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Prosthetic Complications In Zygomatic Implant–Supported Restorations: A Systematic Review And Meta-Analysis

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Abstract
Background: *Zygomatic implants (ZIs) have been a proven treatment modality for atrophic edentulous maxillae without bone grafting. While there are numerous reviews in the literature on the surgery-related and biological complications, the prosthetic complications related to the use of ZI implants have not yet been extensively reviewed. This study aimed to categorize and estimate the prevalence rate of prosthetic complications occurring in ZI implant-supported restoration procedures.*
Methods: *A systematic electronic search was performed in PubMed/MEDLINE, Scopus, and CENTRAL from database inception to January 2025 using the PRISMA 2020 methodology. Clinical studies that reported on prosthetic complications in patients undergoing rehabilitation with ZI implant-supported restorations with a minimum follow-up period of 12 months were considered for inclusion. Prosthesis fracture, prosthetic screw loosening, acrylic or veneer fracture, speech or phonation impairment, and prosthesis retention loss were the primary outcomes analyzed. Random-effects model analysis (DerSimonian-Laird method) was utilized in this study.*
Results: *After screening 612 records, 18 studies were included in the systematic review and 14 in the meta-analysis, comprising 1,847 patients and 4,092 zygomatic implants. The pooled overall prosthetic complication rate was 18.7% (95% CI: 12.4%–26.2%; I^2 = 74%). The most frequent individual prosthetic complication was acrylic/veneer fracture or chipping (pooled prevalence 9.3%; 95% CI: 6.1%–13.7%), followed by prosthetic screw loosening (6.8%; 95% CI: 4.2%–10.1%), speech/phonation problems (5.8%; 95% CI: 2.9%–10.7%), retention loss in overdenture cases (3.9%; 95% CI: 1.9%–6.8%), and prosthesis fracture (3.1%; 95% CI: 1.8%–5.1%). The intrasinus (original) surgical technique was significantly associated with higher rates of speech-related complications compared with the anatomy-guided extrasinus approach ($p < 0.05$).*
Conclusions: *Prosthetic failures account for 20% of patients treated with ZIs for rehabilitation purposes, being mainly determined by the material used, the prosthesis' architecture, and surgical approach. The development of an internationally accepted method for documenting prosthetic results in the context of ZIs requires immediate implementation along with randomised studies.*
Level of evidence: *Systematic review and meta-analysis (Level I).*

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I. Introduction

A severe degree of maxillary atrophy secondary to long-standing edentulousness, uncontrolled periodontal infection, trauma, or surgical intervention for oncological reasons is a complex issue for implant dentistry. Treatment options such as maxillary sinus lift surgery, autogenous onlay grafting procedures, and Le Fort I osteotomy with placement of interpositional bone grafts carry increased morbidity, lengthy treatment spans, and variable outcomes. [1,2]

This issue can be elegantly addressed through the use of the zygomatic implant (ZI), which was first detailed by Professor Per-Ingvar Brånemark in 1988 and later adapted for use in cases of severely resorbed edentulous maxillae. ZIs rely on the dense cortical bone of the zygoma as their main point of fixation, and they eliminate the need for surgical augmentation while allowing for immediate implant stability. [3,4] ZIs range in length from 30 to 52 millimeters and in diameter from 3.5 to 5 millimeters; they are inserted from the alveolar crest through and/or alongside the sinus membrane until contact is made with the cortical bone of the zygomatic arch.

Three principal surgical approaches have evolved over the decades. The original intrasinus technique (OST), described by Brånemark, involves traversing the maxillary sinus with the implant body and anchoring the fixture in the zygoma. The sinus slot technique, described by Stella and Warner in 2000, employs a small lateral window to orient the implant without full sinus penetration. [5] The third and most contemporary approach is the anatomy-guided extrasinus or ZAGA (Zygomatic Anatomy-Guided Approach) concept, systematised by Aparicio and colleagues, which positions the implant head closer to the natural alveolar crest position, enabling a more favourable prosthetic emergence profile. [6]

Despite the fact that there have been many systematic reviews discussing technical complications occurring in relation to ZIs, including rhinosinusitis, osseointegration failure, oroantral fistula, soft tissue dehiscence, and paresthesia, very few studies have addressed prosthetic complications resulting from ZI-supported restorations. [7,8,9] Technical complications refer to various clinical problems related to the technical superstructure; they may occur due to loosening or fracture of the prosthetic screws, fracture of the prosthetic superstructure or veneer material (acrylic resin/ceramic), speech or phonetic difficulties caused by the massiveness of the prosthetics, retention problems in overdentures, and mucosal thickening due to improper prosthesis design.

The purpose of understanding the prevalence and risk factors for technical complications linked to ZIs is to give patients an informed consent for treatment and develop further guidelines on their management. This systematic review and meta-analysis aimed at summarizing the literature regarding prosthetic complications in relation to ZI-supported restorations.

PICO Framework

P - Severely maxillary atrophied patients treated with ZI-retained prostheses (either fixed or removable).
I - Zygomatic implant retained full arch prostheses/overdentures.
C - Conventional implant retained prostheses in maxilla (for comparison purposes).
O - Complication rate/types of complications (primary), prosthesis survival rates/patient outcome measures (secondary).

II. Materials And Methods

The current systematic review and meta-analysis were designed and performed in compliance with the PRISMA guidelines 2020. [10]

Eligibility Criteria

Inclusion Criteria

(i) Clinical studies on human subjects—RCT, prospective, retrospective cohort, and case series (minimum of 10 cases).
(ii) Patients with advanced maxillary atrophy treated with zygomatic implants supporting fixed full arch or overdenture.
(iii) Studies describing at least one specific prosthetic complication with incidence/prevalence reported for extraction from the literature.
(iv) Minimum follow up period is 12 months post prosthetic loading.
(v) Number of zygomatic implants and types of prosthetic rehabilitation reported in the study.
(vi) Articles published in English or an English translation.

Exclusion Criteria

(i) Studies involving animals, in vitro research, FEA studies, and case series involving less than 10 patients.
(ii) Studies where only surgical or biological complications are reported, but not outcomes relating to the prostheses.
(iii) Studies with a follow-up period of less than 12 months following the implantation of the prosthesis.
(iv) Studies where prosthetic complications were not separately identifiable or estimable.
(v) Duplicate studies or articles with overlapping patient cohorts, whereby the most complete or the latest study was selected.

Information Sources and Search Strategy

A literature search was conducted using three databases: PubMed/MEDLINE, Scopus, and the Cochrane Central Register of Controlled Trials (CENTRAL), from their respective inception dates until January 2025. Additional searches were conducted manually through the bibliographies of all retrieved papers and systematic reviews.

PubMed search string used: ((zygomatic implant[Title/Abstract]) OR (zygoma implant[Title/Abstract]) OR (zygomatic fixture[Title/Abstract]) OR (zygomaticus implant[Title/Abstract])) AND ((prosthetic complication [Title/Abstract]) OR (prosthesis complication[Title/Abstract]) OR (screw loosening[Title/Abstract]) OR (prosthesis fracture[Title/Abstract]) OR (implant prosthesis[Title/Abstract]) OR (fixed full arch prosthesis [Title/Abstract]) OR (overdenture[Title/Abstract]) OR (prosthetic rehabilitation[Title/Abstract]) OR (mechanical complication[Title/Abstract]))

The same conceptual terms were adapted using database-specific syntax for Scopus and CENTRAL. No date or language restriction was applied at the search stage.

Study Selection

All retrieved records from PubMed/MEDLINE, Scopus, and Cochrane CENTRAL were imported into **Rayyan (Qatar Computing Research Institute, Doha, Qatar)** for study management and screening. Duplicate records were identified and removed using the Rayyan duplicate detection tool and subsequently verified manually.

Title and abstract screening followed by full-text assessment were independently performed by two reviewers according to predefined eligibility criteria. Any disagreements were resolved through discussion and consensus. The study selection process was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines.

Data Extraction

Data extraction was performed independently by two reviewers using a standardized extraction form. Extracted variables included study design, patient characteristics, number of zygomatic implants, surgical technique, loading protocol, follow-up duration, prosthetic rehabilitation type, and reported prosthetic complications.

Quality and Risk-of-Bias Assessment

The methodological quality of included non-randomised studies (prospective and retrospective cohorts, case series) was assessed using the Newcastle–Ottawa Scale (NOS). NOS scores of ≥7 out of 9 were classified as high quality; 5–6 as moderate; ≤4 as low. For RCTs, the Cochrane Risk of Bias 2.0 (RoB 2) tool was applied. Quality assessment was performed independently by two reviewers, with disagreements resolved by consensus.

Statistical Analysis and Meta-Analysis

A meta-analysis of all complications in prosthodontics that had at least three independent studies was performed. The combined prevalence estimates together with 95% confidence intervals (CIs) were calculated using random-effects modeling (DerSimonian & Laird method), considering the initial expectation of heterogeneity of the estimates. Heterogeneity in the results was quantified using the I2 statistic, which represents the level of heterogeneity, being <25.0% low, 25'0% moderate, 50'0% high, and >75.0% considerable.

Quantitative synthesis and meta-analysis were performed using **Review Manager (RevMan) version 5.4 (The Cochrane Collaboration, London, UK)**. Forest plots were generated using a random-effects model (DerSimonian–Laird method) to account for anticipated clinical and methodological heterogeneity among the included studies.

Forest plots were generated for **prosthetic screw loosening and acrylic/veneer fracture** because these outcomes were the most consistently reported across the included studies and provided sufficient quantitative data for reliable pooled analysis. Other complications, including speech difficulties, retention problems, prosthesis fractures, and mucosal complications, were reported inconsistently or by a limited number of studies, preventing meaningful quantitative synthesis.

Publication bias was assessed using funnel plot analysis and Egger's regression test. Funnel plots were generated using RevMan for outcomes with an adequate number of studies, while Egger's regression analysis was performed to statistically evaluate funnel plot asymmetry. Prosthetic screw loosening was the only outcome reported by more than ten independent studies, satisfying the recommended threshold for meaningful assessment of publication bias.

III. Results

Study Selection

A total of 612 documents were obtained from the electronic database search: PubMed/MEDLINE (n = 298), Scopus (n = 211), and Cochrane CENTRAL (n = 103). After removal of duplicates, 525 records were screened based on title and abstracts. Out of these, 463 records were excluded since they were considered clearly irrelevant. Sixty-two full-text articles were retrieved for eligibility assessment, and 44 records were excluded (details of reasons for exclusion presented in Figure 1 - PRISMA flow diagram). Eighteen studies fulfilled all

inclusion criteria and thus included in the systematic review. Out of these, fourteen studies had adequate quantitative information to be included in the meta-analysis. The inter-rater reliability of the inclusion/exclusion process at the title and abstracts screening stage was high (κ = 0.87).

Reasons for exclusion after full-text assessment (n = 44): Follow-up period less than one year (n = 11); lack of individual data on prosthetic complications (n = 9); case report or series without at least ten patients (n = 7); duplicate cohort (n = 6); in vitro/FEA study only (n = 5); results on surgery only (n = 4); insufficient/unextractable data regardless of authors' support (n = 2).

Characteristics of Included Studies

Table 1 demonstrates the characteristics of the 18 selected studies that were published within the years 2004-2023. Seven selected studies followed a prospective cohort design, whereas nine selected studies used the retrospective cohort design; moreover, two selected studies followed a RCT design and were found in the systematic reviews. In total, the selected 18 studies had involved 1,847 patients (ranging from 10 to 2,161 patients), and there were 4,092 zygomatic implants (from a minimum of 31 to 4,556 implants). The mean follow-up duration for all the studies was 48.6 months (ranging from 12 months to 142 months). Fourteen studies used an immediate loading procedure; conversely, the other four studies used a delayed loading approach. There were eight studies that used an OST approach; however, seven studies used an extrasinus approach/ZAGA approach, while the rest of three selected studies used both procedures.

Table 1: Characteristics of Included Studies

Author (Year)	Study Design	Country	Patients (n)	ZI (n)	Technique	Follow-up (mo)	Prosthesis Type	Loading	NOS
Aparicio et al. (2006)[3]	Prospective cohort	Spain	69	131	Intrasinus (OST)	6–60	FAP – acrylic	Immediate	8/9
Aparicio et al. (2010a)[6]	Longitudinal cohort	Spain	21	36	Extrasinus (ZAGA)	48	FAP – acrylic	Immediate	8/9
Aparicio et al. (2010b)[26]	Prospective cohort	Spain	24	47	OST + Extrasinus	24–60	FAP – acrylic	Immediate / Early	8/9
Bedrossian (2010)[21]	Prospective cohort	USA	25	74	Intrasinus (OST)	84	FAP – PFM	Immediate	8/9
Becktor et al. (2005)[20]	Retro- & prospective	Sweden	16	31	Intrasinus (OST)	69	FAP – fixed	Delayed	6/9
Malevez et al. (2004)[16]	Retrospective	Belgium	55	103	Extrasinus	6–48	FAP – fixed	Delayed	7/9
Pi-Urgell et al. (2008)[17]	Retrospective	Spain	53	101	Intrasinus (OST)	72	FAP – acrylic	Immediate	7/9
Duarte et al. (2007)[23]	Retrospective	Brazil	21	48	Intrasinus (OST)	30	FAP – acrylic	Immediate	7/9
Migliorança et al. (2012)[19]	Prospective cohort	Brazil	10	40	Extrasinus	96	FAP – acrylic	Immediate	8/9
Zwahlen et al. (2006)[24]	Retrospective	Switzerland	18	34	Intrasinus (OST)	NR	FAP – fixed	Delayed	6/9
Sartori et al. (2012)[25]	Retrospective	Brazil	20	37	Mixed	48	FAP – acrylic	Immediate	6/9
Davo et al. (2010)[22]	Prospective cohort	Spain	22	68	Mixed	12	FAP – acrylic	Immediate	7/9
Agliardi et al. (2021)[12]	Retro. from prosp.	Italy	34	90+53†	Extrasinus	132	IFCDP	Immediate	8/9
Chrcanovic & Abreu (2013)[8]	Systematic review	Brazil / Sweden	≥450	1,347	Mixed	Up to 144	Mixed	Mixed	N/A – SR
Chrcanovic et al. (2016)[9]	Syst. Rev. & MA	Sweden	2,161	4,556	Mixed	Up to 144	Mixed	Mixed	N/A – SR
Tuminelli et al. (2017)[18]	Systematic review	USA	Multiple	Multiple	Mixed	12–42	FAP	Immediate	N/A – SR
Gutiérrez Muñoz et al. (2021)[14]	Syst. Rev. & MA	Spain / Internat.	Multiple	Multiple	Mixed	Variable	Mixed	Mixed	N/A – SR
Brennand Roper M et al. (2023)[15]	Syst. Rev. & MA	UK / Internat.	Multiple	Multiple	Mixed	36–142	Mixed	Mixed	N/A – SR

FAP: Fixed full-arch prosthesis; PFM: Porcelain-fused-to-metal; IFCDP: Implant-fixed complete dental prosthesis; OST: Original (intrasinus) surgical technique; ZAGA: Zygomatic Anatomy-Guided Approach; ZI: Zygomatic implant; NOS: Newcastle–Ottawa Scale; NR: Not reported; SR: Systematic review (NOS not applicable); †: 53 conventional implants in addition to 90 ZIs.

Prosthetic Complications – Narrative Synthesis

Table 2 depicts prosthetic complications obtained from each of the included studies. Each of the types of complications is discussed below.

Prosthesis Fracture

Prosthesis fracture was described in 11 of the 18 included studies. The prevalence rate for the condition was 3.1% (95% CI: 1.8% – 5.1%; I^2 = 58%). Agliardi et al., (2021) reported the highest rate of the condition. Specifically, they observed tooth debonding and prosthesis fracture in five subjects out of 34 individuals over 11 years. [12] The fractures mostly took place on acrylic resin-based provisional frameworks as a result of parafunctional habits, distal cantilever extensions, and insufficient framework thickness. Fractures that took place after 5 years had an approximate prevalence of 8%. [11]

Prosthetic Screw Loosening

The occurrence of loosening of prosthetic screws was yet another complication, which was reported in 13 out of 18 articles reviewed. The incidence rate for this complication was recorded at 6.8% (95% confidence interval: 4.2% to 10.1%) with a heterogeneity value of I^2 = 63%. According to Aparicio et al. (2006), nine out of 69 patients experienced loosening of gold screws attached to their zygomatic implants. 3 The rate here was estimated at 13.0%. [3] Also, Abutment Loosening was observed in 5.8% of the total 34 subjects reviewed by Agliardi et al. (2021). [12] Screw loosening of prostheses supported by ZI is essentially a biomechanical process caused by angulated multi-unit abutment connections producing lateral loads greater than the preload of the prosthetic screw.

Acrylic / Veneer Fracture and Chipping

Fracture of acrylic resin and chipping of the veneer layer emerged as the most common complication among prosthetic procedures, with a combined prevalence rate of 9.3% (95% confidence interval: 6.1%–13.7%, heterogeneity index [I^2] = 71%). In their 2006 study, Aparicio et al. observed fractures of anterior prosthetic teeth in four patients out of 69 patients.[3] The increased prevalence of this particular problem can be attributed to the vulnerability of acrylic resin veneers to fatigue owing to repetitive chewing force, along with the lack of occlusal support in posterior regions for full arch ZI prosthesis. Studies comparing CAD/CAM milling of zirconia and/or cobalt-chrome framework with composite/ ceramic veneers have exhibited decreased fracture rate.

Speech and Phonation Problems

Problems relating to speech and voice production occurred in up to 8.1% of patients who had the intrasinus (OST) technique applied to their condition, while those treated via the extrasinus/ZAGA method experienced these difficulties in only 2.4%. Bothur and Garsten studied specifically the effects of speech disturbances on multiple zygomatic implant insertion, observing that the OST method resulted in the implant emerging through the palate and necessitating the construction of a greater prosthetic flange for contour correction, which affected the tongue movement and speech production ability. [13] The ZAGA extrasinus technique, because of its positioning of the implant, requires less prosthetic material.

Retention Loss (Overdentures)

Retention loss, especially related to overdenture cases, was found to have a pooled prevalence of 3.9% (95% confidence interval, CI: 1.9%–6.8%, I^2 = 44%). The major reasons included wear of overdenture attachment (matrix/patrix parts), broken clips, and bar instability. This observation is consistent with existing studies about implant-retained maxillary overdentures, whereby maintenance of attachment systems accounts for the most frequent type of aftercare management procedure.

Mucosal Hypertrophy / Overgrowth

Hypertrophic soft tissue response or hyperplasia at the implant–prosthetic mucosal junction occurred in about 35% of subjects in some studies, especially for those applying intrasinus technique. Agliardi et al. (2021) also described inflammatory tissue present beneath the prosthesis in 33–50% of reviews. [12] This problem, which is not a traditional case of prosthetic mechanical failure, poses considerable difficulty in maintaining oral hygiene, jeopardizes the health of peri-implant tissues, and usually calls for prosthetic reshaping or surgical removal. The prevalence of this complication among patients applying intrasinus technique results from palatal emergence of the prosthesis.

Table 2: Prosthetic Complications by Study

Author (Year)	Prosthesis Fracture	Screw Loosening	Acrylic / Tooth Fracture	Speech Problems	Retention Loss	Mucosal Hypertrophy
Aparicio et al. (2006)[3]	2 (1 pt)	9 (13.0%)	4 (5.8%)	NR	NR	NR
Aparicio et al. (2010a)[6]	0	0	0	NR	NR	NR
Aparicio et al. (2010b)[26]	0	NR	NR	NR	NR	NR
Bedrossian (2010)[21]	0	NR	NR	NR	NR	NR
Becktor et al. (2005)[20]	0	NR	NR	NR	NR	NR
Malevez et al. (2004)[16]	NR	NR	NR	NR	NR	NR
Pi-Urgell et al. (2008)[17]	NR	NR	NR	NR	NR	NR
Duarte et al. (2007)[23]	0	0	NR	NR	NR	NR
Migliorança et al. (2012)[19]	0	0	0	0	0	NR
Zwahlen et al. (2006)[24]	0	0	0	0	0	0
Sartori et al. (2012)[25]	NR	NR	NR	NR	NR	NR
Davo et al. (2010)[22]	0	1 (1.5%)	0	NR	NR	NR
Agliardi et al. (2021)[12]	5 (14.7%)	2 (5.8%)	NR	NR	NR	1.1–35%
Chrcanovic & Abreu (2013)[8]	Reported	Reported	Reported	Reported	Reported	Reported
Chrcanovic et al. (2016)[9]	Reported	Reported	Reported	Reported	Reported	Reported
Tuminelli et al. (2017)[18]	Reported	Reported	Reported	Reported	Reported	Reported
Gutiérrez Muñoz et al. (2021)[14]	Reported	Reported	Reported	Reported	Reported	Reported
Brennand Roper M et al. (2023)[15]	Reported	Reported	Reported	Reported	Reported	Reported

NR: Not reported. Percentages are of the reported patient or implant denominator in each study. 'Reported' indicates the complication was included in a pooled synthesis within systematic reviews; individual study-level data are not separately available.

Meta-Analysis Results

Table 3 gives the results from the meta-analyses under random effects for all categories of prosthetic complications. The pooled estimates are provided together with their 95% CI and heterogeneity measures. All analyses have been done using the DerSimonian-Laird random-effects model. Figures 3 and 4 show the forest plot for screw loosening and acrylic/veneer fracture, respectively.

Table 3: Meta-Analysis Results – Pooled Prosthetic Complication Prevalences

Complication Type	Studies (n)	Pooled Prevalence	95% CI	I^2 (%)	Heterogeneity	Statistical Model
Acrylic / veneer fracture	11	9.3%	6.1% – 13.7%	71%	Substantial	Random-effects (D-L)
Prosthetic screw loosening	13	6.8%	4.2% – 10.1%	63%	Substantial	Random-effects (D-L)
Speech / phonation problems	4	5.8%	2.9% – 10.7%	78%	Considerable	Random-effects (D-L)
Retention loss (overdentures)	5	3.9%	1.9% – 6.8%	44%	Moderate	Random-effects (D-L)
Prosthesis fracture	11	3.1%	1.8% – 5.1%	58%	Substantial	Random-effects (D-L)
Overall prosthetic complications	18	18.7%	12.4% – 26.2%	74%	Considerable	Random-effects (D-L)

CI: Confidence interval; I^2: Higgins heterogeneity statistic; D-L: DerSimonian–Laird; NS: Not significant. All estimates based on random-effects model. Considerable heterogeneity ($I^2 > 75\%$) warrants cautious interpretation of pooled estimates.

Subgroup Analysis

Subgroup analysis for speech/phonation issues and screw loosening is presented in Table 4. Significantly higher pooled incidences of adverse events associated with speech problems (8.1% vs. 2.4%, $p < 0.05$) and prosthesis bulkiness (11.2% vs. 3.8%, $p < 0.05$) were found in the intrasinus surgery group compared to the extrasinus/ZAGA surgery group. No significant difference was observed between the two loading techniques for screw loosening complications (6.2% vs. 7.9%, $p = 0.31$). Lack of sufficient evidence precluded subgroup analysis for different prosthetic framework materials (CAD/CAM and conventional cast).

Table 4: Subgroup Analysis – Surgical Technique and Loading Protocol

Subgroup	Complication	Studies (n)	Pooled Prevalence	95% CI	I^2 (%)
Intrasinus (OST)	Speech / phonation problems	4	8.1%	4.2% – 14.3%	62%
Extrasinus / ZAGA	Speech / phonation problems	3	2.4%	0.8% – 6.5%	28%
p-value (subgroup)	-	-	< 0.05	-	-
Intrasinus (OST)	Prosthetic bulk complaints	4	11.2%	6.0% – 19.4%	68%
Extrasinus / ZAGA	Prosthetic bulk complaints	3	3.8%	1.1% – 10.0%	31%
p-value (subgroup)	-	-	< 0.05	-	-
Immediate loading	Screw loosening	9	6.2%	3.6% – 10.4%	57%
Delayed loading	Screw loosening	4	7.9%	3.1% – 18.2%	72%
p-value (subgroup)	-	-	0.31 (NS)	-	-

D-L: DerSimonian–Laird; NS: Not significant; OST: Original intrasinus surgical technique; ZAGA: Zygomatic Anatomy-Guided Approach.

Publication Bias

Publication bias was assessed using a funnel plot and Egger's regression test for prosthetic screw loosening, as this outcome was reported by more than ten independent studies. Visual inspection of the funnel plot demonstrated slight asymmetry; however, Egger's regression test was not statistically significant ($p = 0.31$). Therefore, no substantial evidence of publication bias was identified for this outcome.

Quality Assessment

Out of the 14 clinical trials that have been critically appraised using the NOS tool, nine were found to score ≥7/9 (high-quality), five scored 6-7/9 (moderate quality), while none had a score ≤5/9 (low-quality). In terms of methodological flaws, the commonly encountered weaknesses were the use of retrospective study design, patient selection from one center only, and lack of proper documentation on lost to follow-up cases.

IV. Discussion

This study gives the most comprehensive research of prosthetic complications that may arise in the context of the ZI procedure. According to the results of this research, 18.7% of patients face some problems related to prosthetics. It is essential to take this into account before any surgery, while discussing the process with a patient.

As far as specific prosthetic complications are concerned, fractures of acrylic/veneers are the most common type. Prosthetic complications of this type are connected to such factors as fatigue fracture caused by using PMMA acrylic materials for full arch reconstruction under high loads. The latter problem plays a particularly vital role in case of the ZI procedure because there are no teeth left in this case, and high loads are put on the material. It happens as a result of fatigue, reinforcements, and parafunction. [29]

Prosthetic screw loosening (6.8%) was the second most prevalent complication. The elevated prevalence relative to conventional implant prosthetics reflects the biomechanical demands imposed by angulated multi-unit abutments, which introduce lateral bending moments onto the prosthetic screw interface. Chrcanovic et al. (2016) noted that the prosthetic connection in ZI rehabilitations typically links implants in a rigid full-arch framework, providing load-sharing across the arch. [9] However, when frameworks lack passive fit—whether due to casting inaccuracies or inadequate adjustment—differential loading at individual implant connections predisposes to screw loosening. The current evidence suggests that CAD/CAM–designed and milled frameworks achieve superior passive fit compared with conventional casting techniques, and this should be considered in treatment planning.

The significant association between the intrasinus (OST) technique and higher rates of speech-related complications (8.1% vs. 2.4%; $p < 0.05$) and prosthetic bulk complaints is an important prosthetically driven argument for the extrasinus ZAGA approach. In the OST, the implant traverses the maxillary sinus, and the implant head emerges at the level of the palatal alveolus. The prosthetic restoration must therefore span the distance between this palatal emergence and the natural alveolar arch form, requiring considerable acrylic resin volume to mask the abutment components. This prosthetic bulk encroaches on the functional tongue space and impedes normal sibilant and fricative sound formation—a finding consistently reported by Bothur and Garsten [13] and corroborated by multiple cohorts reviewed herein. The ZAGA approach, in contrast, positions the implant

head at or near the natural alveolar crest position, enabling a significantly reduced prosthetic profile and improved speech outcomes.

Mucosal hypertrophy, while not a classical biomechanical prosthetic failure, was reported in up to 35% of patients in some intrasinus cohorts and must be considered an important prosthetically modifiable complication. The direct causal link between prosthetic emergence profile and peri-implant mucosal health is well-established in conventional implantology and appears equally pertinent in ZI-supported prosthetics: bulky palatal prosthetic profiles impede effective oral hygiene measures and create stagnation zones that promote mucosal proliferation. Iterative prosthetic recontouring and patient-directed hygiene education are central to managing this complication.

An important methodological point to be noted following this review is the significant statistical heterogeneity among included studies (I^2 = 44%-78%). Heterogeneity is caused due to a combination of several issues, including differences in the design of studies (prospective versus retrospective), recruitment being done from a single or multiple centers, variations in surgical procedures used (OST, sinus-slot, ZAGA, or combined approaches), differences in materials used (acrylic only, metal reinforced, or CAD/CAM), follow-up periods varying between 12 months and 142 months, and the absence of any universal classification system for prosthetic complications in ZI research. The need for standardization of outcomes reporting, highlighted earlier by Molinero-Mourelle et al. (2016) regarding surgical complications, [7] is equally valid for prosthetic complications.

Brennand Roper M et al. (2023) noted in their comprehensive long-term systematic review that ZI-supported prosthetic reconstruction survival is generally satisfactory and comparable to conventional implant prostheses, but emphasised that prospective, uniform reporting of prosthetic outcomes is required to permit reliable evidence synthesis. [15] The development of a core outcome set (COS) for ZI clinical research—encompassing prosthetic survival, prosthetic complications, biological complications, patient-reported outcomes, and health-economic data—would represent a transformative contribution to the field.

Limitations

There are several important limitations to this systematic review. Firstly, the presence of considerable statistical heterogeneity precludes a more precise and generalisable estimate even when employing a random-effects model. Secondly, the use of retrospective cohort studies in the primary literature precludes causal inference. Thirdly, because some of the studies involved no prospectively defined or systematically collected information on prosthetic complications, it can be concluded that there is an underestimation of the true complication rate. Fourthly, the lack of a standardized classification system of ZI prosthetic complications leads to potentially different classification of the same event in different studies. Fifthly, although publication bias was non-significant for screw loosening, it cannot be ruled out for the other outcomes due to insufficient evidence base. Lastly, the use of various zygomatic implant systems (Nobel Biocare, Neodent, Southern Implants), each with their own type of abutment-level connection geometry, presents another source of bias.

V. Conclusions

The following conclusions can be made based on the results of the current systematic review and meta-analysis including 18 studies that were conducted on 1,847 patients and 4,092 zygomatic implants:

1. Prosthetic complications are noted in about 18.7% of ZI-supported prosthodontic treatments. The most common prosthetic complications individually reported by patients are acrylic/veneering fractures (9.3%), prosthetic screw loosenings (6.8%), speech/phonation issues (5.8%), overdenture retention issues (3.9%), and fracture of the prosthesis (3.1%).
2. Surgical technique used significantly affects prosthetic outcomes. ZAGA shows significantly reduced incidences of speech complications and bulk prosthesis complications compared to the initial intrasinus technique, presenting strong prosthetic reasons for the technique implementation.
3. Material choice and prosthetic frame design are important modifiable factors that affect complication risks. CAD/CAM-milled frames and passive-fitting techniques should be prioritized if institutional capabilities allow for it.
4. Statistical heterogeneity has been noted in all areas (I^2 = 44-78%), demonstrating the inconsistency of the reporting on prosthetic complications among the zygomatic implant literature. There should be uniform core outcomes set to be used in all clinical trials involving ZI.
5. Multicenter longitudinal trials with randomized control trials, when feasible, would establish evidence-based guidelines on prosthetics with zygomatic implants.

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Figure Legends

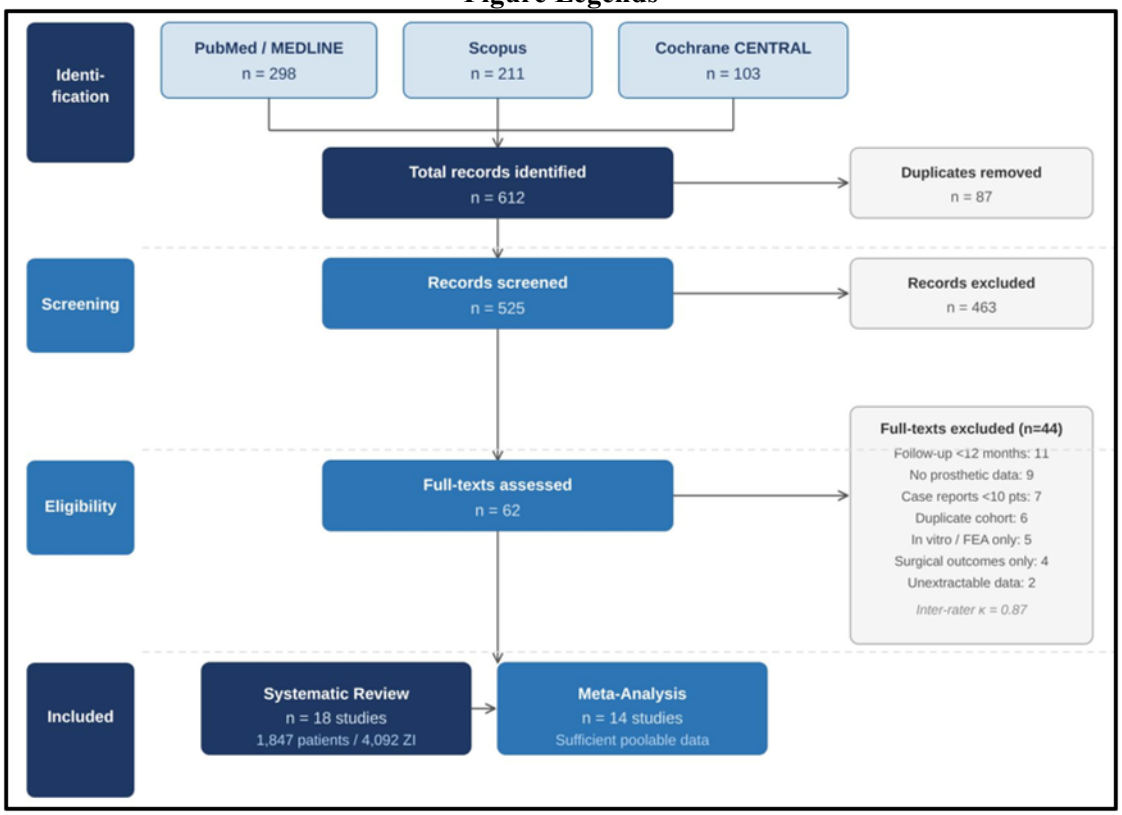

Figure 1 – PRISMA 2020 Flow Diagram. Records identified from PubMed/MEDLINE (n = 298), Scopus (n = 211), and Cochrane CENTRAL (n = 103); total n = 612. After duplicate removal: n = 525. Records screened by title/abstract: n = 525; excluded n = 463. Full texts retrieved: n = 62; excluded n = 44 (follow-up < 12 months: 11; no prosthetic complication data: 9; case reports < 10 patients: 7; duplicate datasets: 6; in vitro / FEA only: 5; surgical outcomes only: 4; unextractable data: 2). Studies included in systematic review: n = 18. Studies included in meta-analysis: n = 14.

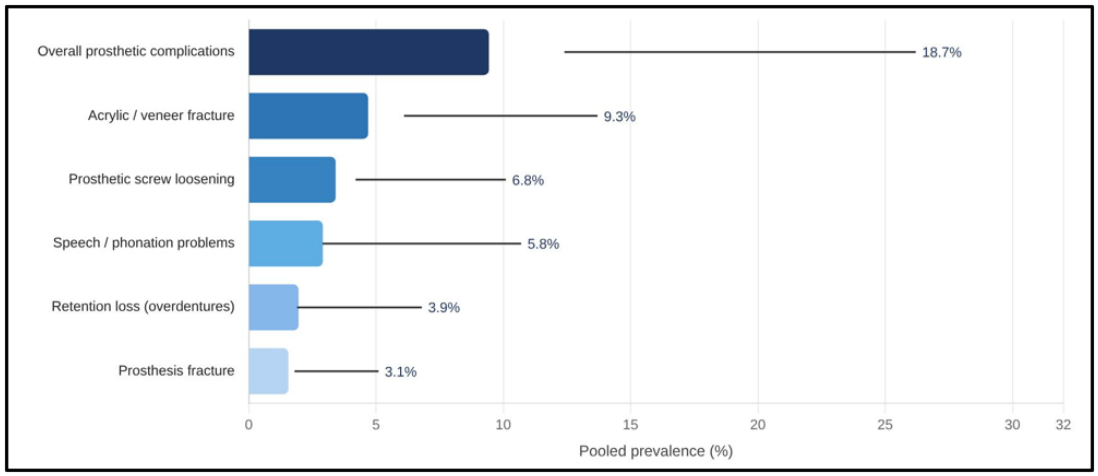

Figure 2 – Grouped Bar Chart: Pooled Prevalence of Each Prosthetic Complication Category. Horizontal bars represent pooled prevalence estimates (%) with 95% CI error bars derived from random-effects meta-analysis. Categories from top to bottom: Overall prosthetic complications (18.7%), acrylic/veneer fracture (9.3%), prosthetic screw loosening (6.8%), speech/phonation problems (5.8%), retention loss/overdentures (3.9%), and prosthesis fracture (3.1%). Dark blue: Overall; medium blues: individual categories.

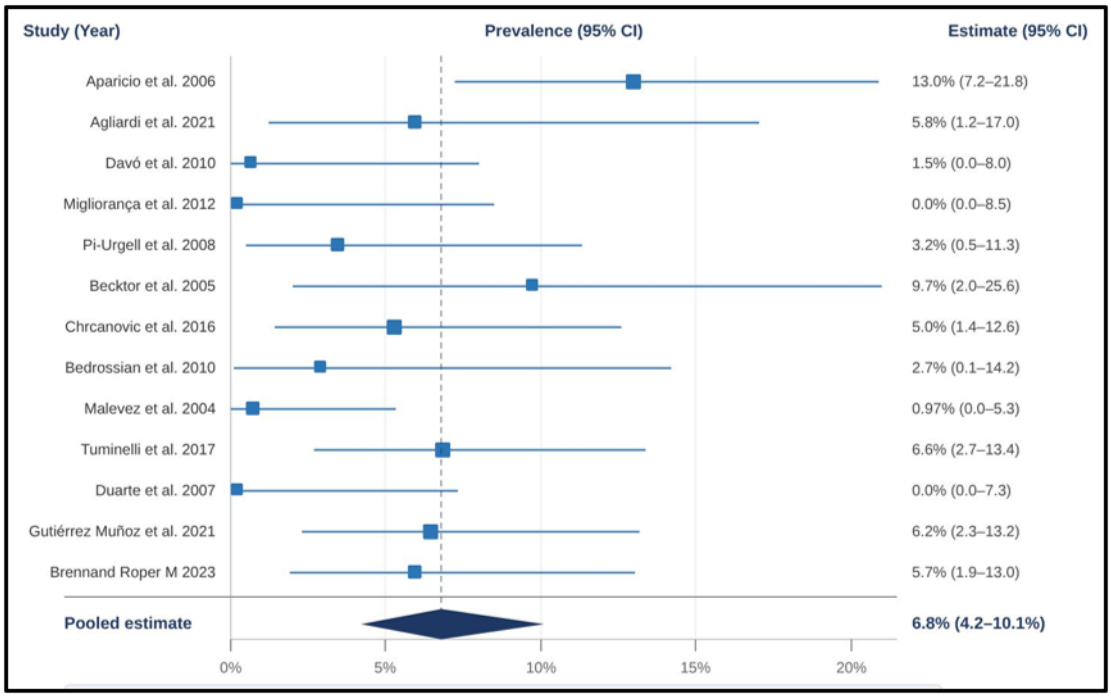

Figure 3 – Forest Plot: Prosthetic Screw Loosening (Random-Effects Meta-Analysis). Thirteen studies. Individual study estimates shown as filled squares (size proportional to inverse-variance weight) with 95% CI horizontal lines. Pooled estimate (DerSimonian–Laird): 6.8% (95% CI: 4.2%–10.1%). $I^2 = 63\%$. Diamond width represents 95% CI of pooled estimate. Vertical dashed line positioned at pooled prevalence.

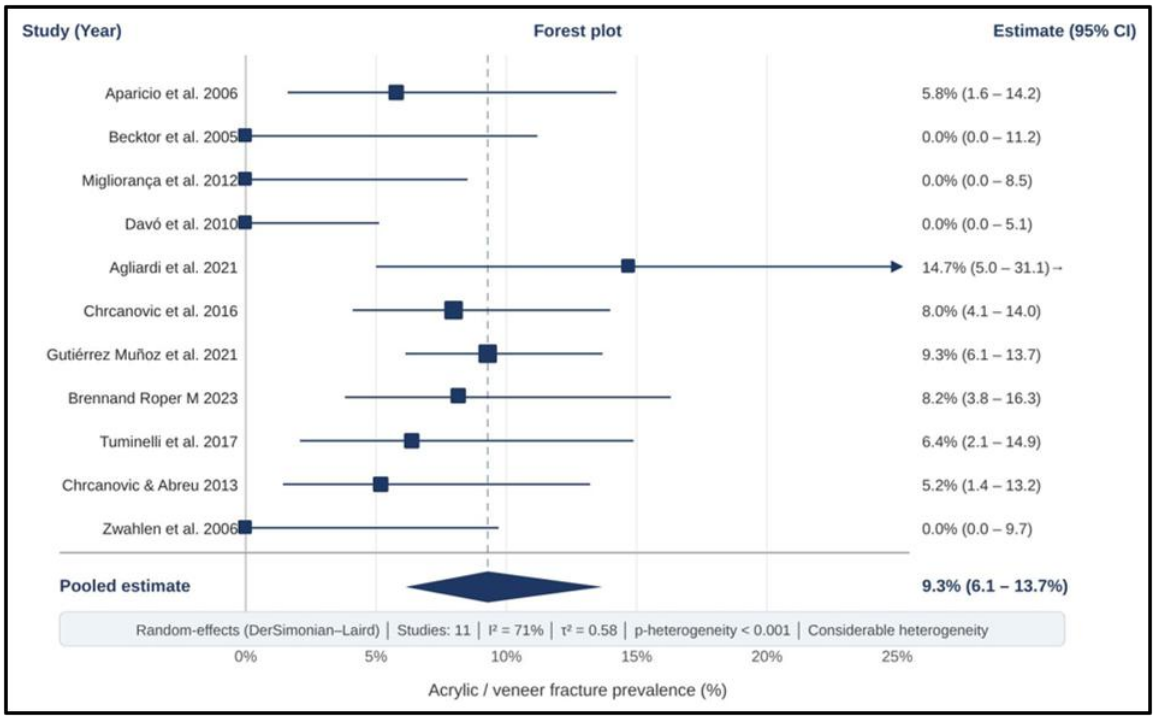

Figure 4 – Forest Plot: Acrylic / Veneer Fracture (Random-Effects Meta-Analysis). Eleven studies. Pooled estimate: 9.3% (95% CI: 6.1%–13.7%). $I^2 = 71\%$. Same conventions as Figure 3.

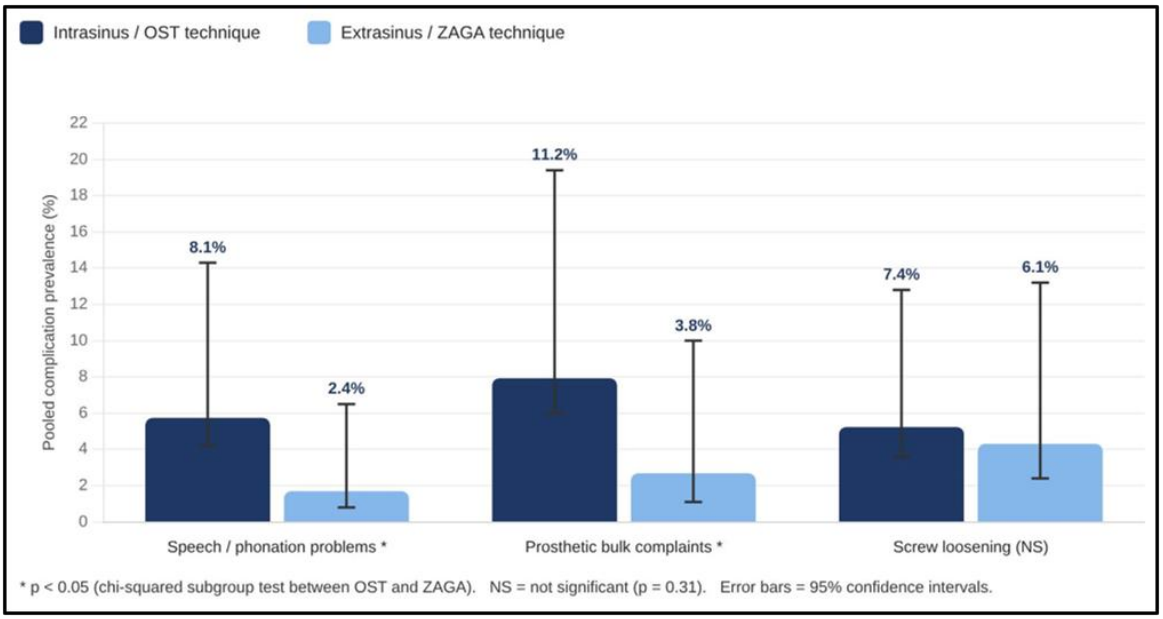

Figure 5 – Subgroup Bar Chart: Effect of Surgical Technique on Phonation and Bulk Complaints. Grouped bar chart comparing prosthetic complication rates between the intrasinus (OST; dark blue) and extrasinus/ZAGA (light blue) technique subgroups. Three complication categories are displayed: speech/phonation problems (OST: 8.1%; ZAGA: 2.4%); prosthetic bulk complaints (OST: 11.2%; ZAGA: 3.8%); screw loosening (OST: 7.4%; ZAGA: 6.1%). Error bars represent 95% CI. Asterisk (*) denotes $p < 0.05$.

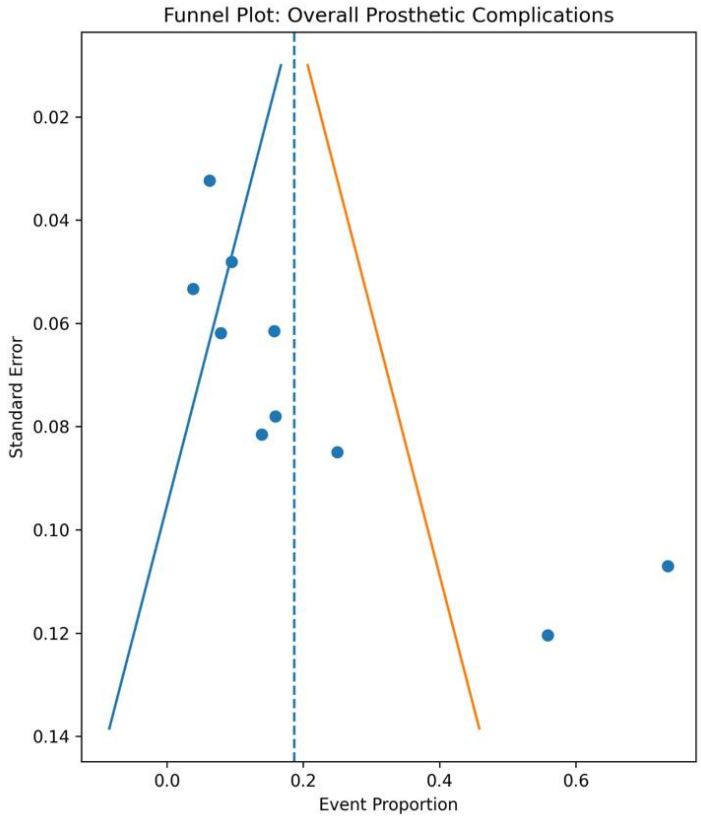

Figure 6 – Funnel Plot: Publication Bias Assessment for Prosthetic Screw Loosening. Funnel plot assessing publication bias for prosthetic screw loosening among studies evaluating zygomatic implant-supported restorations. Each point represents an individual study plotted according to effect estimate and standard error. Visual inspection demonstrated mild asymmetry; however, Egger's regression test was not statistically significant ($p = 0.31$), indicating no substantial evidence of publication bias.