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Prosthetic Outcomes of Implant-Assisted Maxillary Restorations in the Edentulous Maxilla: A Systematic Review and Meta-Analysis

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ABSTRACT

Objectives: To evaluate the prosthetic outcomes of implant-assisted maxillary full-arch restorations with ≥ 3 years of follow-up.

Materials and Methods: A systematic electronic literature search was conducted in five databases to identify randomised controlled trials and prospective clinical studies involving patients who received full-arch rehabilitation in the maxilla. The primary outcome was prosthesis loss; secondary outcomes included complication-free prosthesis survival, complication-free implant survival, implant loss, technical complications, patient-reported outcome measures (PROMS), and marginal bone loss. Meta-analyses of proportions using random-effects models were performed to estimate pooled rates of prosthetic survival, success, and complications.

Results: A total of 20 studies involving 913 patients were included. Among these, 542 patients received fixed prostheses and 371 received removable prostheses. Most of the studies had an observation period in the range of 3 to 6 years, with only two studies (overdentures) reaching 10 years. Overall prosthesis loss was 4.6% (95% CI: 1.2%–10.1%) and complication-free prosthesis survival was 61.9% (95% CI: 48.4%–74.5%). Overall complication-free implant survival was 46.5% and technical complications were 62.9%. Pooled implant loss was 5.5% after adjusting for clustering effects and mean marginal bone loss was < 0.8 mm. Subgroup analysis of fixed and removable prosthesis over a similar observation period revealed similar outcomes.

Conclusions: Implant-assisted maxillary full-arch restorations have low rates of prosthesis and implant loss. However, complication-free survival is moderate, underscoring the importance of maintenance and patient education.

1 | Introduction

Demographic shifts have led to a growing global elderly population, posing challenges for healthcare systems worldwide. Between 1990 to 2021, the global prevalence of edentulism rose by 8%, driven largely by upper-middle-income countries (Bernabe et al. 2025). Age is a major determinant in the epidemiology of edentulism, with older adults being disproportionately affected (Peltzer et al. 2014). Among individuals over 60 years of age, the global average prevalence of edentulism is estimated at 22.7%—nearly one in four people having lost all their teeth (Borg-Bartolo et al. 2022; World Health Organization 2022). Edentulism, defined as the complete loss of natural teeth, has been linked to chronic diseases in older adults (Vemulapalli et al. 2024),

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particularly periodontitis, which ultimately leads to tooth loss (Ng et al. 2021). In addition to increased morbidity and mortality, edentulism and poor masticatory function are associated with adverse health outcomes, including depression, poor self-rated health, compromised oral health-related quality of life, and nutritional deficiencies (Polzer et al. 2010; Tay, Cooray, et al. 2025; Tay, Nascimento, et al. 2025; World Health Organization 2022). Conversely, individuals who receive treatment for edentulism experience lower rates of malnutrition, frailty, and cognitive impairment compared to those left untreated (Gennai et al. 2022).

Managing the fully edentulous maxilla presents unique challenges in Implant Dentistry due to anatomical constraints such as reduced bone volume, progressive maxillary sinus pneumatization, and poor bone quality (Avila-Ortiz et al. 2023). Treatment solutions for edentulism include conventional complete dentures, implant-retained overdentures, and implant-supported fixed prostheses (Jawad 2024). According to the European Federation of Periodontology (EFP) S3-level clinical practice guidelines for stage IV periodontitis, when tooth preservation is no longer viable, implant-supported full-arch fixed prostheses and implant-supported overdentures are recommended over conventional removable prostheses, as they are associated with better quality of life measures (Herrera et al. 2022). While the authors noted common issues with retention, aesthetics, and masticatory function in removable dentures, they did not differentiate between maxillary and mandibular edentulous arches.

Previously, the 2002 McGill Consensus Statement established mandibular two-implant overdentures as the first-choice standard of care for edentulous patients, noting that patients generally experience greater difficulties with lower dentures than with upper dentures (Feine et al. 2002). Over two decades later, two-implant mandibular overdentures are now regarded as the 'minimum standard of care' rather than a first-choice, as the optimal treatment for each patient depends on multiple factors, including economic considerations. In comparison, conventional and implant-assisted complete maxillary prostheses have been reported to be equally successful in restoring quality of life and improving patient satisfaction (Michaud et al. 2025). Nevertheless, implant-assisted full-arch maxillary prostheses can offer distinct advantages for patients with anatomical or functional limitations—such as shallow palates, severe ridge resorption, excessive hard tissue, a pronounced gag reflex, or diminished taste perception.

The main implant-assisted maxillary reconstruction approaches are removable implant overdentures and fixed full-arch implant-supported prostheses (Donos et al. 2022). Although these restorations may be associated with high implant survival rates at 5-years (Ramanauskaite et al. 2022), they are frequently affected by peri-implant disease (Ramanauskaite et al. 2021). To date, a comprehensive comparison of the prosthetic outcomes across different implant-assisted treatment modalities in the edentulous maxilla is lacking.

The objective of this systematic review is to enhance clinical decision-making by offering a comprehensive analysis of the prosthetic outcomes of implant-assisted maxillary rehabilitations, thereby facilitating improved treatment planning and long-term success. The primary aim is to evaluate prosthesis loss. Additionally, the review will assess complication-free prosthesis survival, complication-free implant survival, implant loss, technical complications, marginal bone loss, and PROMs as secondary outcomes.

2 | Materials and Methods

This review adheres to the guidelines of the Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al. 2021). The protocol of this review was registered in the PROSPERO database with the registration number CRD420251001443.

The focused question of this systematic review, based on randomised clinical trials and prospective clinical studies, is the following: "In adults with controlled medical health with a fully edentulous maxilla (Population), what is the efficacy of different types of full-arch implant-assisted maxillary restorations (Intervention and Comparison) in the lifespan domain after ≥ 3 years of follow-up (Outcome)?"

The outcomes used in this study are based on the lifespan domain of the Implant Dentistry Core Outcome Set and Measurement (ID-COSM) (Tonetti et al. 2023):

1. Prosthesis loss: Failure of the prosthesis.
2. Implant loss: Failure of the implant.
3. Complication-free prosthesis survival: Defined as survival of the prosthesis from completion of treatment (delivery of prosthesis) until the patient experiences the first complication requiring intervention.
4. Complication-free implant survival: Defined as survival of the implant from completion of treatment (delivery of prosthesis) until the patient experiences the first complication requiring intervention.
5. Technical complications: Intervention-related adverse events that occur after insertion of the definitive prosthesis.
6. Marginal bone loss: analysed by prosthesis type and further stratified by follow-up period where possible to assess time-dependent patterns of bone loss.

2.1 | Inclusion and Exclusion Criteria

Based on the predefined focus question, the following components of PICOS were as follows:

- Population: Adults (≥ 18 years old) with controlled medical health, with a fully edentulous maxilla receiving full-arch rehabilitation.
- Intervention: Rehabilitation with any type of fixed or removable full-arch implant-assisted maxillary reconstruction.
- Comparison: Different types of full-arch implant-assisted prostheses (e.g., framework or veneering materials and type of retention).

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- Outcomes: The primary outcome was prosthesis loss. The secondary outcomes were complication-free prosthesis survival, complication-free implant survival, implant loss, technical complications (mechanical and technical), patient-reported outcome measures, and marginal bone loss.
- Study: Randomised clinical trials and prospective clinical studies with a minimum of five patients and at least 3-years observation period. Conference abstracts, retrospective studies, case reports/series, in vitro studies, animal studies, and review articles were excluded.

2.2 | Search Strategy

The initial strategy was built for PubMed using free text and MeSH keywords and then reformatted for other databases. The search strategy included terms related to the Population and the Intervention/Comparison investigated in this review, combined with the Boolean operators "AND" and "OR" (Appendix S1). A total of four databases and one data registry were searched, including MEDLINE via PubMed, Scopus, Web of Science, Embase, and the Cochrane Central Register of Controlled Trials. The final electronic search was conducted on 3 March 2025 and included studies published between January 2000 to February 2025. Bibliographies of review articles on this topic and the reference lists of retrieved articles were also screened. Hand searching was performed for the last 2 years in relevant journals where this topic may have been published (*Clinical Oral Implants Research, Clinical Implant Dentistry and Related Research, European Journal of Oral Implantology, International Journal of Periodontics and Restorative Dentistry, Clinical Oral Investigations, Journal of Dentistry, Journal of Prosthodontics, Journal of Prosthetic Dentistry, International Journal of Prosthodontics*, and *Journal of Prosthodontic Research*).

2.3 | Selection Process

All records were transferred to EndNote (version 21, Clarivate, Philadelphia, PA) to remove duplicates, and then transferred to the Rayyan platform for screening (Ouzzani et al. 2016). A two-stage selection process was carried out independently and in duplicate by two reviewers (EN and JRHT). First, studies were assessed based on their titles and abstracts, and those that met the inclusion criteria were then screened for full-text analysis. After completing the screening process, both reviewers individually went through the full text of potentially eligible studies for final selection based on the eligibility criteria. Any differences were discussed by both reviewers openly, and a third reviewer (MR) was consulted if required. The reviewers were not blinded to the author or institutions of the reviews undergoing screening.

2.4 | Data Extraction and Management

Data was extracted independently by three reviewers (E.N., M.R., and L.M.) using a standardised data extraction form. Prior to data extraction, the data extraction process was discussed to ensure consistency and familiarity with the definitions used. In case of missing or unclear information, the authors of the included studies were contacted directly via email for clarification. Final data accuracy and consistency were independently verified by two reviewers (E.N. and J.R.H.T.).

2.5 | Quality Assessment

The assessment of methodological quality and risk of bias of each study was performed unblinded by two independent reviewers (MR and LM) using version 2 of the Cochrane risk-of-bias tool for RCTs (RoB2) (Sterne et al. 2019) and the ROBINS-I V2 tool (Cochrane Methods Bias 2024) for cohort and controlled clinical trial studies. If a study undergoing assessment included a review author as one of its authors, the evaluation was performed by another review author who was not involved in that study. Any disagreements were discussed, and a third author (EN) was consulted if necessary to reach a consensus.

2.6 | Data Synthesis

All included studies were qualitatively evaluated, and extracted data were organized into tables. In addition to the reported outcomes of interest, other data included author(s) and year of publication, country, study setting, study design, mean age, last time point, treatment arms, implant systems, and a description of surgical and prosthetic interventions.

All data analyses were conducted in R (version 4.4.2, R Core Team, Vienna, Austria), and RStudio (2024.12.0.467), using the *metafor* package (Viechtbauer 2010). Data handling and visualization were performed with packages from the *tidyverse*. Articles describing different follow-ups from the same clinical trial were grouped together for the meta-analysis. A random-effects meta-analysis of single proportions was performed to estimate pooled rates of survival, success, and complications, each presented with 95% confidence intervals (CI) (Barker et al. 2021). Proportions were pooled using inverse variance methods with the Freeman–Tukey double arcsine transformation, for stabilizing variance in proportion data (Barker et al. 2021).

Meta-analyses were first stratified by outcome type, followed by time intervals (3–6 years 'medium-term' and ≥ 10 years 'long-term') and by type of prosthesis (overdenture vs. fixed full-arch). Complication outcomes were analyzed separately for technical complications, both overall and stratified by prosthesis type. In addition, complication analyses were further stratified by subtype (e.g., screw loosening, abutment complications, veneering fractures, framework fractures). Multiple complication subtypes could be reported from the same study. Implant survival was analyzed both at the patient- and implant-level, with overall survival rates estimated according to prosthesis type (i.e., overdenture, fixed full-arch, where data were available for meta-analysis), as well as stratified by time intervals. In addition, mean marginal bone loss (MBL) was analyzed by prosthesis type, and further stratified by follow-up period to assess time-dependent patterns of bone loss. An intraclass correlation coefficient (ICC) of 0.07 was assumed to account for within-patient clustering of implant complications and failures (Atieh et al. 2021). To evaluate the robustness of this assumption, sensitivity analyses were performed by repeating the models with intraclass correlation

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coefficient values of 0.05 and 0.30. Between-study heterogeneity was assessed using Tau-squared (τ (Apatzidou et al. 2017)) estimated using the DerSimonian-Laird method, representing the absolute variance between studies, and I^2, indicating the proportion of total variation attributable to heterogeneity. A p-value < 0.05 was considered statistically significant for heterogeneity. To assess potential small-study effects and publication bias, Egger's regression test was performed for the primary outcome (prosthesis loss) when at least 10 studies were available, and funnel plots were visually inspected.

2.7 | Assessing the Certainty of Evidence With GRADE

The GRADE (Grading of Recommendations Assessment, Development and Evaluation)-development framework is a structured and transparent method for evaluating evidence across different outcomes (Guyatt et al. 2008). Following GRADE guidelines, each outcome's certainty was determined based on five categories. Risk of bias was evaluated using the RoB 2 and ROBINS-I V2 tools. Inconsistency was analyzed by looking at variations in results across studies and subgroups. Indirectness was examined in terms of how closely the populations, interventions, and outcomes matched the review question. Imprecision was judged based on confidence interval widths and sample sizes. Publication bias was assessed with Egger's plots. The overall rating for each study outcome was categorized as high, moderate, low, or very low, depending on the degree and impact of issues identified in these domains.

3 | Results

A total of 3529 unique records were identified. 2931 were screened for title and abstract, which led to 57 articles for full-text screening (Appendix S2). Twenty articles met the selection criteria (reasons for exclusion are reported in Appendix S3) and were all included in the quantitative analysis.

3.1 | Study Characteristics

The main characteristics of the 20 studies included in this review are summarised in Table 1. The study designs comprised 13 RCTs (Crespi et al. 2012; Fischer et al. 2008; Jemt et al. 2002; Kortam et al. 2022; Onclin et al. 2023; Ortorp and Jemt 2006; Slot et al. 2016, 2019, 2022, 2023; Tallarico et al. 2016; Toia et al. 2025, 2021), 4 cohort studies (Ferrigno et al. 2002; Jemt and Stenport 2011; Rodriguez et al. 2000; Toljanic et al. 2016), and 3 controlled clinical trials (Ayna et al. 2021; Tealdo et al. 2014; Zou et al. 2013). A total of 14 studies were conducted only in a university/hospital setting, while 6 included private specialist practices (Jemt et al. 2002; Jemt and Stenport 2011; Ortorp and Jemt 2006; Tallarico et al. 2016; Toia et al. 2025, 2021). Overall, 913 patients completed a minimum of 3 years of follow-up. The median follow-up duration was 5 years, and the longest follow-up was 10 years (Slot et al. 2022, 2023). The mean patient age was 61.6 ± 3.6 years.

Regarding treatment modalities, 8 studies evaluated implant overdentures (Ferrigno et al. 2002; Onclin et al. 2023; Rodriguez et al. 2000; Slot et al. 2016, 2019, 2022, 2023; Zou et al. 2013), whereas 13 studies investigated one-piece fixed full-arch (Ayna et al. 2021; Crespi et al. 2012; Ferrigno et al. 2002; Fischer et al. 2008; Jemt et al. 2002; Jemt and Stenport 2011; Kortam et al. 2022; Ortorp and Jemt 2006; Tallarico et al. 2016; Tealdo et al. 2014; Toia et al. 2025, 2021; Toljanic et al. 2016). Periodontitis status was reported in 7 studies (Ayna et al. 2021; Crespi et al. 2012; Fischer et al. 2008; Tallarico et al. 2016; Tealdo et al. 2014; Toia et al. 2025, 2021), and all but two studies reported smoking status (Rodriguez et al. 2000; Toljanic et al. 2016).

3.2 | Intervention Characteristics

Details of the surgical interventions are summarised in Table 2. A total of 4414 standard endosseous implants were placed among patients who completed follow-up. One study did not report the number of implants placed (Rodriguez et al. 2000). The number of implants placed per arch ranged from 4 to 8. In cases where four implants were used to support a one-piece fixed full-arch reconstruction, the approach typically followed the All-on-4 concept (Ayna et al. 2021; Crespi et al. 2012; Kortam et al. 2022; Tallarico et al. 2016; Toia et al. 2025, 2021) with tilted distal implants.

Late implant placement was reported in 17 studies, while two studies included both immediate and late implant placement (Tallarico et al. 2016; Tealdo et al. 2014). One study did not report the timing of implant placement (Rodriguez et al. 2000). The most used implant systems were Nobel Biocare (6 studies), Straumann (5 studies), and Astra Tech (5 studies).

Table 3 describes details of the prosthetic interventions. The most frequently used loading protocol was conventional (13 studies), followed by immediate (5 studies) and early loading (3 studies). One study did not specify the loading protocol (Rodriguez et al. 2000). Implant overdentures were always associated with conventional loading. In contrast, one-piece fixed full-arch restorations were sometimes loaded immediately (Ayna et al. 2021; Crespi et al. 2012; Tallarico et al. 2016; Tealdo et al. 2014; Toljanic et al. 2016) or early (Fischer et al. 2008; Toia et al. 2025, 2021). Most one-piece fixed full-arch restorations were fabricated with PMMA on a metal framework. Exceptions included one study with PMMA on a PEEK framework (Kortam et al. 2022).

For implant overdenture retention, the majority of prostheses were designed with a Dolder or Hader bar (336 prostheses), followed by locator attachments (42 prostheses) and telescopic crowns (10 prostheses). All studies reported the use of cast metal frameworks.

3.3 | Primary Outcome

3.3.1 | Prosthesis Loss

The pooled analysis of prosthesis loss across 18 studies on implant-assisted maxillary restorations (Figure 1) yielded an overall event loss of 4.6% (95% CI: 1.2%–10.1%), with substantial heterogeneity ($I^2 = 88.9\%$). When stratified according to

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TABLE 1 | General characteristics of studies.

Author, year	Country	Study setting (No. of centres)	Study design	Mean age (range in years)	Last time point (years)	Treatment arm 1	Treatment arm 2	Implant system
Ayna et al. 2021	Germany	University (1)	Controlled Clinical Trial	61 (52–69)	6	Fixed full-arch	Fixed full-arch	Nobel Biocare AB
Crespi et al. 2012	Italy	Hospital (1)	RCT	55 (41–81)	3	Fixed full-arch	Fixed full-arch	Sweden-Martina
Ferrigno et al. 2002	Italy	University (6)	Cohort Study	59 (35–79)	6	Overdenture	Fixed full-arch	Straumann
Fischer et al. 2008	Sweden	Hospital (2)	RCT	64 (NR)	5	Fixed full-arch	Fixed full-arch	Straumann
Jemt et al. 2002	Sweden	Hospital and Private Practice (6)	RCT	60 (38–74)	5	Fixed full-arch	Fixed full-arch	Nobel Biocare AB
Jemt and Stenport 2011	Sweden	Private Practice (1)	Cohort Study	65 (38–92)	5	Fixed full-arch	Fixed full-arch	TiUnite Branemark System
Kortam et al. 2022	Egypt	University (1)	RCT	NR (55–64)	3	Fixed full-arch	Fixed full-arch	Dentaurum
Onclin et al. 2023	Netherlands	University (1)	RCT	60 (38–75)	5	Overdenture	Overdenture	Nobel Replace Select TC
Ortorp and Jemt 2006	Sweden	Private Practice (1)	RCT	67 (41–88)	5	Fixed full-arch	Fixed full-arch	Nobel Biocare AB
Rodriguez et al. 2000	United States	Hospital and University (32)	Cohort Study	NR (NR)	3	Overdenture	Overdenture	Core-Vent
Slot et al. 2016	Netherlands	University (1)	RCT	59 (39–80)	5	Overdenture	Overdenture	Astra Tech OsseoSpeed
Slot et al. 2019	Netherlands	University (1)	RCT	60 (34–77)	5	Overdenture	Overdenture	Straumann Standard SLA
Slot et al. 2023	Netherlands	University (1)	RCT	59 (39–80)	10	Overdenture	Overdenture	Astra Tech OsseoSpeed
Slot et al. 2022	Netherlands	University (1)	RCT	60 (34–74)	10	Overdenture	Overdenture	Straumann Standard SLA
Tallarico et al. 2016	Italy	Private Practice (1)	RCT	63 (42–87)	5	Fixed full-arch	Fixed full-arch	NobelSpeedy Groovy
Tealdo et al. 2014	Italy	University (1)	Controlled Clinical Trial	58 (NR)	6	Fixed full-arch	Fixed full-arch	NR

(Continues)

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TABLE 1 | (Continued)

Author, year	Country	Study setting (No. of centres)	Study design	Mean age (range in years)	Last time point (years)	Treatment arm 1	Treatment arm 2	Implant system
Toia et al. 2021	Italy	Private Practice (3)	RCT	67 (48–89)	3	Fixed full-arch	Fixed full-arch	Astra Tech OsseoSpeed
Toia et al. 2025	Italy	Private Practice (3)	RCT	67 (48–89)	5	Fixed full-arch	Fixed full-arch	Astra Tech OsseoSpeed
Toljanic et al. 2016	USA, Sweden	University (2)	Cohort Study	66 (47–83)	5	Fixed full-arch	Fixed full-arch	Astra Tech OsseoSpeed
Zou et al. 2013	China	University (1)	Controlled Clinical Trial	60 (57–79)	3	Overdenture	Overdenture	Straumann

follow-up duration (Appendix S4), studies with 3 to 6 years of follow-up (18 studies) yielded an overall event loss of 1.9% (95% CI: 0.8%–3.6%) and an overall event loss of 47.9% (95% CI: 34.5%–61.5%) for ≥ 10 years (2 studies). Sub-stratification of studies according to prosthesis type was also performed (Appendix S5): overdenture (6 studies) 1.8% prosthesis loss (95% CI: 0.2%–4.9%), and one-piece fixed full-arch (12 studies) 2.1% (95% CI: 0.6%–4.4%) between 3 to 6 years.

When stratified by loading protocol, prosthesis loss remained uncommon for one-piece fixed full-arch and overdenture restorations (Appendix S6). With immediate loading (4 studies), the pooled loss was 3.0% (95% CI 0.0%–12.1%). Under conventional loading (6 studies), the pooled loss was 1.7% (95% CI 0.4%–4.1%). For overdentures managed with conventional loading (5 studies), the pooled prosthesis loss was 2.5% (95% CI 0.3%–6.7%).

Egger's test did not indicate statistically significant small-study effects for the primary outcome ($z = 0.91$, $p = 0.361$). Visual inspection of the funnel plots did not consistently demonstrate convincing symmetry. In the overall prosthesis loss analysis, some dispersion of effect sizes is evident, with a tendency for smaller studies to report higher event proportions. This pattern may reflect true clinical variability, differences in study design, or selective reporting, rather than publication bias alone. In the subgroup analyses (fixed full-arch only and 3–6 years follow-up), the limited number of studies further restricts the interpretability of funnel plot symmetry, making visual assessment inherently subjective and unstable (Appendix S7).

3.4 | Secondary Outcomes

3.4.1 | Complication-Free Prosthesis Survival and Complication-Free Implant Survival Rates

The pooled analysis of complication-free prosthetic survival rates across 12 studies evaluating various implant-assisted maxillary restorations (Figure 2) showed an overall survival rate of 61.9% (95% CI: 48.4%–74.5%). The I^2 was 89.5%, indicating considerable heterogeneity which supported the use of a random-effects model. Sub-group analysis based on prosthesis type was also performed (Appendix S8): overdenture (2 studies) 60.2% survival (95% CI: 17.9%–94.8%), and one-piece fixed full-arch (10 studies) 62.2% survival (95% CI: 47.3%–76.0%).

The pooled patient-level complication-free implant survival rates across 5 studies was 46.5% (95% CI 21.1%–72.9%), with substantial heterogeneity ($I^2 = 93.4\%$) (Figure 3). By prosthesis type, complication-free implant survival was 51.6% for overdentures (95% CI 43.7%–59.6%; 3 studies) and 64.8% for fixed full-arch reconstructions (95% CI 12.4%–99.7%; 2 studies) (Appendix S9). When stratified by follow-up time, studies with 3–6 years of follow-up yielded a pooled survival of 60.5% (95% CI 26.7%–89.4%), and studies with ≥ 10 years were 26.1% (95% CI 17.2%–36%) (Appendix 10).

In analyses using implant-level counts (three studies), the pooled complication-free implant survival, adjusting for within-patient clustering, was 72.2% (95% CI 8.9%–100.0%) (Appendix S11).

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TABLE 2 | Description of surgical interventions.

Author, year	No. of patients completing follow-up	No. of implants placed (after dropouts)	Standard endosseous implants	No. of implants per arch	No. of tilted implants	Implant diameter (<3.75 mm)	Implant diameter (≥3.75 mm)	Timing of implant placement
Ayna et al. 2021	34	136	136	4	2	0	136	Late (136)
Crespi et al. 2012	24	96	96	4	2	0	96	Late (96)
Ferrigno et al. 2002	34	196	196	8 for fixed full-arch, 6 for milled bar overdentures, 4 for dolder bar overdentures	NR	NR	NR	Late (200)
Fischer et al. 2008	23	136	136	5 or 6	0	136	0	Late (136)
Jemt et al. 2002	57	349	349	At least 5	NR	NR	NR	Late (349)
Jemt and Stenport 2011	84	652	652	6	NR	NR	NR	Late (652)
Kortam et al. 2022	30	120	120	4	2	NR	NR	Late (120)
Onclin et al. 2023	43	172	172	4	NR	0	172	Late (172)
Ortorp and Jemt 2006	40	283	283	4 to 8	NR	NR	NR	Late (153)
Rodriguez et al. 2000	92	NR	Yes	5 or 6	NR	NR	NR	NR
Slot et al. 2016	46	228	228	4 or 6	NR	0	224	Late (228)
Slot et al. 2019	60	302	302	4 or 6	NR	0	302	Late (302)
Slot et al. 2023	36	178	178	4 or 6	NR	0	178	Late (178)
Slot et al. 2022	46	224	224	4 or 6	NR	0	224	Late (224)
Tallarico et al. 2016	40	200	200	4 or 6	2 (for all-on-4)	4	196	Immediate 32, late (168)
Tealdo et al. 2014	47	249	249	4 to 9	NR	0	260	Immediate 163, late 97
Toia et al. 2021	53	262	262	4 or 6	Varied per arch	80	182	Late (262)
Toia et al. 2025	47	233	233	4 or 6	Varied per arch	73	160	Late (233)
Toljanic et al. 2016	47	274	274	6	NR	118	162	Late (280)
Zou et al. 2013	30	120	120	4	NR	0	120	Late (120)

Abbreviation: NR, not reported.

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TABLE 3 | Description of prosthetic interventions.

Author, year	Final no. of prostheses	Loading protocol (Gallucci et al. 2009)	Fixed one-piece full-arch	Fixed segmented full-arch	Type of veneering (no.)	Overdenture and type of retention, denture framework
Ayna et al. 2021	34	Immediate	17 PFM, 17 PFM on metal framework	N/A	Porcelain (17) or resin (17)	N/A
Crespi et al. 2012	24	Immediate	24 PMMA on metal framework	N/A	Resin (24)	N/A
Ferrigno et al. 2002	34	Conventional	16 PMMA on metal framework	N/A	Resin (16)	18 bar, cast metal framework
Fischer et al. 2008	23	Early and conventional	23 PPMA on metal framework	N/A	Resin (23)	N/A
Jemt et al. 2002	57	Conventional	57 PMMA on metal framework	N/A	Resin (57)	N/A
Jemt and Stenport 2011	84	Conventional	84 PMMA on metal framework	N/A	Resin (84)	N/A
Kortam et al. 2022	30	Conventional	15 PFM, 15 PMMA on PEEK framework	N/A	Porcelain (15), resin (15)	N/A
Onclin et al. 2023	43	Conventional	N/A	N/A	N/A	20 bar and 23 locators, cast metal framework
Ortorp and Jemt 2006	40	Conventional	40 PMMA on metal framework	N/A	Resin (40)	N/A
Rodriguez et al. 2000	92	NR	N/A	N/A	N/A	83 bar and 9 locators, cast metal framework
Slot et al. 2016	46	Conventional	N/A	N/A	N/A	46 bar, cast metal framework
Slot et al. 2019	60	Conventional	N/A	N/A	N/A	60 bar, cast metal framework
Slot et al. 2023	36	Conventional	N/A	N/A	N/A	36 bar, cast metal framework
Slot et al. 2022	46	Conventional	N/A	N/A	N/A	46 bar, cast metal framework
Tallarico et al. 2016	40	Immediate	40 PMMA on metal framework	N/A	Resin (40)	N/A

(Continues)

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TABLE 3 | (Continued)

Author, year	Final no. of prostheses	Loading protocol (Gallucci et al. 2009)	Fixed one-piece full-arch	Fixed segmented full-arch	Type of veneering (no.)	Overdenture and type of retention, denture framework
Tealdo et al. 2014	47	Immediate and conventional	47 PMMA on metal framework	N/A	Resin (47)	N/A
Toia et al. 2021	53	Early	53 PMMA on metal framework	N/A	Resin (53)	N/A
Toia et al. 2025	47	Early	47 PMMA on metal framework	N/A	Resin (47)	N/A
Toljanic et al. 2016	47	Immediate	47 PMMA on metal framework	N/A	Resin (47)	N/A
Zou et al. 2013	30	Conventional	N/A	N/A	N/A	10 bar, 10 telescopic crowns, 10 locators, cast metal framework

Abbreviations: N/A, not applicable; NR, not reported; PEEK, polyether ether ketone; bar includes Dolder or Hader; PFM, porcelain-fused to metal; PMMA, polymethyl methyl acrylate.

3.4.2 | Technical Complications and Implant Loss

The overall technical complications rate (Figure 4) based on 15 studies was 62.9% (95% CI: 42.4%–81.2%). When stratified by type of reconstruction (Appendix S12), the technical complication rate was 51.4% (95% CI: 29.4%–73.2%) for overdentures (4 studies) and 56.7% (95% CI: 35.4%–76.8%) for fixed full-arch prostheses (11 studies).

For one-piece fixed full-arch restorations (Appendices S13 and S14), veneering acrylic fracture emerged as the most frequent technical complication, affecting approximately 41.4% of prostheses (95% CI: 23.1%–61.0%). In contrast, veneering porcelain fracture in PFM restorations occurred at a much lower rate of 2.8% (95% CI: 0.5%–6.7%). Screw- and abutment-related issues were observed in 7.0% (95% CI: 2.1%–14.5%) and 2.1% (95% CI: 0.8%–3.9%) of cases, respectively. Framework fractures were uncommon across all materials, ranging from 0.7% for titanium cast alloys (95% CI: 0.0%–3.9%) to 3.8% for laser-welded titanium (95% CI: 0.0%–19.5%).

For implant overdentures (Appendices S15 and S16), the most frequent technical events were related to the denture base and occlusal surface, particularly repairs or relines of the acrylic or prosthetic teeth, reported in 91.2% of cases (95% CI: 56.6%–100%). The need for overdenture remakes was reported at 21.3% (95% CI: 2.3%–52.4%), while occlusal readjustments were required in 11.9% (95% CI: 6.9%–18.1%) cases. Complications involving the attachment system such as bar fractures (10%; 95% CI: 0.3%–30.7%) and screw or abutment-related issues (1.8%–3.6%) were less common.

Adjusting for within-patient clustering of implant failures, the pooled implant-level loss for one-piece fixed full-arch restorations was 5.5% (95% CI 2.9%–8.8%). For overdentures, the pooled loss was 5.6% (95% CI 2.7%–9.4%) (Appendix S17). The pooled estimates were broadly stable across plausible ICC values; higher ICCs (i.e., stronger clustering) increased the pooled loss rates modestly for both fixed and overdenture reconstructions (Appendix S18).

3.4.3 | Marginal Bone Loss

Mean marginal bone loss at 3–6 years for fixed full-arch prostheses was 0.78 mm (95% CI: 0.34–1.21) based on 9 studies and 0.78 mm (95% CI: 0.55–1.02) for overdentures from 4 studies (Appendix S19). Marginal bone loss at ≥ 10 years was reported by two studies for overdentures and was stable at 0.64 mm (95% CI: 0.43–0.85).

3.4.4 | PROMs

PROMs were reported in nine studies (Ayna et al. 2021; Onclin et al. 2023; Slot et al. 2016, 2019, 2022, 2023; Toia et al. 2025, 2021; Zou et al. 2013). Several studies employed visual analogue scales (VAS) or numerical rating scales to assess patient satisfaction using questionnaires (Onclin et al. 2023; Slot et al. 2016, 2019, 2022, 2023; Toia et al. 2025, 2021; Zou et al. 2013). Oral Health Impact Profile (OHIP) was used to evaluate changes in

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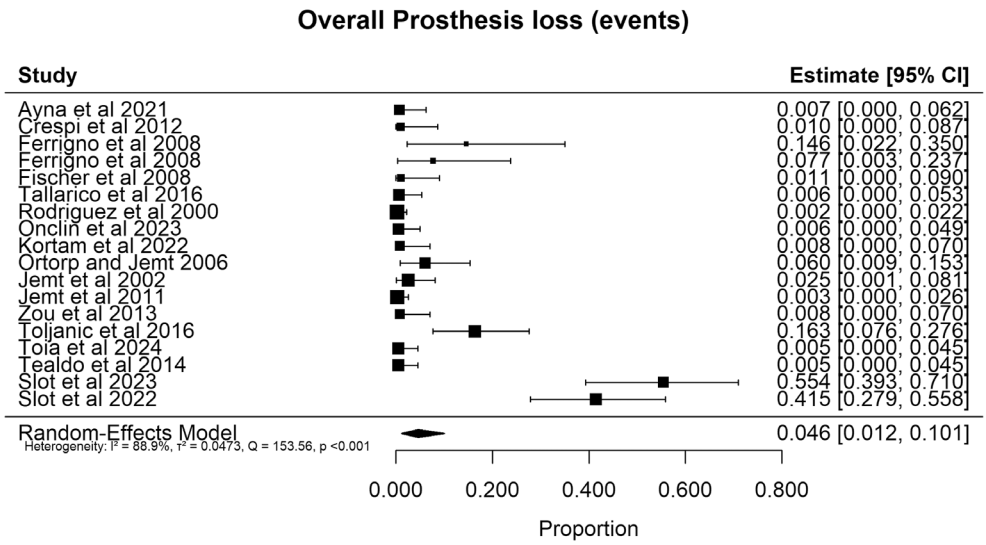

FIGURE 1 | Overall prosthesis loss (events) of implant-assisted maxillary restorations.

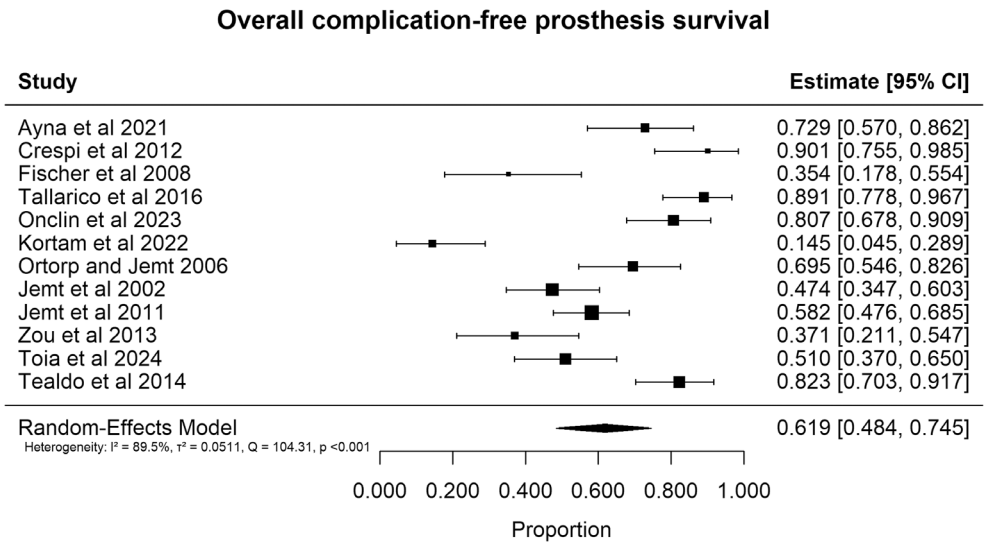

FIGURE 2 | Overall complication-free prosthesis survival of implant-assisted maxillary restorations.

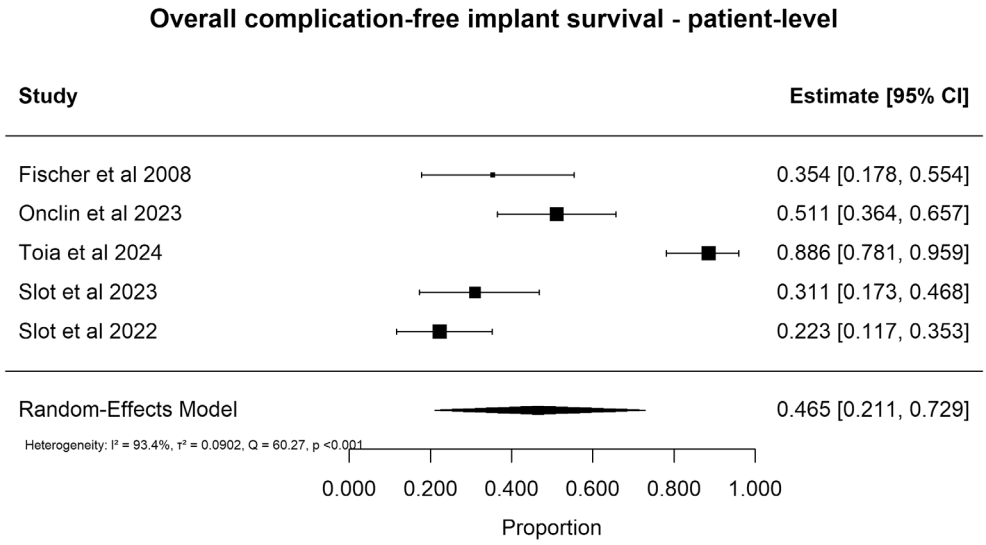

FIGURE 3 | Overall complication-free implant survival of implant-assisted maxillary restorations.

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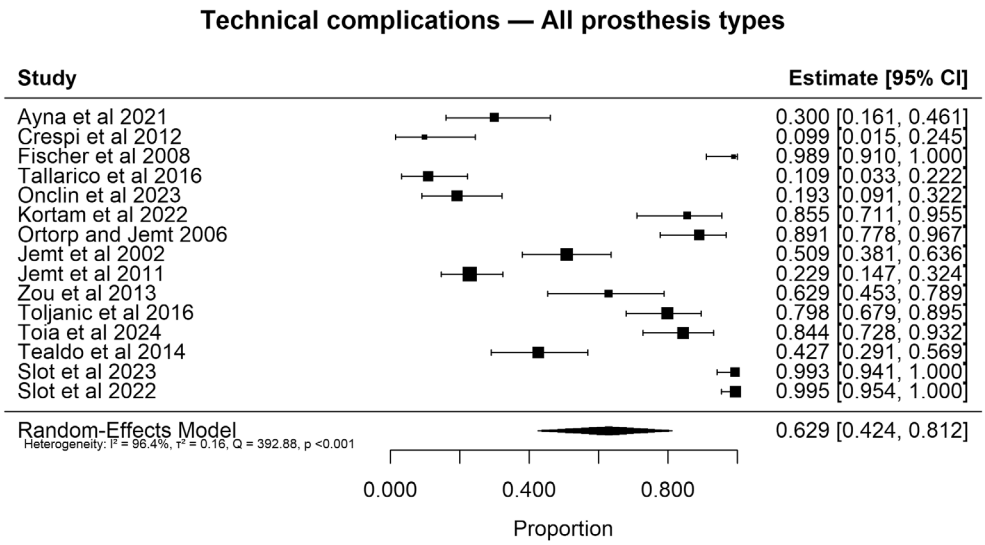

FIGURE 4 | Overall technical complications—All prosthesis types.

quality of life, with one study using OHIP-14 (Ayna et al. 2021) and another using OHIP-49 (Onclin et al. 2023). Although improvements in quality of life were consistently observed following treatment, the heterogeneity in assessment tools and reporting methods limited the comparability of PROMs as an outcome across studies.

3.5 | Risk of Bias Assessment

When assessing RCTs (Appendix S20), most studies presented with some concerns due to bias because of deviations from the intended intervention (Kortam et al. 2022; Onclin et al. 2023; Slot et al. 2016, 2019, 2022, 2023; Tallarico et al. 2016; Toia et al. 2025, 2021) or bias arising from the randomisation process (Crespi et al. 2012; Fischer et al. 2008; Jemt et al. 2002; Kortam et al. 2022; Onclin et al. 2023). Only one study (Ortorp and Jemt 2006) was at low risk of bias, whereas the other RCTs suffered from unclear information on allocation concealment or blinding or ambiguous reporting of trial conduct, which raised uncertainty about possible deviations from the intended intervention protocols.

Of the seven studies assessed with ROBINS-I V2 (Appendix S21), four were at low risk of bias (Jemt and Stenport 2011; Rodriguez et al. 2000; Tealdo et al. 2014; Zou et al. 2013), one study was at moderate risk (Toljanic et al. 2016), and two were considered at critical risk of bias (Ayna et al. 2021; Ferrigno et al. 2002).

3.6 | Grading the Evidence

The quality rating was assessed to be low for prosthesis loss, complication-free prosthesis survival, and technical complications; and very low for complication-free implant survival and implant loss (Table 4). Substantial inconsistency was reflected by high heterogeneity across outcomes. Indirectness was moderate due to differences in study characteristics and intransitivity. Specifically, several cohort studies effectively functioned as single-arm analyses when data were restricted to fixed or removable prostheses, or when studies primarily designed for material comparisons were used to extract outcome data.

4 | Discussion

The findings of this study indicate that implant-assisted maxillary restorations in the fully edentulous maxilla are associated with a low rate of prosthesis loss. However, complication-free prosthesis survival was considerably lower, with pooled estimates indicating that fewer than two-thirds of prostheses remained complication-free over time. This highlights that while catastrophic failures are uncommon, complications over time remain frequent and clinically relevant, affecting both fixed and removable prostheses to a similar extent.

Similarly, complication-free implant survival was modest at the patient level, with only about half of patients remaining free of implant-related complications over the follow-up period. This indicates that complications affecting at least one implant within a patient's prosthesis are common over time. In contrast, implant-level analyses yielded higher survival estimates, with approximately 72% of implants remaining complication-free after adjusting for within-patient clustering. This discrepancy reflects the fact that patients often have multiple implants supporting their prosthesis, meaning that the occurrence of complications at a single implant can categorize the entire patient as having experienced an event, thereby lowering patient-level estimates.

Implant loss was low across restoration types. Accounting for within-patient clustering (effective sample size) yielded conservative pooled estimates across plausible ICC values. The low prosthesis and implant loss rates observed in this review are consistent with findings from previous studies, which similarly reported favorable long-term outcomes for both fixed implant-supported restorations (Del Fabbro et al. 2022; Ramanauskaite et al. 2022) and implant-retained overdentures (Kappel et al. 2021; Kern et al. 2016; Raghoebar et al. 2014).

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TABLE 4 | Certainty of evidence using adapted GRADE principles.

Outcome	No. of studies	Study type	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Certainty
Prosthesis loss	20	Prospective clinical study, randomised controlled trials	Moderate	Serious (high heterogeneity)	Moderate	Low	Low	●●○○ Low
Complication-free prosthesis survival	12	Prospective clinical study, randomised controlled trials	Moderate	Serious (high heterogeneity)	Moderate	Moderate	Low	●●○○ Low
Complication-free implant survival	5	Prospective clinical study, randomised controlled trials	Moderate	Serious (high heterogeneity)	Moderate	Moderate	Low	●○○○ Very low
Technical complications	14	Prospective clinical study, randomised controlled trials	Moderate	Serious (high heterogeneity)	Moderate	Moderate	Low	●●○○ Low
Implant loss	17	Prospective clinical study, randomised controlled trials	Moderate	Serious (high heterogeneity)	Moderate	Moderate	Unclear	●○○○ Very low

While technical complications continue to represent the main long-term challenge in full-arch rehabilitation, they seldom lead to catastrophic failure. In fixed one-piece prostheses, problems concern mainly veneering systems (especially acrylic), whereas overdentures require ongoing maintenance of denture acrylic/teeth and periodic occlusal adjustments. Framework and component fractures are uncommon but clinically relevant when they occur. This pattern mirrors prior reviews reporting screw-related issues and veneering fractures as the dominant drivers of maintenance despite generally excellent survival (Del Fabbro et al. 2022; Ramanauskaite et al. 2022).

Mean MBL for both fixed full-arch prostheses and overdentures remained below 0.8 mm for all analyzable timepoints, which is under the accepted threshold for peri-implantitis (Ng et al. 2024; Renvert et al. 2018). However, these findings should be interpreted with caution due to wide confidence intervals and the possibility of individual implant-level complications not captured in the aggregated estimates.

Most of the included studies employed conventional loading protocols, particularly for implant-supported overdentures, where all studies followed this approach. In contrast, this review found that a substantial proportion of fixed full-arch prostheses utilized immediate loading protocols (5 out of 13 studies). This study is in agreement with other studies and reinforces that immediate loading consistently achieves high survival and success rates, offering important clinical advantages such as reduced treatment time and improved patient satisfaction (Daudt Polido et al. 2018). However, the success of immediate loading is highly case-dependent, requiring careful patient selection due to poorer maxillary bone quality and challenging anatomical presentations. It has been recommended that immediate loading protocols should be limited to implants with a minimal insertion torque of 30 Ncm, as well as the use of surface-modified implants (Papaspyridakos et al. 2014). While there is substantial evidence for conventional loading of both upper and lower arches, and immediate loading for the mandible, more well-designed RCTs are needed to establish guidelines for immediate loading of the maxilla (Abdunabi et al. 2019; Gallucci et al. 2009). Although the point estimate for immediate loading was slightly higher than for conventional loading in one-piece fixed full-arch restorations, the confidence intervals were wide and overlapping, and the number of studies was limited, resulting in imprecise estimates. Caution is therefore warranted in interpreting these findings, and they should not be taken as evidence of a superiority of one protocol over the other. Furthermore, while immediate loading carries a theoretical risk of increased technical complications due to potential lack of passive fit, the available data were insufficient to evaluate this effect. Larger, well-reported comparative studies are required to clarify these risks and inform clinical decision-making.

When rehabilitating the edentulous maxilla, most of the evidence in this review supported at least four implants for either an implant-assisted overdenture or a fixed full-arch one-piece prosthesis when used with the all-on-four concept, and six implants for a full-arch one-piece prosthesis without tilted implants. In this review, implant loss did not appear to be correlated with prosthesis type. These observations are consistent with the existing literature (Daudt Polido et al. 2018; Messias et al. 2021). However, evidence

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directly comparing different implant numbers and configurations is limited. Most studies report implant numbers without comparative analysis (Daudt Polido et al. 2018; de Luna Gomes et al. 2019), and subgroup comparisons are methodologically limited by the lack of adjustment for confounders and appropriate propensity matching (Brignardello-Petersen 2019).

A key strength of this systematic review is its comprehensive evaluation of prosthetic restorations used to rehabilitate the edentulous maxilla with reference to the recently published lifespan domains outcomes from the ID-COSM (Tonetti et al. 2023). In addition, intervention-related complications were systematically evaluated across fixed and removable treatment modalities, providing an estimate on the overall impact on prosthesis maintenance following restoration. Another strength is the inclusion of studies with ≥3 years duration and detailed subgroup analysis including accounting for within-patient clustering. However, these comparisons should be interpreted with caution, as not all included studies reported longitudinal data across all time points, limiting the ability to evaluate changes within the same study cohorts.

There are some limitations to this review. Even among higher-level evidence studies such as randomized controlled trials, limitations exist due to highly selected patient populations and controlled conditions that do not represent routine clinical practice. Amongst the included studies, considerable heterogeneity was observed across studies in terms of implant systems, loading protocols, surgical techniques, and prosthetic designs, limiting the ability to draw definitive conclusions. Furthermore, the quality of evidence for each outcome was primarily downgraded due to inconsistency, as indicated by heterogeneity in study results. However, the GRADE approach also favors RCTs and penalizes observational studies regardless of methodological rigor, sample size, or duration. Notably, an overreliance on RCTs can create evidence gaps in surgical disciplines and undervalue observational studies (Fernainy et al. 2024), which often represent the most practical and relevant evidence in fields where RCTs are not always feasible (Price et al. 2014). An additional limitation concerns the assessment of small-study effects. Funnel plot–based methods, including Egger's regression, are underpowered when few studies are available and may be influenced by clinical and methodological heterogeneity. This restricts the interpretability of funnel plots, and the absence of statistically significant asymmetry should not be interpreted as definitive evidence that publication bias or small-study effects are absent.

Prosthesis survival and success are often under-reported across clinical studies, largely due to the absence of standardized criteria for defining these outcomes. Accordingly, there is need for standardized assessment and reporting of outcomes and outcome measures in clinical research (Messias et al. 2023; Tonetti et al. 2023). Furthermore, not all complications have the same clinical relevance, and there is difficulty distinguishing between a technical complication and a maintenance service. ID-COSM recommends classifying complications according to their severity, distinguishing between minor events—those that can be resolved within a single appointment—and major complications, which require multiple visits for management (Tonetti et al. 2023). For instance, the loss of sealing material from a screw access hole is considered a minor complication, whereas fractures of veneering materials typically necessitate more extensive repairs. Nevertheless, even with the implementation of standardized outcome sets, clinical decision-making may still vary due to differences in operator skill levels and available resources. Notably, higher rates of veneer replacement have been reported in partially implant-supported fixed dental prostheses compared with complete full-arch prostheses, suggesting that clinicians may apply a higher threshold for intervention in full-arch cases because of the greater time, cost, and logistical complexity involved (Pieralli et al. 2018).

The current ID-COSM framework distinguishes between minor and major complications solely by whether resolution requires one or more appointments. In practice, this threshold is practice-dependent, as similar complications may be resolved in a single visit in some settings but require multiple appointments in others. In the present review, the retrospective study designs and heterogeneity of reporting precluded a reliable distinction between minor and major complications, particularly as most studies did not specify this level of detail. Similarly, underreporting of peri-implant mucositis and peri-implantitis also could affect estimates of "complication-free implant survival". Given the retrospective nature of our review and the limited granularity of reporting in the included studies, we restricted our analysis for this parameter to studies reporting both peri-implant mucositis and peri-implantitis. Furthermore, as the ID-COSM was only introduced in 2023 and intended primarily for prospective use, studies published between 2000 and 2023 could not be expected to comply with this framework.

The influence of prosthetic materials, biomechanical considerations such as distal cantilevers, thickness of framework and veneering materials, and patient-related factors (e.g., bruxism) could not be adequately evaluated. A significant proportion of fixed one-piece full-arch prostheses in the included studies utilized PMMA veneered on metal frameworks, while most implant-supported overdentures relied on bar-retained designs. With greater utilization of CAD/CAM materials and digital workflows, coupled with increased uptake of alternatives to expensive traditionally used noble metals, there is a need to clarify indications and validate protocols (Delucchi et al. 2021). Advances in technology may reduce the number of sources of errors while improving the material flaws associated with traditional workflows of casting metals. Comparative evaluation of other newer materials, such as monolithic zirconia, PEEK frameworks, and locator attachment systems are needed.

Future research should also compare success rates based on differing aetiologies of tooth loss, as patients with stage IV periodontitis may present with more severe bone loss and altered peri-implant microbiome profiles compared to those with edentulism resulting from caries, trauma, or endodontic failure (Apatzidou et al. 2017). Although implant-assisted rehabilitations may improve masticatory function and prosthesis stability, evidence supporting their broader impact on overall quality of life, such as nutritional status and cognitive function, remains limited (Gennai et al. 2022). Furthermore, bite force and masticatory efficiency are not determined solely by prosthetic interventions but are also influenced by systemic factors such as frailty and overall muscle strength, which are relevant in older adults (Müller et al. 2013). Further research is needed to determine

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whether these implant-assisted rehabilitations can meaningfully improve these broader health outcomes in elderly populations who would benefit the most from such interventions.

5 | Conclusions

Implant-assisted maxillary restorations demonstrated low levels of prosthesis and implant loss. However, complication-free survival for both prostheses and implants was only moderate, underscoring the importance of ongoing maintenance and patient education during treatment planning. Future studies should distinguish between minor and major complications and adopt standardized reporting for both prosthetic success and patient-reported outcomes. Comparative studies are also needed to clarify the relative efficacy of different reconstruction modalities and their broader impact on oral health, including masticatory function.

Author Contributions

Ethan Ng: conceptualization, methodology, writing – original draft, writing – review and editing, project administration, validation, investigation, visualization. **John Rong Hao Tay:** methodology, writing – original draft, writing – review and editing, visualization, validation. **Maria Rahmat:** writing – review and editing, validation, investigation. **Luis Mezzomo:** writing – review and editing, validation, investigation. **Gil Alcoforado:** validation, supervision. **Nikos Donos:** conceptualization, methodology, writing – review and editing, supervision, validation, project administration.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that supports the findings of this study have been included in the manuscript and the appendices.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** clr70116-sup-0001-DataS1.zip.

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