	318	27	291	91.5	n.r.
n.r.	127	8	119	93.7	n.r.
55.5	225	23	203	90.2	n.r.
n.r.	17	2	15	88.2	n.r.
51	51	12	39	76.5	n.r.
55.8	172	20	152	88.4	<12 months

TABLE 6 (additional columns)

Number of patients (*n*)	Mean age in years	Follow-up period (months)	Number of implants placed (*n*)	Number of implants failed (*n*)	Time of failure (months)	SR (%)
42	n.r.	7–89	100	5	Multiple time points	95
61	51–83	12–24	169	0	n.r.	100
7	65.7	n.r.	19	9	n.r.	52.6
115	67.4	<96	468	2	Early	99.6
10	62	<18	14	0	n.r.	100
12	n.r.	60	23	n.r.	20.9	
55	71	n.r.	121	1	n.r.	99.2
19	67.3	>60	n.r.	18	n.r.	
9	66	<36	57	10	1–96.0	82.5
589	70.2	n.r.	44 in 16 patients	26 in 16 patients	1–132	40.9
100	66	n.r.	153	10	Early	93.5
21	53	<96	46	0	n.r.	100
12	54+	12	60	0	n.r.	100
32	64.4	36–72	98	1	Early	98.98
26	56	2–78	51	3	Early	94.12

TABLE 7 Studies reporting on implant survival in patients with hyposalivation

Study (first author)	Publication year	Study design	Investigated condition	Observation period (in months)	Number of patients (*n*)	Mean age in years	Total number of implants placed in the study period (*n*)	Total number of implants failed in the study period (*n*)	Number of implants survived (*n*)	Calculated implant survival rate (SR%)	Time of failure
Korfage[a]	2016	Retro	Sjögren's	45.6	50 (♀ = 46, ♂ = 4)	67	140	4	136	97.1	Early
		Retro	Healthy controls	60.0	50 (♀ = 46, ♂ = 4)	66	125	0	125	100	n.a.
de Mendonça	2014	Case report	Sjögren's	72	1	58	2	0	2	100	n.a.
Oczakir	2005	Case series	Sjögren's	24–60	2	63.5	12	0	12	100	n.a.
Spinato	2010	Case report	Sjögren's	12	1	62	6	0	6	100	n.a.
Weinlander	2010	Retro	Sjögren's + RA	57.7	4	55.6	21	0	21	100	n.a.

Note. ♀: Women; ♂: Men; n.r.: not reported; Retro: retrospective study; Early: before implant loading; Late: after implant loading; SR: calculated survival rate; n.a.: not applicable.

[a]Different study groups within the same study reported in separate rows.

3.4.5 | Cirrhosis of the liver

No articles reporting on implant survival in patients with cirrhosis of the liver were identified by the search criteria.

3.4.6 | Osteoarthritis

No articles reporting on implant survival in patients with osteoarthritis were discovered by the search criteria.

3.4.7 | Neurocognitive impairment (unipolar depression, Alzheimer's disease and other dementias, and Parkinson's disease)

The search revealed no data regarding implant survival in patients with Alzheimer's disease or other forms of dementia. Studies addressing other forms of neurocognitive impairment and implant survival are listed in Table 9 (Chu, Deng, Siu & Chow, 2004; Deniz, Kokat & Noyan, 2011; Ekfeldt, Zellmer & Carlsson, 2013; Heckmann, Heckmann & Weber, 2000; Jackowski et al., 2001; Packer, Nikitin, Coward, Davis & Fiske, 2009; Wu et al., 2014). One study reported higher implant failure rates in patients taking selective serotonin reuptake inhibitors for depression compared to nonusers of SSRIs (Wu et al., 2014). Case reports and case series with a limited number of participants reported on patients with Parkinson's disease with calculated survival rates ranging between 82.1% (Packer et al., 2009) and 100% (Chu et al., 2004; Heckmann et al., 2000).

4 | DISCUSSION

4.1 | Principal findings

This review identified high implant survival rates in geriatric patients aged 75 years and older. The 1 and 5-year implant survival rates are similar to those reported in younger cohorts (Al-Nawas et al., 2012; Müller et al., 2015), irrespective of the clinical indications or loading protocol (Benic, Mir-Mari & Hammerle, 2014; Papaspyridakos, Chen, Chuang & Weber, 2014; Schimmel et al., 2014; Schrott, Riggi-Heiniger, Maruo & Gallucci, 2014). It is important to note that the 1-year survival rates reflect implants failing to osseointegrate, and therefore, it could be suggested that advanced age does not seem to negatively affect osseointegration.

Clinical decision-making should take into consideration the oral and systemic health of every patient with comorbidities in form of an individualized risk assessment comprising a close collaboration with medical specialists and the family doctor. Implant placement in oncologic patients must be performed with caution and, if at all, an adequate refractory period postradiotherapy (>12 months) should be respected. Individualized treatment planning including assessment of radiation protocol must be carefully tailored and should be performed in a specialist setting; however, the risk of osteonecrosis cannot be ruled out. Implant placement in patients receiving high-dose ART is contraindicated.

TABLE 8 Studies reporting on implant survival in patients with diabetes mellitus

Study (first author)	Publication year	Study design	Investigated condition related to diabetes	Observation period (in months)	Number of patients (*n*)	Mean age (in years)	Total number of implants placed in the study period (*n*)	Total number of implants failed in the study period (*n*)	Number of implants survived (total)	Calculated implant survival rate (SR%)	Time of failure
Aguilar-Salvatierra[a]	2016	Pros	HbA1c ≤ 6, Type 2	24	33	59	33	0	33	100	n.a.
			HbA1c = 6.1–8.0, Type 2	24	30	57	30	1	29	96.6	Late
			HbA1c = 8.0–10, Type 2	24	22	61	22	3	19	86.3	Late
Alsaadi[a]	2008	CS	Type 1	n.r.	n.r.	56.2	1	1	0	0	Early
			Type 2	n.r.	n.r.	56.2	24	1	23	95.83	n.r.
Dowell[a]	2007	Cohort (Pros)	Type 2	4	25	51–81	38	0	38	100	n.a.
			No	4	10	29–61	12	0	12	100	n.a.
Erdogan[a]	2015	Pros	HbA1c = 6.1–7.5, Type 2	>12	12	52.6	22	0	22	100	n.a.
			No	>12	12	49.5	21	0	21	100	n.a.
Eskow[a]	2017	Observational	HbA1c 6–7.9, Type 2	24	9	59.9	21	0	21	100	n.a.
			HbA1c ≥ 8.0, Type 2	24	11	59.9	38	2	36	94.74	n.r.
Oates[a]	2014	Cohort (Pros)	HbA1c ≤ 5.9, Type 2	12	50	64	100	1	99	99	n.r.
			HbA1c = 6.0–8.0, Type 2	12	47	64	94	1	93	98.9	n.r.
			HbA1c ≥ 8.1, Type 2	12	20	64	40	0	40	100	n.a.
Peled	2003	CS	Type 2 diabetes	60	41	n.r.	141	8	133	94.33	Early: 6; Late: 2

Note. *n*: number; n.a.: not applicable; Pros: prospective study; n.r.: not reported; Retro: retrospective study; CS: case series; Early: before implant loading; Late: after implant loading; SR: calculated survival rate.

[a]Different study groups within the same study reported in separate rows.

TABLE 9 Studies reporting on implant survival in patients with neurocognitive impairment

Study (first author)	Publication year	Study design	Investigated condition	Observation period (in months)	Number of patients (*n*)	Mean age in years	Total number of implants placed in the study period (*n*)	Total number of implants failed in the study period (*n*)	Number of implants survived	Calculated implant survival rate (SR%)	Time of failure
Chu	2004	Case report	Parkinson's disease	12	1	83	4	0	4	100	n.a.
Deniz	2009	Case report	Huntington's disease	12	1		2	0	2	100	n.a.
Ekfeldt	2013	Pros	Acquired neurologic disabilities	120	22	44	70	12	58	82.86	n.r.
Heckman	2000	Case report	Parkinson's disease	28–42	3	75.7	9	0	9	100	n.a.
Jackowski	2001	Case report	Huntington's disease	12	1		2	0	2	100	n.a.
Packer	2009	Pros	Parkinson's disease	3	9	63	28	5	23	82.14	n.r.
Wu[a]	2014	Retro	51 Depression treated with SSRIs	72	51	56.4	94	10	84	89.36	n.r.
			No SSRIs		439		822	38	784	95.38	n.r.

Note. n.r.: not reported; Retro: retrospective study; SSRIs: selective serotonin reuptake inhibitors; Early: before implant loading; Late: after implant loading; SR: calculated survival rate; n.a.: not applicable; n.r.: not reported.

[a]Different study groups within the same study reported in separate rows.

Although ranking among the most common diseases in geriatric patients, there is no evidence on implant dentistry on conditions including cirrhosis of the liver, osteoarthritis, or respiratory diseases and sparse knowledge on patients with neurocognitive impairment and their respective treatments. This may constitute a potential risk for implant surgery, osseointegration and implant survival; for example, the use of glucocorticoids might induce osteoporosis and thus, influence bone healing (Krennmair, Seemann & Piehslinger, 2010). With multiple chronic conditions present, their effect on implant treatment becomes complex and poorly understood.

4.1.1 | Cardiovascular disease

The main concern in patients with CVD may be related to the general risk in performing invasive surgery because of prescribed anticoagulants or changes in blood pressure due to vasoconstrictor containing local anaesthetics.

Interestingly, the current review identified one study that reported the positive impact of antihypertensive drugs on implant survival (Wu et al., 2016). The authors hypothesize that this may be related to the positive effect of such drugs including beta-blockers, thiazide diuretics, ACE inhibitors, and ARBs on bone metabolism, which constitutes an interesting field for further research.

4.1.2 | Radiotherapy

The use of head and neck radiotherapy has been associated with a reduced survival rate of implants. In many cases, implants may be the only possibility of a prosthetic restoration, aiming for the patient's functional rehabilitation, social reintegration and psychological well-being (Müller, Schadler, Wahlmann & Newton, 2004). A recent review suggests that recently improved protocols of administering therapeutic radiation doses carry less risk for implant failure and MRONJ, compared to traditional protocols (Schiegnitz, Al-Nawas, Kammerer & Grotz, 2014).

4.1.3 | Antiresorptive therapy and osteoporosis

Antiresorptive therapy with agents that have long-lasting effects on bone metabolism can also be a major obstacle for implant surgery. Patients with Cancer with bone metastases (e.g., from breast or prostate cancer) or with multiple myeloma often receive high-dose intravenous ART. Dental implant treatment is often contraindicated in these patients because of the strongly increased risk of MRONJ (Lazarovici et al., 2010).

Osteoporosis patients, on the other hand, receive ART at much lower doses. As their risk of MRONJ is much lower, implants are increasingly utilized in these patients (Chadha, Ahmadieh, Kumar & Sedghizadeh, 2013). The risk of MRONJ in osteoporosis patients on low-dose bisphosphonates is estimated to be 0.7 per 100,000 person-years of exposure, and fewer than 100 cases of MRONJ after

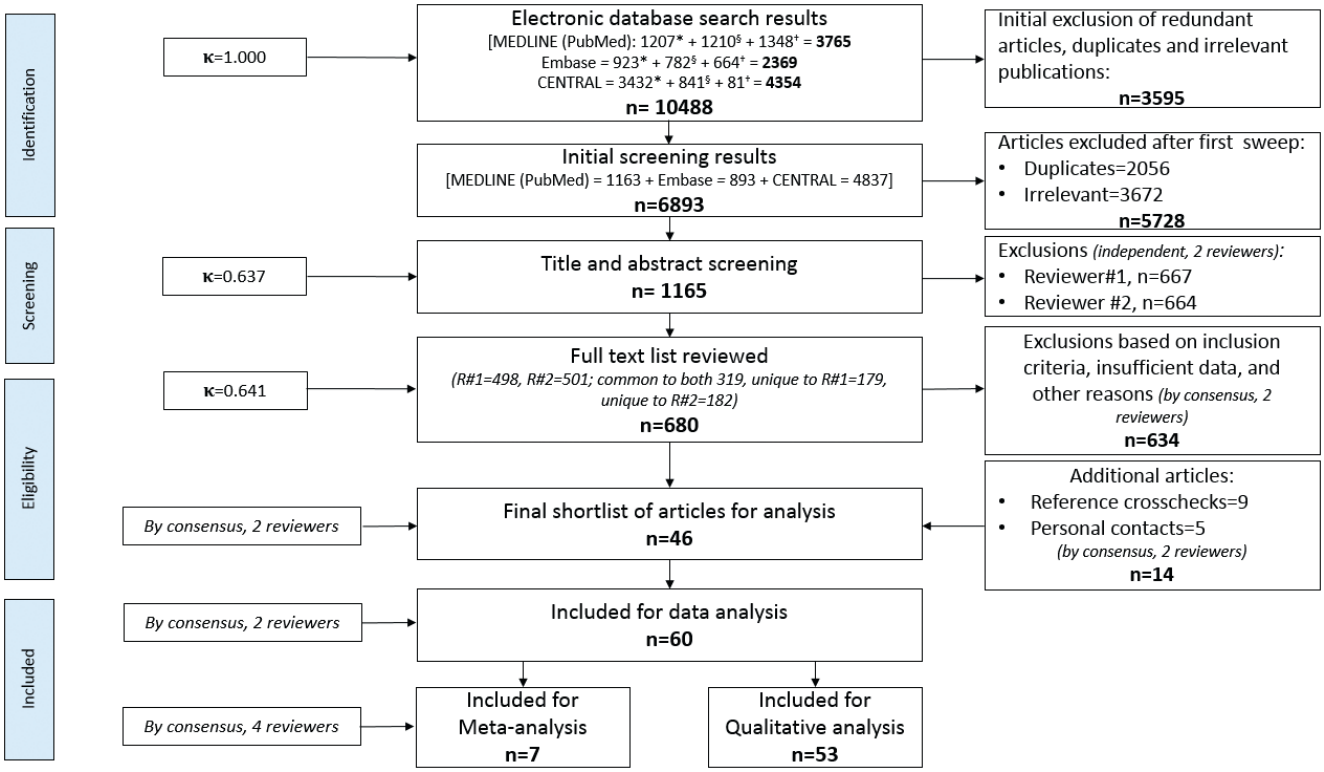

FIGURE 1 The search flow diagram, for the systematic literature search and selection process according to the PRISMA guidelines (*n*, number of articles; κ, Kappa statistics for interinvestigator agreement; R#1, reviewer 1; R#2, Reviewer 2; *, search results for studies with elderly cohort aged ≥75 years AND dental implants AND common medical conditions; §, search results for studies with elderly cohort aged ≥75 years AND dental implants without common medical conditions; †, search results for studies with cohort with dental implants AND common medical conditions without the age (≥75 years) filter]

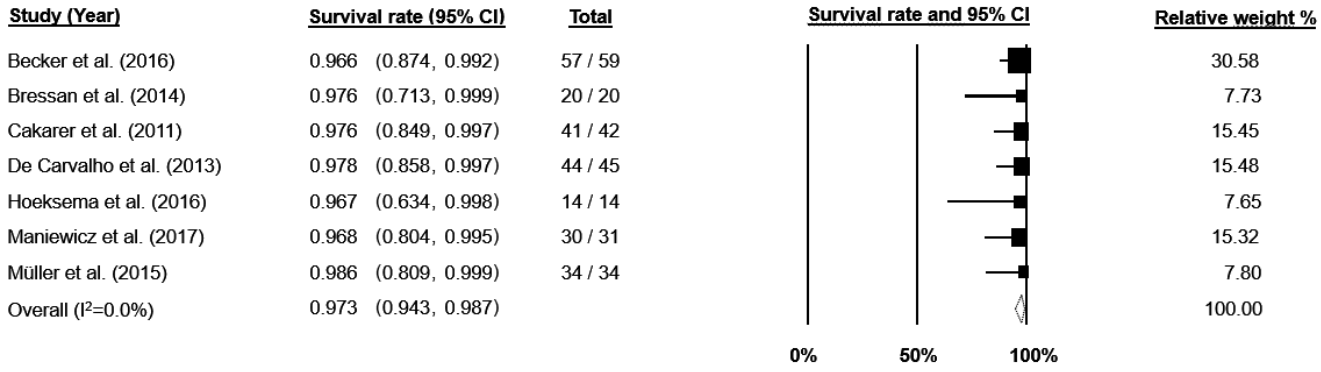

FIGURE 2 Forest plot showing the 1-year postloading implant survival rate (CI, confidence interval)

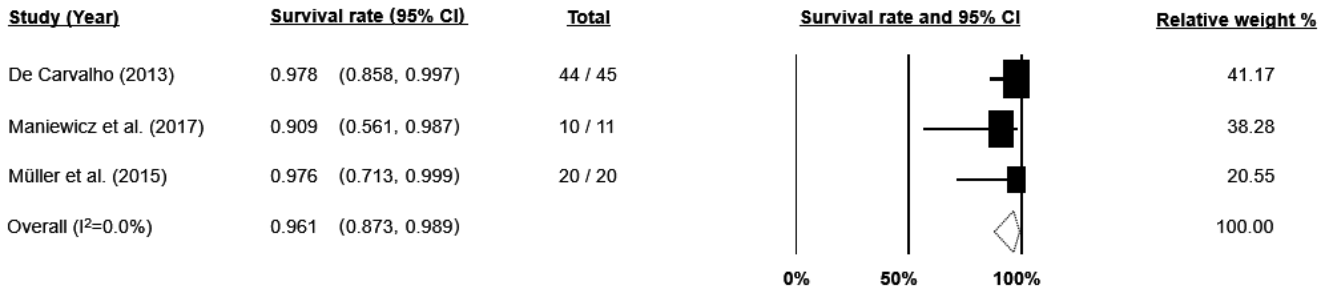

FIGURE 3 Forest plot showing the 5-year postloading implant survival rate (CI, confidence interval)

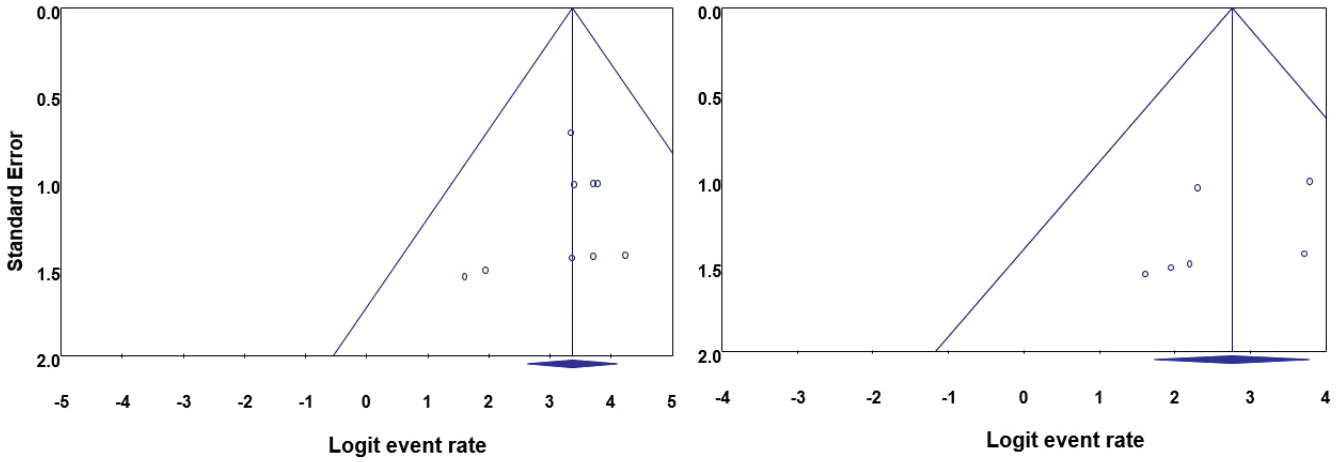

FIGURE 4 Funnel plot of the included prospective studies in the 1-year (a) and in the 5-year (b) analyses showing no publication bias

implant therapy in this group of patients have been reported (Ata-Ali, Ata-Ali, Penarrocha-Oltra & Galindo-Moreno, 2014).

Until now, there is no evidence that the intravenous low-dose administration carries a greater risk of MRONJ than oral medication, but precautions should be taken when planning and performing implant surgery (Schimmel et al., 2017). Moderate level evidence suggests that patients suffering from osteoporosis have a higher incidence of tooth loss (Anil, Preethanath, AlMoharib, Kamath & Anand, 2013). This may be related to a higher level of osteoclastic activity and a less dense bony structure, favoring progress of periodontal bone resorption in response to gingival inflammation (Wang & McCauley, 2016).

4.1.4 | Hyposalivation

Hyposalivation is very frequent among geriatric patients, not only as a consequence of radiotherapy, but mainly as a consequence of polypharmacy. However, no study dealt directly with the influence of this condition on the survival, not to mention success, of implants and implant prosthesis, which constitutes a major knowledge gap in gero-implantology.

There are, however, studies that have investigated the influence of Sjögren's syndrome on implant survival. A very recent comparative study from Korfage et al. (2016) indicated that the condition may be related to a higher risk of early implant failure.

4.1.5 | Diabetes

Type 2 diabetes signifies the body's resistance and inability to produce adequate amounts of insulin. It is the most common form of the disease in geriatric patients. Among other symptoms, Type 2 diabetics can experience microvascular and vascular damage as well as an impaired wound healing. Patients are more susceptible to periodontitis and tooth loss (Persson, 2017). The main marker of glycemic control in diabetic patients is hemoglobin A_{1C} (HbA_{1c}), and numerous studies identified in this review demonstrate that HbA_{1c} levels above 8% may result in reduced implant survival compared to lower levels.

4.2 | Strengths and weaknesses of the review

Prospective clinical studies on implants placed in geriatric patients are scarce. This may be due to a series of logistical challenges where older patients would require examination and treatment in their own home or a residential institution. In addition, older patient cohorts are extremely heterogeneous, as "not all old are old" (Bürger, 1960). The discrepancy between the biological and the numerical age can expand dramatically in advanced age, as the long-term effects of nutrition, lifestyle choices, socioeconomic status, and disease experience accumulate over a lifetime.

The search for eligible studies for this systematic review was limited by the fact that a large body of evidence published in the 1980s and 1990s from prospective geriatric studies studied implants with turned/machined titanium surfaces. These surfaces are not relevant in daily practice anymore; hence these studies were excluded from this review. Further weakness arises from the use of filters in our search that might have inadvertently omitted some relevant articles. The search truncations were not elaborately used for more search terms in "all fields," hence, this could have further limited the search yield. Furthermore, the search process of this review did not include conference proceedings. As the focus of this systematic review was not only on age, but also on comorbidity, a general lack of reporting on the medical status of study participants was noted in many papers, which further reduced the available evidence for highlighting the effect of the most common chronic conditions and their treatment in elderly patients.

Initially, a further exclusion criterion for this systematic search was a minimum sample of 10 participants for each included study. During the abstract screening, it became obvious that many studies would therefore have to be excluded. Relevant evidence would remain unreported in this review, for example, in relation to neurocognitive impairment where evidence is extremely scarce. It was, therefore, decided to remove this exclusion criterion post hoc. However, for the meta-analyses, studies reporting on single cases or case series with less than 10 cases were still excluded, as Stewart

et al. (2015) proposed in the CONSORT-IPD statement the inclusion of IPD would require a different approach.

Unfortunately, patient-reported outcome measures are not included in the analysis for this systematic review due to underreporting of the factors in most implant studies.

The strength of this review is the limitation of the participants included to those aged of 75 years and older. Previous reviews exist on the use of implants in medical compromised patients (Beikler & Flemmig, 2003; Bornstein et al., 2009, 2015), but none have previously focused on the impact of health status in combination with aging and frailty. Despite a comprehensive, meticulous, and systematic search, this review did not identify any studies on implant survival in relation to medical conditions in purely geriatric patients. Hence, this review too was not able to investigate the combined effect of age and chronic disease, and it was post hoc decided to report on any-age implant survival rates in the most common geriatric medical conditions. Yet, knowledge on the interactions of old age, medical conditions, and implant survival or even success would be essential for clinical decision-making and meticulous reporting on medical conditions in elder study participants should be encouraged for future studies on implant survival.

Although this review did not reveal age as a risk factor for osseointegration, immunosenescence can potentially compromise the body's defense mechanisms where the bacterial load around implants challenges the health of the peri-implant mucosa. The term immunosenescence refers to the aging of the immune system. It was suggested that the human immune system declines in effectiveness with age (Preshaw, Henne, Taylor, Valentine & Conrads, 2017). This can be a significant issue for functionally impaired older patients when oral hygiene is neglected (Meyer et al., 2017).

A further factor to be considered is that the implants in patients lost to follow-up were excluded from the survival analysis. However, reporting on the uncensored survival rates could have possibly overwhelmed the results in a negative direction, providing an unrealistically negative picture. Dropout rates are high in geriatric studies, due to the high prevalence of medical conditions, functional impairment, and death. The bias introduced using censored data (the "unknown") on potential knowledge gain, might be more important in geriatric studies than elsewhere in the literature.

4.3 | Clinical relevance of the findings of this systematic review

A particularly pertinent aspect of this review is the clinical relevance of the survival rate of implants in view of the patient's life expectancy and morbidity. For patients affected with head and neck cancer, implants may be the only means to achieve a psychosocial and functional rehabilitation (Müller et al., 2004). Given the undoubted benefits of an implant retained restoration compared to removable alternatives for oncology patients, the use of implants may even be justified when implant survival rates are significantly below those reported for healthy patients. A similar viewpoint may apply to patients with hyposalivation, as wearing a conventional denture may be almost impossible due to a lack of retention and pain caused by the intaglio surface rubbing on the dry and sensitive mucosa. Again, clinical decision-making must not only be based on the survival rate, but rather on the patient's subjective gain in quality of life, comfort, and overall well-being which should outweigh the associated risks. This review provides a valuable insight into the survival rates of implants which are vitally important to advise patients as part of the consent procedure prior to undertaking any intervention.

However, it should be noted that in elderly patients, implant success is rarely assessed in a relevant manner. An implant may be perfectly osseointegrated, but a patient with complex implant prostheses who is dependent on help for the activities of daily living may not wear or clean it anymore, because the management is too complex. This cannot be considered a successful treatment in this patient population (Müller & Schimmel, 2016).

4.4 | Implications for research

Substantial underreporting was noted on several important medical conditions in geriatric patients, which may have an impact on implant survival. Future, high-quality research is needed with comprehensive recording of study participants' medical conditions, and standard protocols for reporting these comorbidities should be defined based on the outcome of this systematic review.

The current review reveals an important knowledge gap when it comes to implant therapy in elderly and geriatric patients. For some of the most common geriatric medical conditions such as cancer and diabetes, there is evidence available in relation to implant surgery and implant prostheses—however, almost exclusively from younger patient groups. This limits the relevance of the findings for geriatric patients, who often take multiple medications and present with immunosenescence (Lopez-Otin, Blasco, Partridge, Serrano & Kroemer, 2013) or delayed wound healing due to qualitative or quantitative protein-energy malnutrition (Schimmel, Katsoulis, Genton & Müller, 2015).

5 | CONCLUSIONS

The provision of implant-supported/retained prostheses in geriatric subjects is a predictable treatment option with a high rate of implant survival. The functional and psychosocial benefits of an implant restoration should outweigh the reported relative risks associated with common medical conditions and their respective treatments.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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