Implant and Prosthodontic Survival Rates with Implant Fixed Complete Dental Prostheses in the Edentulous Mandible after at Least 5 Years: A Systematic Review

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ABSTRACT

Background: The treatment of mandibular edentulism with implant fixed complete dental prostheses (IFCDPs) is a routinely used treatment option.

Purpose: The study aims to report the implant and prosthodontic survival rates associated with IFCDPs for the edentulous mandible after an observation period of a minimum 5 years.

Materials and Methods: An electronic MEDLINE/PubMED search was conducted to identify randomized controlled clinical trials and prospective studies with IFCDPs for the edentulous mandible. Clinical studies with at least 5-year follow-up were selected. Pooled data were statistically analyzed and cumulative implant- and prosthesis survival rates were calculated by meta-analysis, regression, and chi-square statistics. Implant-related and prosthesis-related factors were identified and their impact on survival rates was assessed.

Results: Seventeen prospective studies, including 501 patients and 2,827 implants, were selected for meta-analysis. The majority of the implants (88.5% of all placed implants) had been placed in the interforaminal area. Cumulative implant survival rates for rough surface ranged from 98.42% (95% confidence interval [CI]: 97.98–98.86) (5 years) to 96.86% (95% CI: 96.00–97.73) (10 years); smooth surface implant survival rates ranged from 98.93% (95% CI: 98.38–99.49) (5 years) to 97.88% (95% CI: 96.78–98.98) (10 years). The prosthodontic survival rates for 1-piece IFCDPs ranged from 98.61% (95% CI: 97.80–99.43) (5 years) to 97.25% (95% CI: 95.66–98.86) (10 years).

Conclusion: Treatment with mandibular IFCDPs yields high implant and prosthodontic survival rates (more than 96% after 10 years). Rough surface implants exhibited cumulative survival rates similar to the smooth surface ones ($p > .05$) in the edentulous mandible. The number of supporting implants and the antero-posterior implant distribution had no influence ($p > .05$) on the implant survival rate. The prosthetic design and veneering material, the retention type, and the loading protocol (delayed, early, and immediate) had no influence ($p > .05$) on the prosthodontic survival rates.

KEY WORDS: dental implants, edentulous mandible, evidence-based dentistry, fixed complete prosthesis, full arch, implant survival rates

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INTRODUCTION

Treatment with dental implants represents a scientifically and clinically proven treatment modality for the restoration of the edentulous jaw. The longitudinal effectiveness of endosseous implants has been demonstrated for both partially and completely edentulous patients.[1,2] Nowadays, new materials and treatment protocols have heralded a new era for implant dentistry. From smooth surfaced implants and up to 6 months of submerged healing to allow for osseointegration, rough implant surfaces and new loading protocols have led to faster healing times and early or immediate restoration of function and esthetics in carefully selected cases.[3] Prosthodontic protocols have also significantly evolved since the mandibular hybrid prostheses with acrylic teeth on a cast gold alloy framework, especially due to the introduction of computer-aided design/computer-assisted manufacturing (CAD/CAM) technology.[4]

As the average life expectancy is constantly increased and the old age population increases as well, it becomes clear that the need for dental implant treatment for the completely edentulous patients will increase. In the United States, the percentage of edentulous patients is 10% of the total US population and is expected to increase in the following years as the life expectancy also increases.[5,6] Although the incidence of complete edentulism in the United States has been steadily declining (approximately 6% between 1988 and 2000), the continuous growth of the population of 65 years and older indicates that the complete edentulism rates will remain constant or even increase over the next decades.[7]

Many implant surgical and prosthodontic protocols have been reported for the treatment of the edentulous mandible.[3] Early or immediate loading protocols of roughened surface implants have shortened healing times and restoration of function.[3] Moreover, new prosthetic designs and materials for the restoration of the edentulous mandible are currently used.[8] Choosing the most appropriate protocol for the rehabilitation of the edentulous mandible may represent a challenge and should rely on evidence-based, thorough information. It is generally accepted that meaningful interpretation of the clinical outcomes of dental implant treatment requires a follow-up period of at least 5 years.[9] From the clinician's point of view, controlled studies comparing different treatment options are necessary to determine the effectiveness or superiority of different treatment modalities. From the socioeconomical viewpoint, the patient preference for specific treatment options relies on the longitudinal efficacy of the option, coupled with the associated cost and maintenance.

A recent descriptive analysis of implant and prosthodontic survival rates with implant fixed complete dental prostheses (IFCDPs) for the edentulous maxilla showed good long-term survival rates.[10] The purpose of this systematic review was to analyze randomized controlled clinical trials (RCTs) and prospective clinical studies of at least 5 years with IFCDPs for the edentulous mandible, and report the 5- and 10-year implant and prosthodontic survival rates with this treatment modality. The focused question was whether or not the treatment of mandibular edentulism with dental implants and IFCDPs yields high implant and prosthodontic survival rates.

MATERIALS AND METHODS

Search Strategy

An electronic search using the MEDLINE/PubMED database was performed for articles published in English. The time period extended from January 1980 up to December 2011. The search strategy included the following keyword combinations: "edentulous mandible" AND "implant," "complete edentulous" AND "mandible," "full arch" AND "edentulous mandible," "implant complete prostheses" AND "fixed," "fixed complete prostheses" AND "implant." Articles were collected in reference manager software (Endnotes, Thomson Reuters, New York, NY, USA) and duplicates were discarded electronically. The inclusion criteria were as follows:

- The studies should be RCTs or prospective studies.
- Articles should be in the English language.
- The studies should report on IFCDPs for edentulous mandibles.
- The studies should report data on implant- and prosthodontic survival rates.
- The studies should include at least 10 edentulous patients and follow-up for a minimum of 5 years.
- Only studies with solid screw-type implants were considered. Studies reporting on zygoma, pterygomaxillary, and transitional implants were excluded. Animal studies were excluded.

Titles and abstracts were initially screened by two calibrated reviewers (P.P. and M.M.) for potential inclusion. If no abstract was available in the database, the abstract of the printed article was used. If title and abstract did not provide sufficient information regarding the inclusion criteria, the full report was obtained as well. All titles and abstracts selected by the two reviewers were discussed individually for full-text reading inclusion. The full-text reading of selected publications was carried out independently by the reviewers. Consensus between the reviewers was reached in every step of the review. The electronic search was supplemented by manual search of the bibliographies of all the full-text articles that were selected from the initial search. Moreover, the Cochrane Database of Systematic Reviews was searched and the bibliographies of previous systematic reviews relevant to the topic were searched for full-text articles. Inter-reviewer agreement between the two reviewers was always determined with the use of Cohen's kappa K-statistics. In cases where information was not clear, the issue was elucidated by contacting the authors of the pertinent study via e-mail.

The initial search yielded 4,563 hits after discarding duplicate references (Figure 1). The subsequent search at the title level exhibited 2,507 titles (k-score = 0.75) and further at the abstract level identified 612 abstracts (k-score = 0.85). The independent abstract investigation revealed 35 articles for full-text reading (k-score = 0.95).

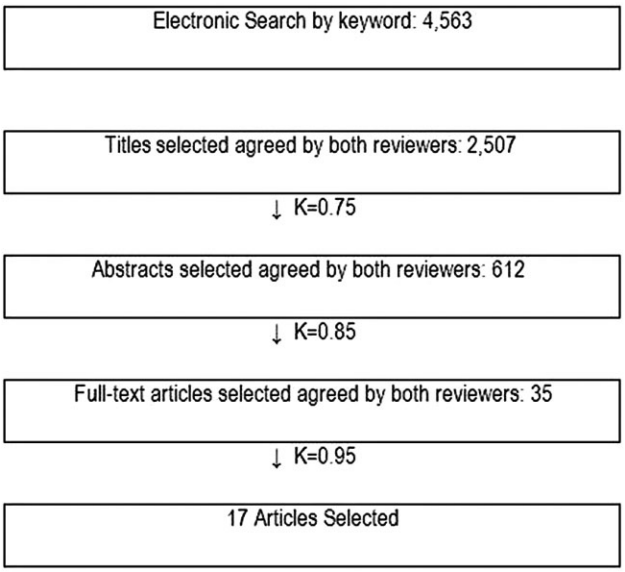

Figure 1 Search strategy.

Data Extraction

Data extraction for each of the 35 selected full-text articles was done by the reviewers using a standardized electronic spreadsheet. Data extracted included patient characteristics/demographics, implant and prosthodontic survival rates, as well as implant and prosthesis details. For studies with mixed data and follow-up period ranging from less than 5 to more than 5 years, data were extracted to include only patients followed up for minimum 5 years and thus implant- and prosthodontic survival rates were identified and recorded. Survival was defined as the prosthesis remaining in situ at the examination visit with or without modifications.[2] For the purpose of descriptive analysis, 5-, 10- and 20-year end points were selected.

Assessment of Study Quality

After the selection of papers on the basis of inclusion and exclusion criteria, studies were rated on their quality. Specific study design-related information such as randomization (if applicable), patient characteristics, patient selection, intervention, evaluation method, outcome, and follow-up was individually assessed for all included publications, using the Newcastle–Ottawa quality assessment scale for case control and cohort studies. The risk of bias was defined as low, medium, or high. To reduce the risk of bias as much as possible, we excluded studies showing high risk of bias.

Excluded Studies

Out of the 35 studies selected for full-text reading, 18 were finally excluded (Table 1). The main reasons for exclusion included: less than 10 patients followed up for minimum 5 years, retrospective study design, mixed data on implant and prosthodontic survival rates, and lack of response to the e-mails requesting further details on the published data.[11–28] In addition to that, multiple publications on the same cohort of patients were also excluded and the most recent was included for statistical analysis. Excluding some recent studies due to their retrospective design may have resulted in the loss of a considerable amount of data. However, strict inclusion criteria were selected for this systematic review to reduce the high risk of bias of retrospective studies. Hence, we excluded retrospective studies.

TABLE 1 Characteristics of Excluded Studies and Reasons for Exclusion

Study	Study Type	Total Number of Patients Followed Up	Follow-Up Time (years)	Implant System	Type of Prostheses/ Material	Reasons for Exclusion
Al-Nawas and colleagues[11]	Retrospective	NA	10	AstraTech TiOblast	NA	Retrospective, mixed data
Browaeys and colleagues[13]	Retrospective	NA	Up to 7	3i Osseotite	Metal-resin	Retrospective chart review, mixed data
Lethaus and colleagues[20]	Prospective	13	5	Straumann	Resin	Removable prostheses
Malo and colleagues[21]	Retrospective	174	5	Smooth and TiUnite Branemark	Metal-resin	Retrospective, mixed data
Friberg and Jemt[18]	Retrospective	19	5	TiUnite Branemark	Metal-resin	Retrospective, mixed data
Schwarz and colleagues 2010[26]	Prospective	25	5	Frialoc Friadent	Metal-resin	Mixed data, no e-mail response
Eliasson and colleagues[15]	Retrospective	47	5	Branemark, AstraTech and Straumann	Metal-resin/metal ceramic	Retrospective, mixed data
Ortorp and Jemt[22]	Retrospective	65	15	Smooth Branemark	Laser-welded metal-resin	Retrospective
Pikner and colleagues[23]	Retrospective	NA	Up to 20	Smooth Branemark	Metal-resin	Retrospective, mixed data
Testori and colleagues[27]	Prospective	7	5	3i Osseotite	Metal-resin	Less than 10 patients followed up for 5 years
Romeo and colleagues[24]	Prospective	2	5	Straumann	Metal-resin	Less than 10 patients followed up for 5 years
Davis and colleagues[14]	Retrospective	29	5	Smooth Branemark	Metal-resin	Retrospective
Engstrand and colleagues[17]	Prospective	9	5	Smooth Branemark	Metal-resin	Less than 10 patients followed up for 5 years
Wolfinger and colleagues[28]	Retrospective	9	5	Smooth Branemark	Metal-resin	Less than 10 patients followed up for 5 years
Eliasson and colleagues[16]	Retrospective	53	5	Smooth Branemark	Metal-resin	Retrospective, mixed data
Schnitman and colleagues[25]	Retrospective	10	10	Smooth Branemark	Metal-resin	Retrospective
Brånemark and colleagues[12]	Retrospective	72	10	Smooth Branemark	Metal-resin	Retrospective
Hemmings and colleagues[19]	Retrospective	25	5	Smooth Branemark	Metal-resin	Retrospective

NA = not available.

Statistical Analysis

The estimated implant and prosthesis survival rate were calculated from the negative exponential failure (event) rate.[2] The 5- and 10-year survival rates were also estimated from the negative exponential failure (event) rates, which were multiplied by 5 and 10, respectively. The 95% confidence intervals (CIs) for the survival rates were also presented.[29]

As the number of events for implant/IFCDP loss was counted by Poisson distribution (count events), the count events were weighted by total exposure time which then subsequently applied to data analysis for this study. chi-square statistics were computed and analyzed. All statistical analyses were performed using a statistical software program (StataCorp, Version 11.2, 2009, College Station, TX, USA), and the level of statistical significance (alpha level) was based at 0.05.

RESULTS

Included Studies/Study Characteristics

The full-text reading yielded 17 prospective and no RCTs, including 501 patients and 2,827 implants that satisfied the inclusion criteria and were used for statistical analysis (Tables 2 and 3). These studies were conducted in academic institutions and private clinics.[1,30–45] The year of publication ranged from 1997 to 2012. The summary of random-effects meta-analysis using survival rates, CIs, and the weight of each study by exposure time is shown in Figure 2. The figure performs a random-effects meta-analysis of the effect of prosthesis and implants on the incidence of failure between studies in the Forest plot. The overall risk ratio (RR) is 1.48 (95% CI: 0.79–2.77), and the I^2 statistic indicates that the percentage of between-study heterogeneity is 2.4%, with p value = .423. There is no significant difference (p value > .05) for overall RR.

Implant Survival by Implant Surface. Only studies with at least 5-year follow-up were included. The data were considered cumulative and implant survival rates were pooled. Cumulative implant survival rates for rough surface ranged from 98.42% (95% CI: 97.98–98.86) (5 years) to 96.86% (95% CI: 96.00–97.73) (10 years); smooth surface implant survival rates ranged from 98.93% (95% CI: 98.38–99.49) (5 years) to 97.88% (95% CI: 96.78–98.98) (10 years).

TABLE 2 Characteristics of Included Prospective Clinical Studies

Study	Study Type	Total Number of Patients Followed Up	Follow-Up Time (years)	Implant System	Type of Prostheses/ Material	Risk of Bias
Ortorp and Jemt[42]	Prospective	42	10	Branemark	CNC titanium-resin	Medium
Heschl and colleagues[39]	Prospective	21	5	Friadent	Metal-resin	Medium
Eliasson and colleagues[35]	Prospective	24	5	Paragon	Metal-resin	Medium
Degidi and colleagues[33]	Prospective	28	5	BioHorizons	Metal-ceramic	Medium
Gallucci and colleagues[38]	Prospective	45	5	Straumann	Metal-resin/metal ceramic	Medium
Åstrand and colleagues[1]	Prospective	17	20	Branemark	Metal-resin	Medium
Friberg and colleagues[37]	Prospective	10	5	Branemark	Metal-resin	Medium
Purcell and colleagues[43]	Prospective	46	5	SteriOss	Metal-resin	Medium
Rasmusson and colleagues[44]	Prospective	17	10	AstraTech	Metal-resin	Medium
Attard and Zarb[32]	Prospective	29	20	Branemark	Metal-resin	Medium
Åstrand and colleagues[31]	Prospective	31	5	Branemark, AstraTech	Metal-resin	Medium
Ekelund and colleagues[34]	Prospective	30	20	Branemark	Metal-resin	Medium
Murphy and colleagues[41]	Prospective	26	5	AstraTech	Metal-resin	Medium
Tinsley and colleagues[45]	Prospective	17	5	Calcitek	Metal-resin	Medium
Ferrigno and colleagues[36]	Prospective	14	5	Straumann	Metal-resin	Medium
Arvidson and colleagues[30]	Prospective	91	5	AstraTech	Metal-resin	Medium
Makkonen and colleagues[40]	Prospective	13	5	AstraTech	Metal-resin	Medium

TABLE 3 Implant/Prosthesis Survival Rates

Study	Total Number of Patients Followed Up	Total Number of Prostheses Followed Up	Total Number of Prostheses Lost	Total Number of Implants Followed Up	Total Number of Implants Lost	Total Implant/ Prosthesis Exposure Time (years)	Implant Survival Rate	Prosthesis Survival Rate
5-year follow-up								
Heschl and colleagues[39]	21	21	0	84	2	420/105	97.6	100
Eliasson and colleagues[35]	24	24	0	144	1	720/120	99.3	100
Degidi and colleagues[33]	28	28	0	210	0	1050/140	100	100
Gallucci and colleagues[38]	45	45	2	237	0	1185/225	100	95.6
Friberg and colleagues[37]	10	10	0	50	3	250/50	94	100
Purcell and colleagues[43]	46	46	0	233	0	1165/230	100	100
Åstrand and colleagues[31]	31	31	0	155	13	775/155	91.6	100
Ferrigno and colleagues[36]	14	14	0	112	4	560/70	96.4	100
Murphy and colleagues[41]	26	26	0	131	4	655/130	96.9	100
Tinsley and colleagues[45]	17	17	0	79	0	395/85	100	100
Arvidson and colleagues[30]	91	91	0	525	8	2625/455	98.5	100
Makkonen and colleagues[40]	13	13	0	77	0	385/65	100	100
10-year follow-up								
Ortorp and Jemt[42]	42	42	1	194	1	1940/420	99.5	97.6
Rasmusson and colleagues[44]	17	17	0	90	3	900/170	96.7	100
20-year follow-up								
Åstrand and colleagues[1]	17	17	1	96	1	1920/340	99	94.1
Attard and Zarb[32]	29	29	5	168	22	3360/580	86.9	82.8
Ekelund and colleagues[34]	30	30	2	179	1	3580/600	99.4	93.3
Total	501	501	11	2764	63	21885/3940	97.7	97.8

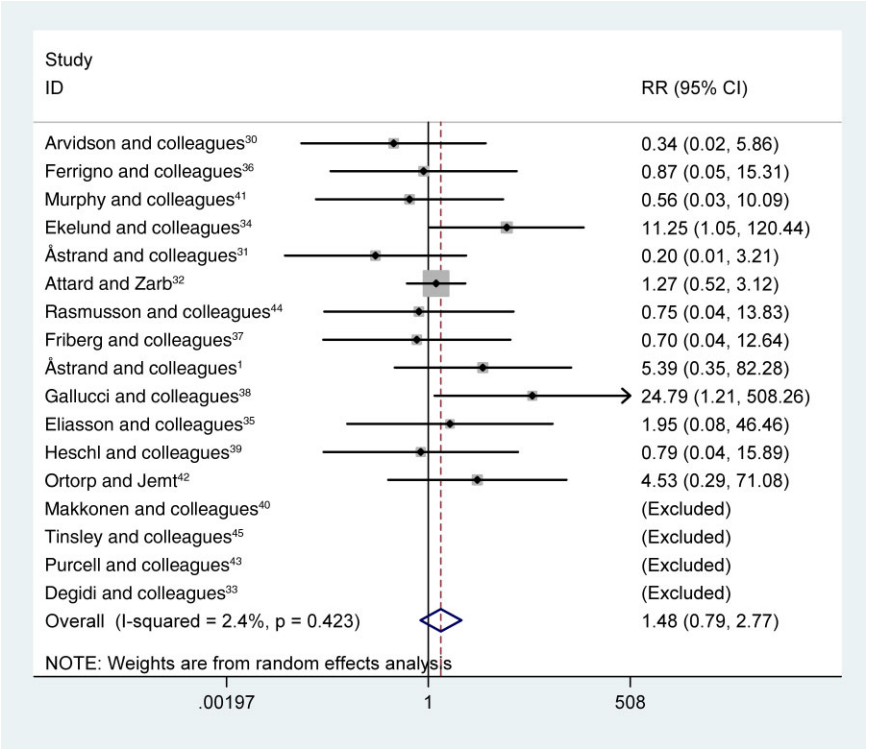

Figure 2 Forest plots of relative risk ratio for implants and prostheses.

The effect of implant surface texture on survival rates was assessed by dividing the data into two groups: smooth (machined) surface and rough surface independent of the surface treatment and of degree of roughness. The implant surface had no influence ($p > .05$) on the implant survival in the edentulous mandible (Table 4).

Implant Survival by N of Implants and Implant Distribution. Cumulative implant survival rate estimates at 5- and 10-year end points depending on number of supporting implants and antero-posterior implant distribution are shown in Table 4. The effect of the number of supporting implants and the implant distribution had no influence ($p > .05$) on the implant survival (Table 4). Out of 2,827 implants placed, 2,501 had been placed interforaminally, which stands for the 88.5% of all the implants.

Prosthodontic Survival by Prosthesis Design, Retention Type, Prosthetic Material Type, and Loading Protocol. The parameters given for prosthesis survival and success were inconsistent and varied from continuous prosthesis stability to a number of maximum prosthetic maintenance events.

The prosthodontic survival rate estimates for one-piece IFCDPs ranged from 98.61% (95% CI: 97.80–99.43) (5 years) to 97.25% (95% CI: 95.66–98.86) (10 years). No data were available for segmented or noncantilevered prostheses. Out of the 501 IFCDPs, 94.4% were screw retained and 93.6% were metal resin IFCDPs, respectively. Only 6.4% of the 501 IFCDPs were metal ceramic.

The prosthodontic survival rates for screw- and cement-retained IFCDPs, metal ceramic and metal resin IFCDPs, and different loading protocols can be seen in Table 5. The prosthetic design, the veneering material, and the retention type had no influence ($p > .05$) on the prosthodontic survival rates. The loading protocol also had no influence on the prosthodontic survival rates (Table 5).

DISCUSSION

As implant dentistry is continuously growing, the demand for quality clinical research that offers evidence-based clinical guidelines is increasing. The objective of this systematic review was to report the implant and prosthodontic survival rates with mandibular IFCDPs for edentulous patients after 5- and 10-year follow-up. Seventeen prospective studies,

TABLE 4 Summary of Implant-Related Variables

Factor		Total Number of Implants	Implants Lost	Total Implant Exposure Time	Estimated 1-Year Implant Survival Rate (%) (95% CI)	Cumulative 5-Year Estimated Implant Survival Rate (%) (95% CI)	Cumulative 10-Year Estimated Implant Survival Rate (%) (95% CI)	*p* Value
Surface	Smooth	1459	49	15360	99.68 (99.59–99.77)	98.42 (97.98–98.86)	96.86 (96.00–97.73)	.1753
	Rough	1305	14	6525	99.76 (99.67–99.90)	98.93 (98.38–99.49)	97.88 (96.78–98.98)	
Implants per patient	4	84	2	420	99.52 (98.87–100)	97.65 (94.48–100)	95.35 (89.26–100)	.6754
	5	545	18	2725	99.34 (99.04–99.65)	96.75 (95.29–98.24)	93.61 (90.79–96.51)	
	6	24	2	120	98.35 (96.10–100)	92.00 (81.97–100)	84.65 (67.19–100)	
	8	112	4	560	99.29 (98.60–99.99)	96.49 (93.17–99.93)	93.12 (86.81–99.96)	
	4 to 5	181	1	1415	99.93 (99.79–100)	99.65 (98.96–100)	99.30 (97.93–100)	n/a
	4 to 6	996	12	5430	99.78 (99.65–99.90)	98.90 (98.28–99.52)	97.81 (96.60–99.05)	n/a
	5 to 6	612	24	10165	99.77 (99.68–99.87)	98.88 (98.42–99.33)	97.76 (96.86–98.67)	n/a
	5 to 9	210	0	1050	100	100	100	n/a
Implants distribution	Anterior	2442	59	20835	99.63 (99.54–99.71)	98.15 (97.74–98.55)	96.33 (95.53–97.13)	.5882
	Antero-posterior	322	4	1050	99.62 (99.29–99.99)	98.11 (96.30–99.96)	96.26 (92.73–99.92)	

The *p*-value is based on the standard Poisson's regression, assessing the existence of statistical difference between different surfaces, number of implants per patient, and distribution of implants.
n/a = not applicable.

TABLE 5 Summary of Prosthesis-Related Variables

Factor		Total Number of Prostheses	Total Number of Prostheses Lost	Total Prosthesis Exposure Time	Estimated 1-Year Prosthesis Survival Rate (%) (95% CI)	Cumulative 5-Year Estimated Prosthesis Survival Rates (%) (95% CI)	Cumulative 10-Year Estimated Prosthesis Survival Rates (%) (95% CI)	*p* Value
Design	One piece	501	11	3940	99.72 (99.56–99.89)	98.61 (97.80–99.43)	97.25 (95.66–98.86)	n/a
	Segmented	0	0	0	n/a	n/a	n/a	
	Cantilevered	501	11	3940	99.72 (99.56–99.89)	98.61 (97.80–99.43)	97.25 (95.66–98.86)	n/a
	Non-cantilevered	0	0	0	n/a	n/a	n/a	
Retention	Screw retained	473	11	3800	99.71 (99.54–99.88)	98.56 (97.72–99.41)	97.15 (95.50–98.82)	.3723
	Cement retained	28	0	140	100	100	100	
Materials	Metal-resin	469	11	3780	99.71 (99.54–99.88)	98.56 (97.71–99.41)	97.13 (95.48–98.82)	.3396
	Metal-ceramic	32	0	160	100	100	100	
Loading	Conventional	455	11	3710	99.70 (99.53–99.88)	98.53 (97.67–99.40)	97.08 (95.39–98.79)	.516
	Early	10	0	50	100	100	100	
	Immediate	36	0	180	100	100	100	

The *p* value is based on the standard Poisson's regression, assessing the existence of statistical difference between different designs, retention types, materials and loading protocols.
n/a = not applicable.

including 501 patients and 2,827 implants, were included in the present meta-analysis.

Implant survival rates were similar for the *rough surface* and the *machined surface* implants at all time-points for the edentulous mandible. There were 49 (3.36%) failures out of 1,459 smooth surface implants placed, and 14 (1.1%) failures out of 1,305 rough surface implants placed. Cumulative implant survival rates for rough surface ranged from 98.42% (95% CI: 97.98–98.86) (5 years) to 96.86% (95% CI: 96.00–97.73) (10 years); smooth surface implant survival rates ranged from 98.93% (95% CI: 98.38–99.49) (5 years) to 97.88% (95% CI: 96.78–98.98) (10 years). The difference was not statistically significant. The clinical implications are that treatment of the edentulous mandible with endosseous implants has longitudinal effectiveness, with more than 96% survival after 10 years.

The findings of this study for the mandible are in contrast with the findings of a descriptive meta-analysis by Lambert and colleagues for implants in the edentulous maxilla.[10] That study reported better survival rates with rough surface implants than with machined implants for the edentulous maxilla. However, the findings of the present review are in accordance with another longitudinal 5-year study that found similar time-dependent survival rates between smooth-surface and rough-surface implants.[46] The implants were placed in various locations of the mouth and not only on the mandible. A possible explanation is the fact that the host alveolar bone in the interforaminal mandible is of optimal quality and quantity that the implant surface does not have an impact on the implant survival.

The *number of implants* for every mandibular IFCDP was ranging from four to nine implants. Placement interforaminally was the most common technique. Out of the 2,827 implants placed, 88.5% was inserted in the interforaminal area. A larger number of failures (59 out of 2,442 or 2.41%) on implants placed interforaminally was observed, when compared with 4 failures out of 322 (1.24%) implants placed antero-posteriorly, but it was not statistically significant. The studies did not clarify if the four implant failures in the anterior-posterior group were indeed posterior or anterior implants. The number of supporting implants and the antero-posterior implant distribution had no statistically significant influence on the implant survival rate. The dental literature has started to point out that "all on four" types of IFCDPs may be a viable prosthetic option, in contrast to the belief that more implants is better.[21] No statistical difference was found regarding the number of supporting implants in the present study.

The selection of the *prosthetic design* should be based on scientific evidence as much as possible. Implant survival directly affects the prosthesis survival, but the prosthesis design may not be a determining factor in implant survival for edentulous patients.[47] The findings of the present review are in agreement with the previous study.

The one-piece prosthetic design with incorporation of posterior cantilevers into mandibular IFCDPs was the most common. The local conditions of the posterior residual edentulous ridge often preclude the possibility to place implants posteriorly. For implant-supported fixed dental prostheses, the incorporation of cantilevers into implant-borne prostheses may be associated with a higher incidence of technical complications but was not associated per se with complications after 5-year follow-up.[48] However, the presence of cantilevers in mandibular IFCDPs had no influence on the prosthesis survival. No comparison could be made between one-piece versus segmented prosthetic design or cantilever versus non-cantilevered prostheses due to the absence of segmented and noncantilevered prostheses.

The one-piece design was the only one identified in the present meta-analysis. The one-piece IFCDP fabricated with CAD/CAM technology offers ease of insertion due to elimination of interproximal contact adjustments and splinting of the implants where necessary. Other options have also been proposed for the complete arch fixed rehabilitation with segmented prostheses and strategically positioned implants. Segmentation of the complete arch prosthetic rehabilitation has been proposed to improve ease of fabrication and maintenance issues.[49–52]

Prosthetic design was stratified into *metal resin and metal ceramic* IFCDPs. The preponderance of literature reported on metal-resin IFCDPs (93.6% of all IFCDPs). The longitudinal effectiveness of the metal-resin IFCDPs has been demonstrated in the literature, and technical complications like chipping encountered with this type of prostheses may be easily fixable. No studies comparing metal-ceramic IFCDPs to metal-resin IFCDPs were identified. Only two studies reported on metal-ceramic IFCDPs, but the number was too low to draw any conclusions (469 metal-resin vs 32 metal-ceramic IFCDPs).[33,38] Moreover, there is paucity

of reports on complications with metal-ceramic IFCDPs for edentulous mandibles, with observation periods of at least 5 years.

Screw retention was the most common type of retention (94.4% of all IFCDPs) and had no influence on the implant survival rate. Only the study by Degidi and colleagues reported on cement-retained IFCDPs.[33] No direct comparison with cement retention could be carried out due to the small number of reported cement-retained IFCDPs (28 cement-retained IFCDPs vs 473 screw-retained IFCDPs). A recent meta-analysis showed that technical complications are frequently encountered with IFCDPs during 5 to 10 years of clinical function.[53] Technical complications after the definitive prosthesis placement may not lead to implant loss but can result in an increased number of repairs and maintenance sessions. The 10-year cumulative rate of "prosthesis free of complications" of 8.6% (95% CI: 7.1–10.3) reported in that review epitomizes the advantage of retrievability of screw-retained IFCDPs vs cement-retained metal-ceramic IFCDPs. Where applicable, a segmented prosthetic design may be recommended for the complete arch implant rehabilitation, for prosthetic maintenance reasons.[49–52]

A previous consensus meeting reported that for the edentulous mandible, both immediate and 6 to 8-week post-implant placement *loading protocols* were supported by the literature.[3] Conventional loading defined as greater than 2 months after implant placement was also equally predictable. The findings of the present meta-analysis are in agreement with the aforementioned consensus report. The loading protocol had no influence on the estimates of prosthodontic survival rate at the 5- and 10-year end points.

Even though there was an abundance of retrospective studies reporting on various amounts of patients, the decision was made to strictly include only RCTs and prospective clinical trials, in order to reduce the high risk of bias that the retrospective design inherently carries. As no RCTs were identified during the full-text reading, only prospective cohort studies were included in the meta-analysis. It becomes clear that further long-term RCTs are necessary in order to assist the dentists in making the right everyday decisions based on evidence-based quality research findings.

Only 5 out of the 17 included studies reported on both survival and success rates.[35,36,38,39,45] The success rates reported in these studies were lower than the survival rates. This is clearly manifested in the study by Gallucci and colleagues,[38] with a significant difference between the reported 100% implant survival rate and 86.7% treatment success rate, when prosthesis survival and complications where taken into consideration. In another study by Eliasson and colleagues,[35] the cumulative implant survival rate of 99.4% contradicts the success rate of 86.2% when implant fractures and excessive annual radiographic bone loss where also considered. The advances in contemporary oral implantology coupled with the patients' high esthetic expectations underscore the necessity for more factors to be included in the success criteria assessment of the implant prostheses, besides the implant survival.[54]

Patient-centered outcomes are frequently overlooked, in spite of the obvious ramifications in the success of the dental implant therapy.[55] Most of the included articles did not present data on patient-centered outcomes. Restoration of function, esthetics, and patient satisfaction is the goal when treating the edentulous patient with dental implants and thus new studies should report on these important parameters of the implant treatment.

In this context, well-defined success criteria should be established and used for reporting and assessing implant, prosthetic, and patient-centered outcomes as well as biological and technical complications. Longitudinal clinical studies should ideally report on complications in order to provide clinicians with reliable and thorough information for evidence-based treatment planning.

CONCLUSION

The 5- and 10-year estimated implant and prosthodontic survival rates with all IFCDPs clearly demonstrate that treatment with mandibular IFCDPs yields high implant and prosthodontic survival rates (more than 96% survival after 10 years). Rough surface implants exhibited cumulative survival rates similar to the smooth surface ones in the edentulous mandible. The number of supporting implants and the anteroposterior implant distribution had no influence on the implant survival rate. The prosthetic design, the veneering material, and the retention type had no influence on the prosthodontic survival rates. The loading protocol also had no influence on the prosthodontic survival rates. However, the results of this study should be carefully interpreted as they present survival and do not

reflect success. Further clinical trials with metal ceramic IFCDPs and at least 5-year follow-up are necessary.

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REFERENCES

1. Åstrand P, Ahlqvist J, Gunne J, Nilson H. Implant treatment of patients with edentulous jaws: a 20-year follow-up. Clin Implant Dent Relat Res 2008; 10:207–217.
2. Pjetursson BE, Brägger U, Lang NP, Zwahlen M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). Clin Oral Implants Res 2007; 18(Suppl 3):97–113.
3. Weber HP, Morton D, Gallucci GO, Roccuzzo M, Cordaro L, Grutter L. Consensus statements and recommended clinical procedures regarding loading protocols. Int J Oral Maxillofac Implants 2009; 24(Suppl):180–183.
4. Kapos T, Ashy LM, Gallucci GO, Weber HP, Wismeijer D. Computer-aided design and computer-assisted manufacturing in prosthetic implant dentistry. Int J Oral Maxillofac Implants 2009; 24(Suppl):110–117.
5. Petersen PE, Yamamoto T. Improving the oral health of older people: the approach of the WHO global oral health program. Community Dent Oral Epidemiol 2005; 33:81–92.
6. Felton D, Cooper L, Duqum I, et al. Evidence-based guidelines for the care and maintenance of complete dentures: a publication of the American College of Prosthodontists. J Prosthodont 2011; 20(Suppl 1):S1–S12.
7. Douglass CW, Shih A, Ostry L. Will there be a need for complete dentures in the United States in 2020? J Prosthet Dent 2002; 87:5–8.
8. Papaspyridakos P, Lal K, White GS, Weber HP, Gallucci GO. Effect of splinted and non-splinted impression techniques on the accuracy of fit of implant fixed prostheses in edentulous patients: a comparative study. Int J Oral Maxillofac Implants 2011; 26:1267–1272.
9. Eckert SE, Choi YG, Sanchez AR, Koka S. Comparison of dental implant systems quality of clinical evidence and prediction of 5-year survival. Int J Oral Maxillofac Implants 2005; 20:406–415.
10. Lambert FE, Weber HP, Susarla SM, Belser UC, Gallucci GO. Descriptive analysis of implant and prosthodontic survival rates with fixed implant-supported rehabilitations in the edentulous maxilla. J Periodontol 2009; 80:1220–1230.
11. Al-Nawas B, Kämmerer PW, Morbach T, Ladwein C, Wegener J, Wagner W. Ten-year retrospective follow-up study of the TiOblast dental implant. Clin Implant Dent Relat Res 2012; 14:127–134.
12. Brånemark PI, Svensson B, van Steenberghe D. Ten-year survival rates of fixed prostheses on four or six implants ad modum Brånemark in full edentulism. Clin Oral Implants Res 1995; 6:227–231.
13. Browaeys A, Defrancq J, Dierens MC, et al. A retrospective analysis of early and immediately loaded Osseotite implants in cross-arch rehabilitations in edentulous maxillae and mandibles up to 7 years. Clin Implant Dent Relat Res 2011. [Epub ahead of print].
14. Davis DM, Packer ME, Watson RM. Maintenance requirements of implant-supported fixed prostheses opposed by implant-supported fixed prostheses, natural teeth, or complete dentures: a 5-year retrospective study. Int J Prosthodont 2003; 16:521–523.
15. Eliasson A, Blomqvist F, Wennerberg A, Johansson A. A retrospective analysis of early and delayed loading of full-arch mandibular prostheses using three different implant systems: clinical results with up to 5 years of loading. Clin Implant Dent Relat Res 2009; 11:134–148.
16. Eliasson A, Palmqvist S, Svenson B, Sondell K. Five-year results with fixed complete-arch mandibular prostheses supported by 4 implants. Int J Oral Maxillofac Implants 2000; 15:505–510.
17. Engstrand P, Gröndahl K, Ohrnell LO, Nilsson P, Nannmark U, Brånemark PI. Prospective follow-up study of 95 patients with edentulous mandibles treated according to the Brånemark Novum concept. Clin Implant Dent Relat Res 2003; 5:3–10.
18. Friberg B, Jemt T. Clinical experience of TiUnite implants: a 5-year cross-sectional, retrospective follow-up study. Clin Implant Dent Relat Res 2010; 12(Suppl 1):e95–103.
19. Hemmings KW, Schmitt A, Zarb GA. Complications and maintenance requirements for fixed prostheses and overdentures in the edentulous mandible: a 5-year report. Int J Oral Maxillofac Implants 1994; 9:191–196.
20. Lethaus B, Kälber J, Petrin G, Brandstätter A, Weingart D. Early loading of sandblasted and acid-etched titanium implants in the edentulous mandible: a prospective 5-year study. Int J Oral Maxillofac Implants 2011; 26:887–892.
21. Malo P, de Araújo Nobre M, Lopes A, Moss SM, Molina GJ. A longitudinal study of the survival of All-on-4 implants in the mandible with up to 10 years of follow-up. J Am Dent Assoc 2011; 142:310–320.
22. Ortorp A, Jemt T. Early laser-welded titanium frameworks supported by implants in the edentulous mandible: a 15-year

comparative follow-up study. Clin Implant Dent Relat Res 2009; 11:311–322.
23. Pikner SS, Gröndahl K, Jemt T, Friberg B. Marginal bone loss at implants: a retrospective, long-term follow-up of turned Brånemark System implants. Clin Implant Dent Relat Res 2009; 11:11–23.
24. Romeo E, Lops D, Margutti E, Ghisolfi M, Chiapasco M, Vogel G. Long-term survival and success of oral implants in the treatment of full and partial arches: a 7-year prospective study with the ITI dental implant system. Int J Oral Maxillofac Implants 2004; 19:247–259.
25. Schnitman PA, Wöhrle PS, Rubenstein JE, Da Silva JD, Wang NH. Ten-year results for Brånemark implants immediately loaded with fixed prostheses at implant placement. Int J Oral Maxillofac Implants 1997; 12:495–503.
26. Schwarz S, Gabbert O, Hassel AJ, Schmitter M, Séché C, Rammelsberg P. Early loading of implants with fixed dental prostheses in edentulous mandibles: 4.5-year clinical results from a prospective study. Clin Oral Implants Res 2010; 21:284–289.
27. Testori T, Meltzer A, Del Fabbro M, et al. Immediate occlusal loading of Osseotite implants in the lower edentulous jaw. A multicenter prospective study. Clin Oral Implants Res 2004; 15:278–284.
28. Wolfinger GJ, Balshi TJ, Rangert B. Immediate functional loading of Brånemark system implants in edentulous mandibles: clinical report of the results of developmental and simplified protocols. Int J Oral Maxillofac Implants 2003; 18:250–257.
29. Kirkwood BR, Sterne JAC. Chapter 26: survival analysis: displaying and comparing survival patterns. In: Kirkwood BR, Sterne JAC, eds. Essential medical statistics. Oxford: Blackwell Science Ltd, 2003: 272–286.
30. Arvidson K, Bystedt H, Frykholm A, von Konow L, Lothigius E. Five-year prospective follow-up report of the Astra Tech Dental Implant System in the treatment of edentulous mandibles. Clin Oral Implants Res 1998; 9:225–234.
31. Åstrand P, Engquist B, Dahlgren S, Gröndahl K, Engquist E, Feldmann H. Astra Tech and Brånemark system implants: a 5-year prospective study of marginal bone reactions. Clin Oral Implants Res 2004; 15:413–420.
32. Attard NJ, Zarb GA. Long-term treatment outcomes in edentulous patients with implant-fixed prostheses: the Toronto study. Int J Prosthodont 2004; 17:417–424.
33. Degidi M, Iezzi G, Perrotti V, Piattelli A. Comparative analysis of immediate functional loading and immediate nonfunctional loading to traditional healing periods: a 5-year follow-up of 550 dental implants. Clin Implant Dent Relat Res 2009; 11:257–266.
34. Ekelund JA, Lindquist LW, Carlsson GE, Jemt T. Implant treatment in the edentulous mandible: a prospective study on Brånemark System implants over more than 20 years. Int J Prosthodont 2003; 16:602–608.
35. Eliasson A, Narby B, Ekstrand K, Hirsch J, Johansson A, Wennerberg A. A 5-year prospective clinical study of submerged and nonsubmerged Paragon system implants in the edentulous mandible. Int J Prosthodont 2010; 23:231–238.
36. Ferrigno N, Laureti M, Fanali S, Grippaudo G. A long-term follow-up study of non-submerged ITI implants in the treatment of totally edentulous jaws. Part I: ten-year life table analysis of a prospective multicenter study with 1286 implants. Clin Oral Implants Res 2002; 13:260–273.
37. Friberg B, Raghoebar GM, Grunert I, Hobkirk JA, Tepper G. A 5-year prospective multicenter study on 1-stage smooth-surface Brånemark System implants with early loading in edentulous mandibles. Int J Oral Maxillofac Implants 2008; 23:481–486.
38. Gallucci GO, Doughtie CB, Hwang JW, Fiorellini JP, Weber HP. Five-year results of fixed implant-supported rehabilitations with distal cantilevers for the edentulous mandible. Clin Oral Implants Res 2009; 20:601–607.
39. Heschl A, Payer M, Platzer S, Wegscheider W, Pertl C, Lorenzoni M. Immediate rehabilitation of the edentulous mandible with screw type implants: results after up to 10 years of clinical function. Clin Oral Implants Res 2012; 23:1217–1223.
40. Makkonen TA, Holmberg S, Niemi L, Olsson C, Tammisalo T, Peltola J. A 5-year prospective clinical study of Astra Tech dental implants supporting fixed bridges or overdentures in the edentulous mandible. Clin Oral Implants Res 1997; 8:469–475.
41. Murphy WM, Absi EG, Gregory MC, Williams KR. A prospective 5-year study of two cast framework alloys for fixed implant-supported mandibular prostheses. Int J Prosthodont 2002; 15:133–138.
42. Ortorp A, Jemt T. CNC-milled titanium frameworks supported by implants in the edentulous jaw: a 10-year comparative clinical study. Clin Implant Dent Relat Res 2012; 14:88–99.
43. Purcell BA, McGlumphy EA, Holloway JA, Beck FM. Prosthetic complications in mandibular metal-resin implant-fixed complete dental prostheses: a 5- to 9-year analysis. Int J Oral Maxillofac Implants 2008; 23:847–857.
44. Rasmusson L, Roos J, Bystedt H. A 10-year follow-up study of titanium dioxide-blasted implants. Clin Implant Dent Relat Res 2005; 7:36–42.
45. Tinsley D, Watson CJ, Russell JL. A comparison of hydroxylapatite coated implant retained fixed and removable mandibular prostheses over 4 to 6 years. Clin Oral Implants Res 2001; 12:159–166.
46. Balshe AA, Assad DA, Eckert SE, Koka S, Weaver AL. A retrospective study of the survival of smooth- and rough-surface dental implants. Int J Oral Maxillofac Implants 2009; 24:1113–1118.
47. Bryant SR, MacDonald-Jankowski D, Kim K. Does the type of implant prosthesis affect outcomes for the completely

edentulous arch. Int J Oral Maxillofac Implants 2007; 22(Suppl):117–139.

48. Aglietta M, Siciliano VI, Zwahlen M, et al. A systematic review of the survival and complication rates of implant supported fixed dental prostheses with cantilever extensions after an observation period of at least 5 years. Clin Oral Implants Res 2009; 20:441–451.
49. Papaspyridakos P, White GS, Lal K. Flapless CAD/CAM-guided surgery for staged transition from failing dentition to complete arch implant rehabilitation: a 3-year clinical report. J Prosthet Dent 2012; 107:143–150.
50. Belser UC, Bernard JP, Buser D. Implant placement in the esthetic zone, chapter 40. In: Lindhe J, Karring T, Lang NP, eds. Clinical periodontology and implant dentistry. 4th ed. Oxford: Wiley-Blackwell, 2003:915–944.
51. Gallucci GO, Bernard JP, Belser UC. Treatment of edentulous patients with fixed implant-supported restorations: three consecutives cases of simultaneous immediate loading in both maxilla and mandible. Int J Periodontics Restorative Dent 2005; 25:27–37.
52. Gallucci GO, Bernard JP, Bertosa M, Belser UC. Immediate loading with fixed screw-retained provisional restorations in edentulous jaws: the pickup technique. Int J Oral Maxillofac Implants 2004; 19:524–533.
53. Papaspyridakos P, Chen CJ, Chuang SK, Weber HP, Gallucci GO. A systematic review of biologic and technical complications with fixed implant rehabilitations for edentulous patients. Int J Oral Maxillofac Implants 2012; 27: 102–110.
54. Papaspyridakos P, Chen CJ, Singh M, Weber HP, Gallucci GO. Success criteria in implant dentistry: a systematic review. J Dent Res 2012; 91:242–248.
55. Dierens M, Collaert B, Deschepper E, Browaeys H, Klinge B, De Bruyn H. Patient-centered outcome of immediately loaded implants in the rehabilitation of fully edentulous jaws. Clin Oral Implants Res 2009; 20:1070–1077.