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REVIEW ARTICLE

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Effect of dental implant therapy on the preservation of orofacial tissues: A systematic review and meta-analysis

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Abstract

Objective: Fundamentally, this review addresses the following question: In partially or fully edentulous patients, do implant-supported dental prostheses preserve orofacial tissues when compared to conventional prostheses or no therapy?

Materials and Methods: This study was conducted according to the 2020 PRISMA guidelines for systematic reviews. Electronic searches were conducted at PubMed and Embase databases followed by manual search. Clinical studies comparing the effect of implant-supported prostheses with conventional rehabilitation or no treatment on alveolar bone resorption, remaining teeth, and jaw muscle thickness were considered for inclusion. A qualitative synthesis was conducted with all included studies, and data from selected studies were pooled quantitatively to perform a meta-analysis.

Results: A total of 14 studies were selected for analysis. Six studies reported on the effect of implant therapy on alveolar bone resorption ($n = 453$), six on the remaining teeth ($n = 1014$), while four studies evaluated masseter muscle thickness ($n = 158$). The results of the meta-analyses assessing alveolar bone resorption in the posterior mandible and in the anterior area of the maxilla, both fixed and random effects models, yielded no benefit of rehabilitation with implant-supported prostheses when compared to conventional prostheses. For masseter bone thickness, however, a significant benefit for implant-supported prosthesis was observed.

Conclusions: This systematic review and meta-analysis were unable to unequivocally answer the focus question. There are some indicators of the benefit of implant-supported prostheses over conventional prostheses or no therapy in preserving orofacial tissues, particularly for masseter muscle thickness. However, the evidence is still insufficient to confirm such perception.

KEYWORDS
alveolar bone resorption, dental implant, implant therapy, masseter muscle thickness, orofacial tissue, tooth survival

1 | INTRODUCTION

The effectiveness of dental implants over time has been scientifically validated for both partially and fully edentulous patients (Gallucci et al., 2014; Jemt, 2018; Papaspyridakos, 2015; Papaspyridakos et al., 2020). Published data indicate that the number of patients rehabilitated with dental implants are steadily increasing every year (Douglass & Merin, 2002). Since the 1980s, the success of the dental implant therapy has been evaluated based on implant survival and crestal bone remodeling (Albrektsson et al., 1987; Buser et al., 1990) and, as a result, implant-related biologic and mechanical complications have been under close scrutiny (Chochlidakis et al., 2020; Heitz-Mayfield et al., 2014; Zarb & Schmitt, 1990). Over the years, as implant therapy has evolved into a routine treatment modality, several different types of implants such as the pterygoid, zygoma, short, and ceramic implants have progressively been added to clinicians' armamentarium. As a result, other variables have also been receiving attention from the scientific community when assessing the success of implant-supported restorations (Papaspyridakos et al., 2012). These include the search for natural-looking esthetics, quality of peri-implant soft tissues, different prosthodontic features, as well as patient satisfaction (Furhauser et al., 2005).

With the increase in life expectancy, more patients are bound to present with missing teeth due to periodontal disease, caries, trauma, or a combination of these (Sarafidou et al., 2022). Clinicians may recommend fixed or removable conventional or implant-supported rehabilitation to treat both partially and fully edentulous spaces or even no restoration. Treatment choice must be carefully considered based on its long-term impact on function and esthetic, and to preserve remaining teeth as much as possible (Okuni et al., 2022). Fully edentulous elderly individuals have been shown to significantly benefit from rehabilitation with implant-supported overdentures (I-OD) compared to conventional removable complete dentures (RCD) due to the improved stability, retention, increased bite force, larger chewing cycles, masticatory ability, and efficiency (Awad et al., 2000). Logically, it would be expected that rehabilitation with implant-supported prostheses may also help preserving different orofacial tissues such as the alveolar bone, remaining teeth, and jaw muscles when compared to conventional treatment modalities, or no treatment, but data remains controversial.

In a recent systematic review, although overdentures supported by 4 implants presented significantly less alveolar bone resorption in the posterior edentulous mandible than RCD, such advantage, however, was not observed when overdentures were supported by 2 implants (Oh, 2020). When edentulous spaces are rehabilitated with tooth-supported removable partial dentures using adjacent teeth as abutments, biological complications such as tooth loss, caries, and crown fractures can arise (Phang et al., 2020). Conversely, implant-supported fixed dentures do not rely on the surrounding dentition for support, which may result in the preservation of remaining teeth over time (Krennmair et al., 2003). The conversion of RCD into I-OD has also been shown to significantly improve chewing efficiency and bite force (van Kampen et al., 2004). Moreover, patients rehabilitated with overdentures over two implants (Muller et al., 2013) and implant-supported removable partial prostheses (Gonçalves et al., 2013) have also demonstrated increased maximum bite force and increased masseter muscle thickness when compared with conventional rehabilitation.

The pertinent data requires pooling and proper assessment in order to better ascertain the present level of the evidence. Such information can assist clinicians in their therapeutical recommendations, and also patients when weighing the long-term benefits and limitations of each type of intervention. Therefore, the present systematic review and meta-analysis were conducted to answer the following question: In partially or fully edentulous patients, do implant-supported dental prostheses preserve orofacial tissues when compared to conventional prostheses or no therapy?

2 | METHODS

The study protocol followed the 2020 PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) guidelines (Page et al., 2021) and was registered at PROSPERO under the No. CRD42022354693. Considering that all the evidence was obtained from publicly accessible documents, an institutional ethical approval was not required for this systematic review.

2.1 | Eligibility criteria

2.1.1 | Inclusion criteria

- Studies including partially or fully edentulous patients rehabilitated with implant-supported prostheses in comparison with conventional rehabilitation (fixed or removable), or no treatment;
- Clinical studies, that is, cross-sectional, cohort and case–control, controlled clinical trials (CCT), and randomized clinical trials (RCT);
- Minimum 10 patients (to distinguish cohort studies from case series); and
- Studies presenting at least one of the outcomes of interest, that is, effect of implant therapy on remaining teeth, alveolar bone resorption, and/or jaw muscles thickness.

2.1.2 | Exclusion criteria

- Studies presenting insufficient information regarding the number of patients and follow-up time;
- Studies lacking information on the primary outcomes;
- Multiple publications using the same population (only the publication with the longest follow-up period was considered for inclusion); and
- Studies published in languages other than English.

2.2 | Information sources and search strategy

The search for clinical studies followed the PICO (Population, Intervention, Comparison, Outcomes) format, and was conducted electronically on the MEDLINE (PubMed) and EMBASE databases from 20 January up to 30 August 2022. The search strategy was limited to studies in English, and the descriptors used are shown in Table 1. In addition to the electronic search, a manual search was conducted in the reference lists of all articles retrieved for full-text analysis.

2.3 | Selection process

Based on the eligibility criteria, two authors (KV and FM) independently screened the titles and abstracts derived from the initial search. In case the abstracts presented insufficient information regarding the inclusion criteria, full texts were obtained for further analysis. Any disagreements at any of the stages above were resolved through discussions with a third reviewer (AS). Article screening was conducted with Rayyan software, and Endnote (Endnote X7, Thompson Reuters) was used for reference management and electronically identify and discard duplicates.

2.4 | Data items and collection process

The reviewers independently extracted the data from all included studies using data extraction tables. All extracted data were double-checked, and any questions arising at this stage were resolved through group discussions. The following information was extracted from the selected articles: authors, year of publication, study design, number of patients, mean age, jaw (maxilla or mandible), follow-up time, area in the mouth (anterior or posterior), type of edentulism (partial or full), test group (partial or full implant-supported prostheses), control group (full or partial conventional prosthesis, or no treatment), and outcomes.

2.5 | Risk of bias in individual studies

The quality of the included studies was assessed with the Cochrane Collaboration's tool for assessing risk of bias. RCTs were assessed in the following 5 domains: (D1) bias arising from the randomization process; (D2) bias due to deviations from intended interventions; (D3) bias due to missing outcome; (D4) bias in the measurement of outcomes; and (D5) bias in selection of the reported result. Observational studies were assessed in 7 different domains: (D1) bias due to confounding factors; (D2) bias in the selection of participants; (D3) bias in the classification of interventions; (D4) bias due to deviations from intended interventions; (D5) bias due to missing data; (D6) bias in the measurement of outcomes; and (D7) bias in the selection of the reported result. The selected studies were initially screened by one reviewer (A.S.), who collected the information on each individual study. A second reviewer (K.V.) crosschecked the collected information and confirmed its accuracy.

TABLE 1 Systematic review search strategy.

PICO	Search strategy
Population	#1—Partially Edentulous Patients OR Fully Edentulous Patients OR Posterior Partial Edentulous OR Dental Implant OR Implant OR Edentulous Mouth OR Edentulous Mouths OR Mouth, Toothless OR Toothless Mouth OR Jaw, Edentulous, Partially OR Edentulous Jaw OR Edentulous Jaws OR Jaws, Edentulous
Intervention or exposure	#2—Partial Implant-Supported Fixed Dental Prostheses OR Full-arch Implant-Supported Fixed Dental Prostheses OR Fixed Dental Implant Prostheses OR Dental Prosthesis, Implant-Supported OR Implant-Supported Dental Prosthesis OR Dental Prostheses, Implant-Supported OR Implant-Supported Dental Prosthesis OR Implant-Supported Dental Prostheses OR Prostheses, Implant-Supported Dental OR Prosthesis, Implant-Supported Dental OR Denture, Implant-Supported OR Denture, Implant-Supported OR Implant-Supported Denture OR Dentures, Implant-Supported OR Fixed Implant-Supported Denture OR Fixed Implant-Supported Dentures OR Prosthesis Dental, Implant-Supported OR Dental, Implant-Supported Prosthesis OR Dentals, Implant-Supported Prosthesis OR Implant-Supported Prosthesis Dental OR Implant-Supported Prosthesis Dentals OR Prosthesis Dental, Implant-Supported OR Prosthesis Dentals, Implant-Supported
Comparison	#3—Partial tooth-supported fixed dental prostheses OR full-arch tooth-supported fixed dental prostheses OR Removable Partial Denture OR Denture OR Fixed Bridge OR Bridge, Fixed OR Bridges, Fixed OR Fixed Bridges OR Fixed Partial Denture OR Denture, Fixed Partial OR Dentures, Fixed Partial OR Fixed Partial Dentures OR Partial Denture, Fixed OR Partial Dentures, Fixed OR Pontic OR Pontics OR Complete Denture OR Complete Dentures OR Dentures, Complete OR Denture, Complete, Upper OR Denture, Complete, Lower
Outcome	#4—teeth prognosis OR teeth survival OR survival of adjacent teeth OR alveolar bone loss OR alveolar bone crest OR ridge bone loss OR bone resorption OR ridge resorption OR periodontal status OR jaw muscles OR masticatory muscles OR Mucosa, Mouth OR Oral Mucosa OR Mucosa, Oral OR Buccal Mucosa OR Periodontal Atrophies OR Atrophy of Periodontium OR Periodontium Atrophies OR Periodontium Atrophy OR Gingivo-Osseous Atrophy OR Gingivo-Osseous Atrophy OR Gingivo-Osseous Atrophies OR Alveolar Processes OR Process, Alveolar OR Processes, Alveolar OR Alveolar Ridge OR Ridge, Alveolar

Any disagreements were resolved through discussions with a third reviewer (F.M.). Risk of bias was classified as being low, moderate or high.

2.6 | Study outcomes

- Effect on remaining teeth—survival rate (percentage), complication rates (caries or other types of tooth structure loss, periodontal lesions, and crown fracture);
- Alveolar bone resorption—area measurements conducted on digital panoramic radiographs in relative terms (%), or changes in the area index over time; and
- Jaw muscles thickness—measured in millimeters with real-time linear ultrasound scanner and linear array transducer.

2.7 | Synthesis methods

To facilitate the interpretation of the results found, included studies were grouped according to their main outcome (alveolar bone resorption, effect on remaining teeth, and jaw muscle thickness). A qualitative and quantitative synthesis of the studies were conducted. The data from selected studies were pooled quantitatively to perform meta-analysis using the R Software (version 4.1.2., R Foundation for Statistical Computing). Heterogeneity among studies was assessed with Cochran's Q test, and meta-analysis for the final values (i.e., weighted mean differences and 95% confidence intervals, and random-effect model to account for potential methodological differences between studies), and forest plots were also evaluated. A fixed effect model was used when no statistically significant heterogeneity was observed among studies ($p > .05$).

2.8 | Reporting bias assessment

Potential publication bias in the meta-analysis was assessed via funnel plot asymmetry using Egger's test.

3 | RESULTS

3.1 | Study selection

The identification, inclusion, and exclusion of studies is illustrated in Figure 1. A total of 2609 records were initially identified in the electronic search (PubMed = 1432; Embase = 1177). After the exclusion of 774 duplicates by automation, 1835 titles were screened, from which 1799 were considered irrelevant, resulting in 36 titles for retrieval. The manual search of references in the retrieved studies resulted in six more studies for full-text analysis. From the 42 texts analyzed, 28 were excluded for different reasons (Table S1). As a result, 14 studies fulfilled the eligibility criteria and were selected for qualitative analysis, of which seven were pooled quantitatively to perform meta-analyses.

3.2 | Study characteristics

A summary containing the data items collected from 14 studies included in the qualitative analysis can be found in Tables 2–4. Only one study was an RCT (Maniewicz et al., 2019). Of the 13 observational studies, nine were retrospective in design (Alrajhi et al., 2020; Hatta et al., 2021; Jacobs et al., 1992, 1993; Khuder et al., 2017; Kordatzis et al., 2003; Yamada et al., 2022; Yamazaki et al., 2013a), three studies were prospective (Amaral et al., 2019; Okuni et al., 2022; Tymstra et al., 2011), and one was a cross-sectional study (Muller et al., 2012).

3.3 | Risk of bias

The included RCT (Maniewicz et al., 2019) presented a low risk of bias for all the five domains analyzed (Table 5). On the other hand, most of the selected longitudinal studies presented an overall moderate risk of bias. For all three studied outcomes, the main areas for risk of bias within the observational studies were related to domain D1 (confounding factors) and domain D2 (selection of participants). Domain D5 (missing data) also represented an area of risk of bias for the outcome "effect on remaining teeth." One observational study (Jacobs et al., 1992) presented high risk of bias for domains D2 (selection of participants) and D3 (classification of interventions), which resulted in this study being classified with an overall high risk of bias (Table 6).

3.4 | Alveolar bone resorption

3.4.1 | Results of individual studies

Six observational studies assessed alveolar bone resorption in fully edentulous patients, five retrospective studies (Alrajhi et al., 2020; Jacobs et al., 1992, 1993; Khuder et al., 2017; Kordatzis et al., 2003), and one prospective study (Tymstra et al., 2011). The number of participating patients ranged between 30 and 140, totaling 453 individuals. All studies had removable complete dentures (RCD) as control groups, while the test groups were composed by implant-supported overdentures (I-OD) and/or implant-supported fixed complete dentures (I-FCD). Mean follow-up time was 6.3 ± 4.4 years for the groups with RCD, 6.4 ± 4.1 years for I-FCD, and 6.5 ± 3.2 years for I-OD. Alveolar bone measurements were conducted on panoramic

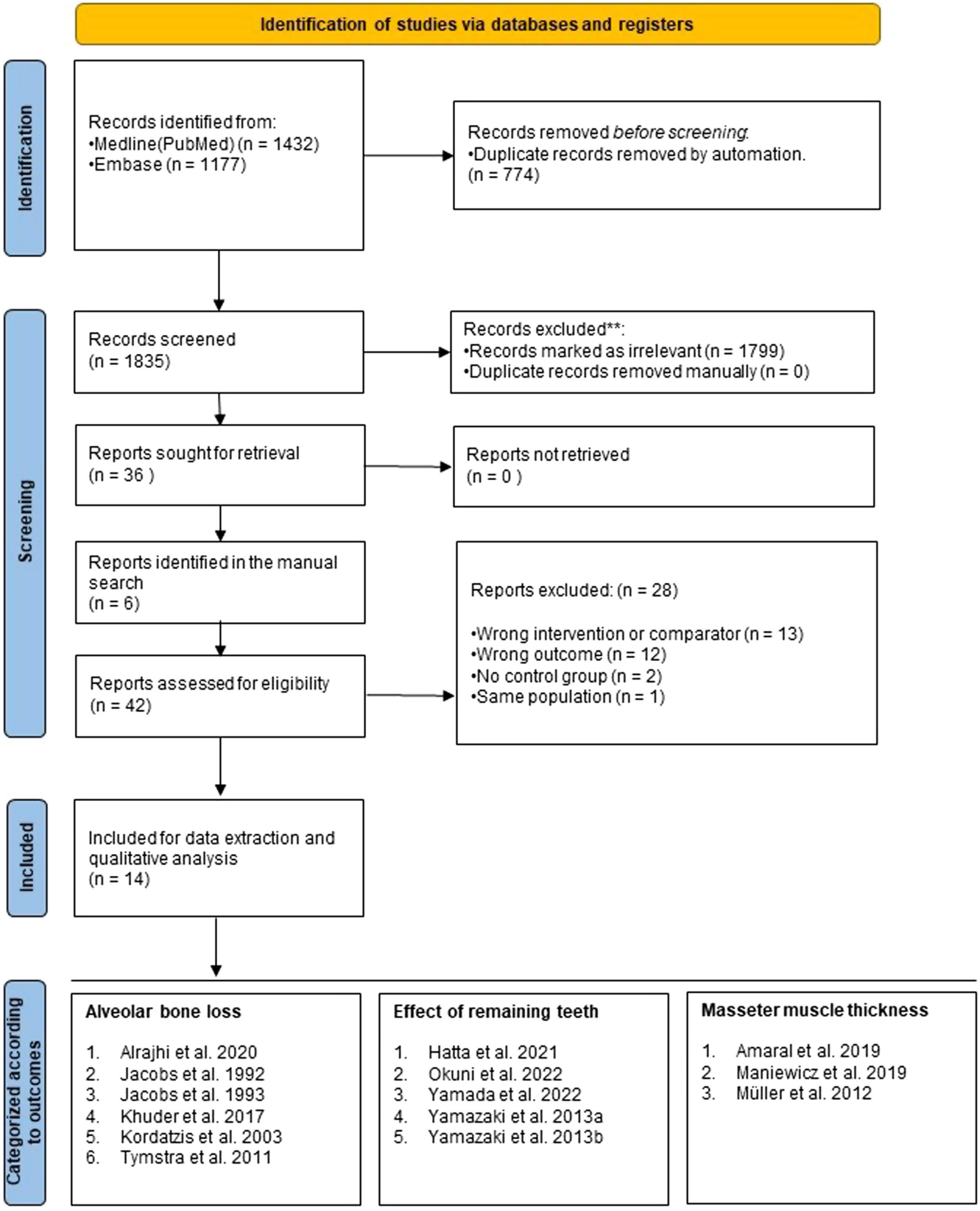

FIGURE 1 PRISMA flowchart for study selection.

radiographs in all studies. One study evaluated vertical bone resorption in the maxilla (Alrajhi et al., 2020), while two studies in the posterior area of the mandible (Jacobs et al., 1992; Kordatzis et al., 2003), and three studies in the posterior area of the mandible and the antagonist ridges (Jacobs et al., 1993; Khuder et al., 2017; Tymstra et al., 2011; Table 2).

TABLE 2 Summary of included articles on alveolar bone resorption in fully edentulous patients.

Authors (Year)	Study design	Patients (*n*)	Jaw	Age (years)	Time in function (years)	Control group (*n*)	Test group (*n*)	Outcomes
Jacobs et al. (1992)	RS	140	Man	RCD (59) I-OD (54) I-FCD (57)	RCD (13) I-OD (10) I-FCD (11)	RCD (85)	I-OD (30) I-FCD (25)	RBL[a]
Jacobs et al. (1993)	RS	44	Max/Man	RCD (56.0 ± 10) I-OD (61.0 ± 11.0) I-FCD (50.0 ± 6.0)	RCD (0.83) I-OD (3.6) I-FCD (3.1)	RCD (12)	I-OD (20) I-FCD (12)	RBL[a]
Kordatzis et al. (2003)	RS	73	Man	(54; 31–76)	(5)	RCD (34)	I-OD (39)	RBL[b]
Khuder et al. (2017)	RS	46	Max/Man	RCD (64.9 ± 9.7) I-OD (66.2 ± 8.4)	(4)	RCD (23)	I-OD (23)	RBL[c]
Tymstra et al. (2011)	PS	120	Max/Man	RCD (56.9) I-OD on two implants (54.0) I-OD on four implants (55.7)	(10)	RCD (60)	I-OD on two implants (30) I-OD on four implants (30)	RBL[d]
Alrajhi et al. (2020)	RS	30	Max	RCD (58.6 ± 3.0) I-FCD (59.2 ± 3.4)	(5)	RCD (15)	I-FCD on four implants (15)	RBL[d]

Abbreviations: I-OD, implant-supported Overdenture; loss I-FCD, implant-supported fixed complete denture; Man, mandible; Max, maxilla; PS, prospective study; RBL, radiographic alveolar bone; RCD, removable complete denture; RS, retrospective study.

[a]Wilding et al. (1987).

[b]Wright and Watson (1998).

[c]Kreisler et al. (2000) for maxillary arch and by Wilding et al. (1987) for posterior mandibular.

[d]Kreisler et al. (2000).

TABLE 3 Summary of included articles on the effect on remaining teeth in partially edentulous patients.

Authors (year)	Study design	Patients	Jaw	Age (years)	Time in function	Control group (*n*)	Test group (*n*)	Outcomes
Okuni et al. (2022)	PS	514	Max/Man (single bounded missing tooth)	I-FPD (51.9 ± 16.1) R-FPD (55.9 ± 15.1) T-FPD (61.2 ± 11.2)	10 years	R-FPD (216) T-FPD: (195)	I-FPD (103)	SR and other complications of remaining TAES.
Yamada et al. (2022)	RS	233	Max/Man	I-FPD (58.6 ± 8.8) T-RPD (66.9 ± 9.0)	55.6 ± 35.3 months	T-RPD (144)	I-FPD (89)	SR and other complications of remaining TAES, TNAES, TOES.
Yamazaki et al. (2013a)	RS	103	Max/Man (missing at least four continuous teeth)	I-FPD (46.4 ± 15.0) T-RPD (60.6 ± 12.7)	10 years	T-RPD (82)	I-FPD (21)	SR of remaining ART; TAES, TOES.
Yamazaki et al. (2013b)	RS	84	Max/Man (missing unilateral free-end 2 or 3 teeth)	(55.8 ± 9.4)	I-FPD 6.6 ± 4.1 years T-RPD 5.0 ± 3.4 years NR 6.0 ± 4.1 years	T-RPD (41) NR (10)	I-FPD (33)	SR and other complications of remaining ART, TAES, TOES
Hatta et al. (2021)	RS	56	Man (posterior unbonded unilateral)	51 subjects in the 70-year group and 5 subjects in the 80-year group	6 years	NR (28)	I-FPD (28)	SR of remaining TAES.

Abbreviations: ART, all remaining teeth; I-FPD, implant-supported fixed partial denture; Man, mandible; Max, maxilla; NR, no restoration; PS, prospective study; RCT, randomized controlled trial; R-FPD, resin-bounded fixed partial denture; RS, retrospective study; SR, survival rate; TAES, teeth adjacent to edentulous space; T-FPD, tooth-supported fixed partial denture; TNAES, teeth not adjacent to edentulous space; TOES, teeth opposing edentulous spaces; T-RPD, tooth-supported removable partial denture; TS, tooth survival.

TABLE 4 Summary of included articles on masseter muscle thickness in fully edentulous patients.

Authors (year)	Study design	Patients (n)	Jaw	Age (years)	Time in function	Control group (n)	Test group (n)	Outcomes
Amaral et al. (2019)	PS	12	Max/Man	(68.7 ± 5.2)	2 months	RCD (12)	I-OD (12)	MMT[a] (Highest value on either side)
Maniewicz et al. (2019)	RCT	32	Man	RCD (85.0 ± 6.2) I-OD (84.8 ± 5.4)	7 years	RCD (16)	I-OD (16)	MMT[a] (Mean of 2 readings on P-CS and NP-CS)
Müller et al. (2012)	CSS	80	Max/Man	RCD: (68.2 ± 6.2) Fully Dentate (66.0 ± 8) I-OD (68.1 ± 4.6) I-FPD (61.5 ± 8.3)	RCD (3.3 ± 3 years) I-OD (4.0 ± 2.6 years) I-FPD (3.9 ± 2.1 years)	RCD (20) Fully Dentate (20)	I-OD (20) I-FCD (20)	MMT[a] (Mean of 2 readings on both sides)

Abbreviations: CSS, cross-sectional study; I-FCD, implant-supported fixed complete denture; I-OD, implant-supported overdenture; RCD, removable complete denture; Man, mandible; Max, maxilla; MMT, masseter muscle thickness; NP-CS, not preferred chewing side; P-CS, preferred chewing side; PS, prospective study; RCT, randomized controlled trial.

[a]MMT measured with real-time linear ultrasound scanner and linear array transducer.

3.4.2 | Results of the qualitative synthesis

In rehabilitated ridge

Alrajhi et al. (2020) showed that patients rehabilitated with maxillary I-FCD opposed by remaining mandibular anterior teeth presented significantly less maxillary anterior and posterior alveolar bone resorption when compared with those rehabilitated with RCD. Similarly, when evaluating the mandibular posterior ridge, patients rehabilitated with I-OD demonstrated less alveolar bone resorption when compared with patients rehabilitated with RCD in two studies (Khuder et al., 2017; Kordatzis et al., 2003), but only one of them reaching statistical significance (Kordatzis et al., 2003). Jacobs et al. (1992) also demonstrated significantly less alveolar bone resorption in patients rehabilitated with I-FCD when compared to those rehabilitated with RCD. Conversely, two studies demonstrated slightly more posterior bone resorption in patients rehabilitated with I-OD when compared to those rehabilitated with RCD without, however, reaching statistical significance (Jacobs et al., 1992; Tymstra et al., 2011; Table 7).

In the antagonist ridge

Of the three studies reporting on maxillary alveolar bone resorption in the antagonistic ridge, two showed more bone resorption in patients rehabilitated with I-OD than those rehabilitated with RCD without, however, reaching statistical significance (Khuder et al., 2017; Tymstra et al., 2011). However, the third study showed significantly more bone resorption in patients rehabilitated with I-OD and RCD when compared to those rehabilitated with I-FCD (Jacobs et al., 1993; Table 7).

3.4.3 | Results of the quantitative synthesis

In the posterior mandible of the rehabilitated ridge

A meta-analysis was conducted with four studies (number of observations: $o = 324$) that compared alveolar bone resorption in the posterior mandible of the rehabilitated ridge between patients treated with RCD and those treated with I-OD (Jacobs et al., 1992; Khuder et al., 2017; Kordatzis et al., 2003; Tymstra et al., 2011). According to the pooled results of the meta-analysis, both fixed and random effects models yielded no benefit of rehabilitation with I-OD when compared to RCD. Additionally, Cochran's Q test ($p = .04$) also indicated heterogeneity among the pooled studies (Figure 2).

In the anterior maxilla of the antagonistic ridge

A meta-analysis was also conducted with three studies (number of observations: $o = 168$) that compared alveolar bone resorption in the anterior maxilla of the antagonistic ridge between patients rehabilitated with RCD and those rehabilitated with I-OD (Jacobs et al., 1993; Khuder et al., 2017; Tymstra et al., 2011). According to the pooled results, both fixed and random effects models yielded

TABLE 5 Risk of bias for the included randomized clinical trial.

Author (year)	D1	D2	D3	D4	D5	Overall risk of bias
Maniewicz et al. (2019)	Low	Low	Low	Low	Low	Low

Note: Domains of Bias: (D1) bias arising from the randomization process; (D2) bias due to deviations from intended interventions; (D3) bias due to missing outcomes; (D4) bias in measurement of the outcome; (D5) bias in selection of the reported result.

TABLE 6 Risk of bias for the included observational studies.

Author (year)	D1	D2	D3	D4	D5	D6	D7	Overall risk of bias
Alveolar bone resorption								
Alrajhi et al. (2020)	Moderate	Low	Moderate	Low	Low	Moderate	Low	Moderate
Jacobs et al. (1993)	Moderate	Moderate	Moderate	Low	Low	Moderate	Low	Moderate
Khuder et al. (2017)	Moderate	Moderate	Low	Low	Low	Moderate	Low	Moderate
Kordatzis et al. (2003)	Moderate	Moderate	Low	Low	Low	Low risk	Low	Moderate
Tymstra et al. (2011)	Moderate	Moderate	Moderate	Low	Moderate	Low risk	Low	Moderate
Jacobs et al. (1992)	Moderate	High risk	High	Low	Low	Moderate	Low risk	High
Effect on remaining teeth								
Okuni et al. (2022)	Moderate	Moderate	Low	Low	Moderate	Low	Low	Moderate
Yamada et al. (2022)	Moderate	Moderate	Moderate	Low	Moderate	Low	Low	Moderate
Yamazaki et al. (2013a)	Moderate	Moderate	Low	Low	Moderate	Low	Low	Moderate
Yamazaki et al. (2013b)	Moderate	Moderate	Low	Low	Moderate	Low	Low	Moderate
Hatta et al. (2021)	Moderate	Moderate	Low	Low	Moderate	Moderate	Low	Moderate
Masseter thickness								
Amaral et al. (2019)	Moderate	Moderate	Low	Low	Low	Low	Low	Moderate
Muller et al. (2012)	Moderate	Moderate	Low	Low	Low	Low	Low	Moderate

Note: Domains of Bias: (D1) bias due to confounding; (D2) bias in the selection of participants into the study; (D3) bias in classification of interventions; (D4) bias due to deviations from intended interventions; (D5) bias due to missing data; (D6) bias in measurement of outcomes; (D7) bias in selection of the reported results.

no benefit of rehabilitation with I-OD when compared to RCD. Additionally, Cochran's Q test ($p = .0001$) also indicated heterogeneity among the pooled studies (Figure 3).

3.5 | Effect on remaining teeth

3.5.1 | Results of individual studies

Five observational studies assessed the effect of different types of rehabilitation on the preservation of remaining teeth in partially edentulous patients, four retrospective studies (Hatta et al., 2021; Yamada et al., 2022; Yamazaki et al., 2013a, 2013b), and one prospective study (Okuni et al., 2022). The number of participants ranged between 24 and 514, totaling 1014 individuals. All studies presented I-FPDs in the test group, while the control groups were composed by resin-bonded fixed partial dentures (R-FPD), tooth-supported fixed partial dentures (T-FPD), tooth-supported removable partial dentures (T-RPD), and/or no restoration (NR). Time in function ranged from 3.4 to 10 years. Four studies evaluated both the maxilla and mandible (Okuni et al., 2022; Yamada et al., 2022; Yamazaki et al., 2013a, 2013b), and one study only assessed the mandible (Hatta et al., 2021). All five studies evaluated survival rates (SR) of remaining teeth adjacent to edentulous spaces (TAES). Three studies evaluated the SR of teeth opposing edentulous spaces (TOES; Yamada et al., 2022; Yamazaki et al., 2013a, 2013b). One study also evaluated survival rates (SR) of remaining teeth nonadjacent to edentulous spaces (TNAES) (Yamada et al., 2022), while two studies analyzed the SR of all remaining teeth (ART) (Yamazaki et al., 2013a, 2013b). Three studies also reported on teeth complications such as fracture or loss of cementation of prosthetic crowns, tooth fracture, caries, periapical lesions,

TABLE 7 Mean (±SD) alveolar bone resorption of residual ridge (in millimeters).

Authors (year)	Time in function (years)	Edentulism (years)	RCD	I-OD	I-FCD	*p*-value
Rehabilitated ridge						
Anterior maxilla						
Alrajhi et al. (2020)	5	3	0.51 ± 0.04	N/A	0.15 ± 0.02	<.001
Posterior maxilla						
Alrajhi et al. (2020)	5	3	0.30 ± 0.03	N/A	0.11 ± 0.02	<.001
Posterior mandible						
Jacobs et al. (1992)	I-OD: 2 I-FCD: 2.1	>10	0.10 ± 0.19	0.14 ± 0.2	0.04 ± 0.06	<.05
Kordatzis et al. (2003)	5	22	0.14 (−0.02–0.37)	0.06 (−0.12–0.24)	N/A	<.001
Tymstra et al. (2011)	10	>20	0.08 ± 0.11	2 implants 0.11 ± 0.07 4 implants 0.07 ± 0.08	N/A	>.05
Khuder et al. (2017)	1–7	5.8	0.12 ± 0.11	0.08 ± 0.07	N/A	=.116
Antagonistic ridge						
Anterior maxilla						
Jacobs et al. (1993)	2	>10	0.13 ± 0.13	0.04 ± 0.05	0.04 ± 0.06	<.05
Tymstra et al. (2011)	10	>20	0.04 ± 0.11	2 implants 0.12 ± 0.14 4 implants 0.11 ± 0.10	N/A	>.05
Khuder et al. (2017)	1–7	5.8	0.142 ± 0.102	0.074 ± 0.073	N/A	=.116

Abbreviations: I-FCD, implant-supported fixed complete denture; I-OD, implant-supported overdentures; N/A, nonapplicable; RCD, removable complete dentures.

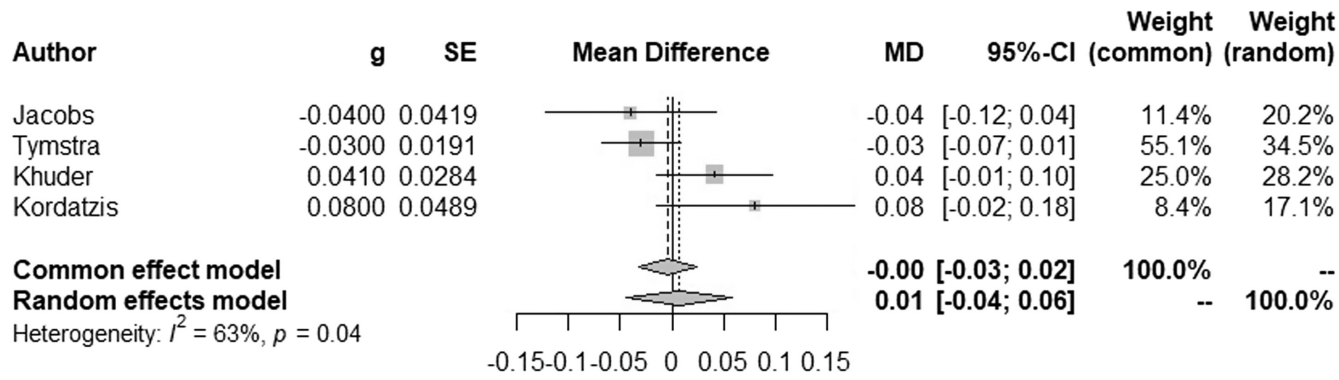

FIGURE 2 Forest plot of mean difference among the selected studies on posterior mandibular alveolar bone resorption.

and periodontal disease (Okuni et al., 2022; Yamada et al., 2022; Yamazaki et al., 2013a; Table 3).

3.5.2 | Results of the qualitative synthesis

Survival rates of teeth adjacent to edentulous spaces (TAES)

The study by Okuni et al., 2022 showed no statistical differences between patients rehabilitated with R-FPD and T-FPD and those rehabilitated with I-FPD. The study by Hatta et al., 2021 showed statistically higher SR of patients rehabilitated with I-FPD when compared with patients with NR. Conversely, three studies showed no statistically significant differences in the SR of patients rehabilitated with T-RPD and those rehabilitated with I-FPD (Yamada et al., 2022; Yamazaki et al., 2013a, 2013b; Table 8).

Survival rates of teeth nonadjacent to edentulous spaces (TNAES)

In the only study to clearly report on the SR of TNAES, a significant higher SR rate was observed in patients rehabilitated with I-FPD when compared with T-RPD (Table 8).

Survival rates of teeth opposing edentulous spaces (TOES)

Among the three studies to report the SR of TOES, one showed a significantly higher SR in patients rehabilitated with I-FPD when

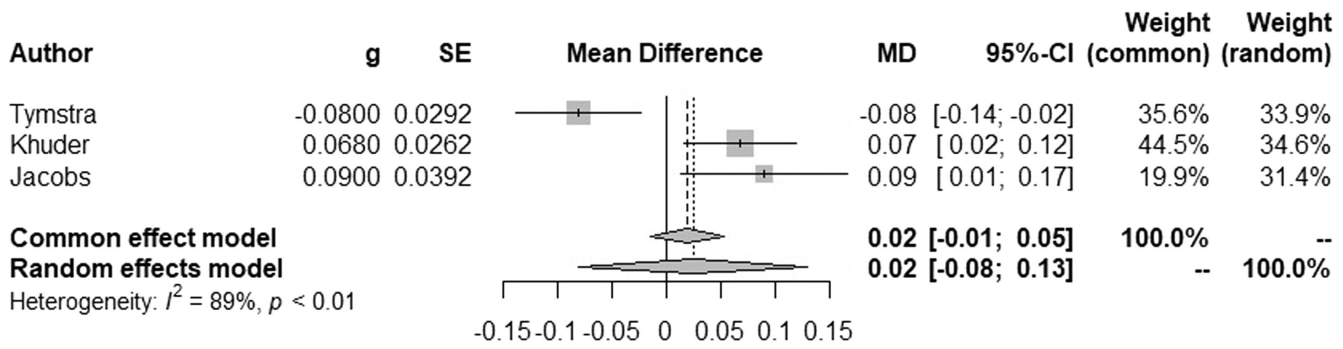

FIGURE 3 Forest plot of mean difference among the selected studies on anterior maxillary alveolar bone resorption.

TABLE 8 Survival rates (%) of remaining teeth of partially edentulous patients.

Authors (year)	Time in function (years)	R-FPD	T-FPD	T-RPD	NR	I-FPD	*p*-value
TAES							
Okuni et al. (2022)	10	89.0%	75.9%[a]	N/A	N/A	92.6%[a]	=.037[a]
Yamada et al. (2022)	4.6	N/A	N/A	89.7%	N/A	92.8%	=.567
Yamazaki et al. (2013a)	10	N/A	N/A	61.8%	N/A	62.2%	>.05
Yamazaki et al. (2013b)	10	N/A	N/A	80%	N/A	98%	>.05
Hatta et al. (2021)	6	N/A	N/A	NA	75%	100%	=.010
TNAES							
Yamada et al. (2022)	4.6	N/A	N/A	91.6%[a]	N/A	98.1%[a]	=.002[a]
TOES							
Yamada et al. (2022)	4.6	N/A	N/A	93.9%	N/A	97.5%	=.311
Yamazaki et al. (2013a)	10	N/A	N/A	83.8%	N/A	75%	>.05
Yamazaki et al. (2013b)	10	N/A	N/A	95%	75%	95%	>.05
ART							
Yamazaki et al. (2013a)	10	N/A	N/A	24.4%	N/A	40%	<.05
Yamazaki et al. (2013b)	10	N/A	N/A	50%	3%[a]	57%[a]	=.01[a]

Abbreviations: ART, all remaining teeth; I-FPD, implant-supported fixed partial denture; NR, no restoration; R-FPD, resin-bounded fixed partial denture; TAES, teeth adjacent to edentulous space; T-FPD, tooth-supported fixed partial denture; TNAES, teeth not adjacent to edentulous space; TOES, teeth opposing edentulous spaces; T-RPD, tooth-supported removable partial denture.

[a]Statistical difference between groups.

compared to those with NR, but no difference was observed with those rehabilitated with T-RPD (Yamazaki et al., 2013b). Two studies found no statistically significant differences between the SR in patients rehabilitated with I-FPD in comparison with those rehabilitated with T-RPD (Yamada et al., 2022; Yamazaki et al., 2013a; Table 8).

Survival rates of all remaining teeth (ART)

In the study by Yamazaki et al., 2013a, with a follow-up of 10 years, in patients with large partially edentulous areas (>3 missing teeth) the SR of ART was significantly higher in patients rehabilitated with I-FDP than those rehabilitated with T-RPD. Another retrospective study conducted by the same group demonstrated that in patients with short-span edentulous areas, the SR of ART in patients restored with I-FPD was comparable with those rehabilitated with T-RPD, but significantly higher when compared to those patients that received NR (Yamazaki et al., 2013b; Table 8).

Other complications in remaining teeth

Of the three studies that reported on the complications in the remaining teeth, the study of Yamada et al. (2022) showed significantly more complications in TAES, TNAES, and TOES in patients rehabilitated T-RPD when compared to those rehabilitated with I-FPD. Loss of retention was observed in 30 TAES (7.0% of the total subjects), and caries were observed in 80 TNAES (8.1% of the total subjects) and 46 TOES (7.3% of the total subjects). Caries was the most frequent complication in all patients, except for TAES in patients rehabilitated with T-RPD, in which loss of retention was the complication most frequently observed. The study by Yamazaki et al. (2013a) demonstrated that the incidence of complications in ART in patients rehabilitated with I-FPD (42%) was also lower than those rehabilitated with T-RPD (59%) and NR groups (90%). Patients treated with T-RPD lost approximately 80% of their TAES due to periodontal lesions. Regarding TOES, 4.8% of patients of patients rehabilitated with I-FPD, and 8.5% of patients

rehabilitated with T-RPD lost their teeth during the observation period. The cause for the only case of tooth loss in I-FPD group was periodontal lesion, whereas patients in T-RPD group mainly lost their teeth due to caries. Okuni et al. (2022) found no significant differences in the cumulative complication-free rates among patients treated with R-FPD, T-FPD, and I-FPD. Among the complications, the authors reported 87 cases of caries (79.1%), three cases of crown fracture (3.6%), and 19 cases of tooth extraction (17.3%) due to a periodontal lesion. They also showed that the main risk factors for the loss of TAES in patients treated with T-FDP in comparison to I-FPD in single-bounded edentulous spaces were the prosthetic material and deep periodontal probing depth.

3.5.3 | Results of the quantitative synthesis

Due to the heterogeneity of study designs, a meta-analysis could not be conducted with the studies that examined the effect of different types of prostheses on remaining teeth.

3.6 | Masseter muscle thickness

3.6.1 | Results of individual studies

Three studies evaluated jaw muscle thickness in fully edentulous patients, all of them specifically measuring masseter muscle thickness (MMT), one RCT (Maniewicz et al., 2019), one cross-sectional (Muller et al., 2012), and one prospective study (Amaral et al., 2019). The number of participating patients ranged between 12 and 80, totaling 158 individuals. All studies presented RCD, and one study also had fully dentate individuals as controls (Muller et al., 2012). The test groups were composed by I-OD in two studies, and I-OD and I-FCD in another (Muller et al., 2012). Time in function ranged from 2 months to 7 years. All studies evaluated MMT with the use of real-time linear ultrasound scanner and a linear array transducer (Table 4).

3.6.2 | Results of the qualitative synthesis

Although the three studies demonstrated more MMT in the I-OD groups when compared to the RCD groups, two studies reached statistical significance (Amaral et al., 2019; Muller et al., 2012). Maniewicz et al. (2019) showed no changes in MMT in the preferred chewing side (P-CS) and a nonsignificant increase of MMT in the not preferred chewing side (NP-CS; Table 9).

3.6.3 | Results of the quantitative synthesis

The meta-analysis was conducted with all three studies (number of observations: $o=108$) that compared masseter muscle thickness in patients rehabilitated with RCD and those rehabilitated with I-OD (Amaral et al., 2019; Maniewicz et al., 2019; Muller et al., 2012). According to the pooled results of the meta-analysis, both fixed and random effects models yielded a significant benefit of rehabilitation with I-OD when compared to RCD. Moreover, Cochran's Q test p-value $=.5919$ indicated no heterogeneity among the studies (Figure 4).

3.7 | Reporting biases

Egger's test indicated no publication bias of studies pooled to assess alveolar bone resorption in the posterior region of the mandible ($p=.4508$), in the anterior region of the maxilla ($p=.8719$), and masseter bone thickness ($p=.8013$). However, this meta-analysis contains a small number of studies, and Egger's test may lack the statistical power to detect bias when the number of studies is small (i.e., $k<10$).

4 | DISCUSSION

This review and meta-analysis provide a synthesis of the dental literature on the possible positive effect of interventions using implant-supported protheses on orofacial tissues over conventional prostheses or no treatment of fully and partially edentulous patients. From the 14 selected studies, three main outcomes emerged: alveolar bone resorption, effect on remaining teeth, and masseter muscle thickness. In this discussion, the main findings of each outcome and their possible implications to the clinical practice are highlighted.

4.1 | Bone resorption

Following tooth extraction, the alveolar process undergoes a series of physiological events that leads to a significant reduction in size

TABLE 9 Mean (±SD) of masseter muscle thickness during muscle contraction (in millimeters).

Authors (year)	Time in function	P-CS				NP-CS			
		RCD	I-OD	Diff	p- value	RCD	I-OD	Diff	p-value
Amaral et al. (2019)	2 months	9.8 ± 0.9	10.8 ± 1.0	+1.0	.01	N/A	N/A	N/A	—
Maniewicz et al. (2019)	7 years	11.0 ± 1.62	11.4 ± 2.10	0.0	.97	11.1 ± 1.0	11.4 ± 2.1	+0.3	.26
Muller et al. (2012)	At least 1 year	11.98 ± 1.84	13.29 ± 2.07	+1.3	.043	N/A	N/A	N/A	—

Abbreviations: Diff, difference between groups; I-OD, implant-supported overdenture; NP-CS, nonpreferred chewing side; P-CS, preferred chewing side; RCD, removable complete denture.

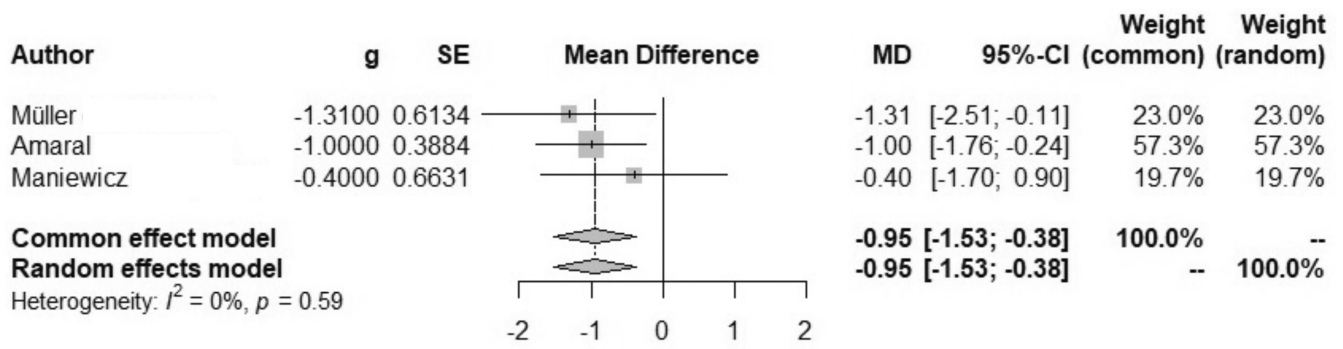

FIGURE 4 Forest plot of mean difference among the selected studies on masseter bone thickness.

and volume during and after healing (Araujo et al., 2006; Chappuis et al., 2017). When multiple adjacent teeth are extracted alveolar bone resorption is more significant, leading to horizontal and vertical deficiencies (Al-Askar et al., 2013). Even though it has been demonstrated that implant placement immediately after tooth extraction does not prevent the natural course of bone remodeling (Araujo et al., 2019), only a limited number of studies evaluated bone remodeling prospectively after functional oral rehabilitation with implants. In fully edentulous patients, it is believed that the constant compressive occlusal forces on the alveolar mucosa cause a gradual bone resorption of the underlying alveolar ridge (Ahmad et al., 2015; Carlsson, 2004; Maruo et al., 2010). In the long term, the occlusal stress on the alveolar ridge can lead to denture retention loss, and make implant rehabilitation more challenging (Huumonen et al., 2012).

This review has shown that adequate data on alveolar ridge resorption in fully edentulous patients following different rehabilitation modalities are still lacking. Although the qualitative analysis suggests that implant therapy may represent an advantage compared to conventional therapy, the meta-analysis of the pooled studies failed to show any such advantage. Differences in edentulism time may have had an important influence on the results. According to Jacobs et al. (1992), despite the more alveolar bone resorption observed in patients treated with I-OD when compared with RCD, when patients had been edentulous for more than 10 years, differences tended to disappear. This could be explained by the fact that after many years of edentulism, most of the alveolar bone process tends to resorb, leaving behind basal bone mostly. Moreover, alveolar bone resorption was also correlated with the status of the opposing arch (Jacobs et al., 1992; Khuder et al., 2017), a fact that may explain the reason why patients rehabilitated with I-OD presented similar bone resorption on the antagonistic ridge than those rehabilitated with RCD. These findings seem to reinforce the perception that regular maintenance appointments for the assessment of the occlusal adjustments can be fundamental in the prevention of maxillary bone resorption.

4.2 | Effect on remaining teeth

Failure to replace missing teeth can lead to a series of disruptions to the stomatognathic system (Shugars et al., 2000). It is a natural consequence of teeth adjacent to edentulous spaces to present extrusion and/or tilting, as well as occlusal disruptions over the years, which may lead to periodontal disease and an increased risk of caries (Aquilino et al., 2001; Shugars et al., 1998). It has been recently demonstrated that older patients with 4 or more missing teeth were more likely to experience multiple additional tooth loss, mainly caused by deeper probing pocket depth and lack of posterior support (Mihara et al., 2020). Several treatment modalities might be proposed for teeth or increasing partially edentulous patients. These individuals might be rehabilitated with conventional T-FPD, R-FPD, and T-RPD, or I-RPD and I-FPD, or even receive NR.

Not unexpectedly, the qualitative analysis showed that patients that received implant-supported therapy presented a tendency for higher SR and/or less tooth complications when compared to conventional therapy or no treatment. Nevertheless, care must be exercised, since significant differences exist in terms of the type of edentulism (single vs. multiple missing teeth; anterior vs. posterior; bounded vs. unbounded), treatment modalities, and the studied outcomes (TAES, TNAES, TOES, ART). Because of the diversity observed among studies, no meta-analysis could be conducted, clearly indicating the need for well-designed long-term prospective clinical studies that can permit comparisons between the effect of different types of restorations on the remaining dentition.

4.3 | Masseter muscle thickness

The consequences of age and full edentulism on masticatory masseter muscle atrophy and density have been previously demonstrated (Newton et al., 1987; Raustia et al., 1996). As the masseter muscle tissue age, a reduction in fiber diameter as well quantity seem to occur, being replaced by fat and connective tissue over time (Larsson, 1995). It has been demonstrated that overdentures supported by two to five teeth prevented the progress of masseter muscle atrophy when compared to completely edentulous patients that were rehabilitated with RCD (Newton et al., 2004). Moreover, in a case report that followed a 97-year-old patient during and after relining his mandibular RCD, MMT showed a 17% decrease during denture abstention and a significant increase beyond the preimplant level after I-OD insertion, suggesting that

masseter muscle bulk in old age may be dependable of denture function (Schimmel et al., 2010).

This review has shown that rehabilitation with I-OD may increase bite force and result in more masseter muscle thickness (Amaral et al., 2019; Muller et al., 2012). The only RCT included in this review, however, could not observe any significant differences in MMT either on the preferred chewing side or not preferred chewing side over a period of 7 years of observation (Maniewicz et al., 2019). A possible explanation is that aging might mask a possible training effect of the I-OD. Thus, although the meta-analysis of the pooled studies yielded a significant benefit for I-OD in comparison to RCD, the time factor seems to have an important effect in this type of analysis. Due to the differences observed in the results, MMT can only be properly assessed with long-term prospective clinical studies to better ascertain if the rehabilitation with I-OD actually offers an advantage over RCD.

4.4 | Limitations and future research directions

To the best of the authors' knowledge, this study represents the first attempt to systematically analyze the effect of implant therapy on the preservation of orofacial tissues. It remains unclear whether implant therapy has a positive effect in the sense of maintaining the alveolar ridge bone, preserving remaining teeth, or increasing/maintaining masseter muscle thickness in the long term when compared to conventional or no therapy. Therefore, due to a series of shortcomings involving study design and quality, definitive conclusions cannot be drawn.

Although efforts have been placed in making this review as comprehensively as possible, the gray literature was not consulted, and the search was restricted to articles in English published in journals available electronically, which may have resulted in some relevant studies being missed during the search procedure. Among the selected studies, only one was an RCT, which observed MMT over a period of 7 years, without finding any significant differences between treatment modalities. When contrasted with the work of Amaral et al. (2019), which found a significant MMT increase only 2 months after RCD had been relined into I-OD, it becomes clear that time emerges as a crucial factor in the analysis of the studied outcomes, which cannot be adequately dealt with by retrospective studies. Apart from that, in terms of quality, all the observational studies presented a moderate risk of bias, especially concerning confounding factors and the selection of participants in the study. Also, the diversity observed in the selected studies in terms of types of edentulism, populations, follow-up time and study designs all have a significant impact on the results, preventing a more consistent analysis. For instance, no comparative clinical study evaluating the effect of implant therapy on the course of bone remodeling in partially edentulous patients was found. On the other hand, no studies were found on the effect on the remaining teeth of patients that received complete restorations in the antagonistic arch.

Despite a tendency towards implant therapy, findings continue to be insufficient and controversial. It seems that this gap can only be overcome by the conduction of well-designed prospective comparatives studies, preferably RCT, so that the outcomes studied can be better ascertained in relation to the time factor. Nonetheless, while the therapeutical approach to a partially or fully edentulous patient may depend upon multiple factors such as individual anatomical features and overall treatment time and cost, the findings presented here should not discourage dentists from recommending implant-supported rehabilitation. This study has shown that implant-supported restorations, if not superior, they are at the very least equivalent to conventional rehabilitation in preserving orofacial tissues over time.

5 | CONCLUSIONS

This systematic review and meta-analysis were unable to unequivocally answer the focus question. While there are some indicators of the benefit of implant-supported prostheses over conventional prostheses or no therapy in preserving orofacial tissues, the evidence is still insufficient to confirm such perception. Long-term comparative longitudinal studies are strongly encouraged.

AUTHOR'S CONTRIBUTION

André B. De Souza and Flavia Matarazzo conceived the ideas, analysed the data, led the writing and reviewed the manuscript; Konstantinos Vazouras extracted the data and summarized the results; Panos Papaspyridakos and Hans-Peter Weber analysed the data and reviewed the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no private or commercial competing interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

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