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Oral function in completely edentulous patients rehabilitated with implant-supported dental prostheses: A systematic review and meta-analysis

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Abstract

Objectives: This review evaluated the effects of rehabilitation with implant-supported prostheses on the oral function of completely edentulous adults.

Materials and Methods: Systematic literature searches were performed to identify records reporting on oral function in completely edentulous adults rehabilitated with implant-supported prostheses. Meta-analyses were performed on various outcomes including bite force, masticatory performance, muscle activity, mandibular movement/chewing pattern, and salivary flow.

Results: 5507 records were identified. Thirty studies qualified for data extraction and analysis. The kappa (κ) for the search and identification strategy ranged between 0.50 and 1.00. Meta-analysis was performed grouping the studies by outcomes and split by time points of 6–12 months, 12–36 months, and >36 months after implant therapy. The meta-analyses revealed a significant improvement in oral function of completely edentulous adults after rehabilitation with implant-supported prostheses at 6–12 months ($Z = -4.895$, $p < .001$; 95% CI: −0.703, −0.301; $\tau^2 = .609$; $Q = 114.953$, df = 17, $p < .001$; $I^2 = 85.2\%$), at 12–36 months ($Z = -4.886$, $p < .001$; 95% CI: −0.580, −0.248; $\tau^2 = .908$; $Q = 280.611$, df = 35, $p < .001$; $I^2 = 87.5\%$) and at more than 36 months ($Z = -9.108$, $p < .001$; 95% CI: −1.472, −0.951; $\tau^2 = .019$; $Q = 7.918$, df = 7, $p = .340$; $I^2 = 11.6\%$). The included studies demonstrated a low to moderate risk of bias.

Conclusions: This systematic review concluded that the oral function of completely edentate adults significantly improved with implant-supported/retained prostheses, even when only one jaw received implant therapy. Therefore, implant therapy should be promoted for edentulous adults to alleviate the shortcomings of conventional complete removable dental prostheses.

KEYWORDS
bite force, complete removable dental prosthesis, implant-supported dental prostheses, masticatory performance, meta-analysis, oral function, salivary flow, systematic review

1 | INTRODUCTION

Oral health is considered an important aspect of ageing and frailty (Castrejón-Pérez et al., 2017). Frailty is a condition that is a precursor to complex health problems; it increases the morbidity and mortality of older adults. Nutrition plays an important role in the etiology of frailty. Tooth loss is a bane that results in impaired oral functions, and is linked to problems with mobility, cognitive decline, and malnutrition. Components of oral function including chewing function, bite force, articulatory motor skills, oral tactile sensitivity, and oral diadochokinesis, decline with old age and with tooth loss (Hoeksema et al., 2017; Shwe et al., 2019; Watanabe et al., 2017). A conceptual model on orofacial health proposed that, based on an individual's biological prerequisites and resources, the orofacial functional capacity is developed throughout the entire life. The ageing process along with the medical comorbidities influence this orofacial functional capacity and may lead to a state of oral hypofunction (Schimmel et al., 2021). The absence of an efficient rehabilitation further compromises oral hypofunction and may develop into oral frailty (Matsuo et al., 2016; Minakuchi et al., 2018). Malnutrition is a frequent problem in elderly edentulous patients especially in those who have ill-fitting or poorly fabricated dentures (Altenhoevel et al., 2012). It is imperative that an efficient rehabilitation, is carried out that will restore the oral functions, in order to reestablish and maintain a healthy nutritional state.

Complete removable dental prostheses (CRDPs) have been used to treat completely edentulous patients for more than a century and are considered a "gold standard" treatment for restoring edentulous patients. However, it is important to understand that the patients' oral functions are not entirely restored when rehabilitated with conventional CRDPs (Carlsson, 1984; Fontijn-Tekamp et al., 1998; Michael et al., 1990). Studies have demonstrated that the bite forces of CRDP wearers are impaired which may be attributed to a combination of factors including retention and stability of the CRDPs, reduced muscle force, degree of jaw opening, as well as pain or frailty (Haraldson et al., 1988; Kapur & Garrett, 1984; Mericske-Stern et al., 1993; Michael et al., 1990; Slagter et al., 1993). The use of implant support for the rehabilitation of edentulous jaws is a successful treatment modality that improves mastication, patient satisfaction as well as the oral health-related quality of life (OHRQoL), and these changes are observed even in dependent older adults (Feine et al., 2002; Feine, de Grandmont, et al., 1994; Feine, Maskawi, et al., 1994; Heydecke et al., 2003; Maniewicz et al., 2019; Meijer et al., 2009; Müller et al., 2004, 2012, 2013; Nogueira et al., 2021; Payne et al., 2017; Rashid et al., 2011; Schimmel et al., 2010; Srinivasan et al., 2017; Thomason et al., 2003, 2009, 2012; van der Bilt et al., 2006; van Kampen et al., 2004; Visser et al., 2005; Wismeijer et al., 1997; 2013). There is robust evidence to support dental implant therapy as a predictable long-term treatment option, in terms of improvement of CRDP retention and stability, implant survival, clinically acceptable peri-implant marginal bone level changes, and minimal complications. However, scientific evidence evaluating the efficacy of implant therapy in improving the parameters of oral function is still scarce or missing.

Therefore, the aim of this systematic review was to examine the body of evidence, available in current literature, evaluating the effect of dental implant therapy on the parameters of oral function (bite force, masticatory performance, swallowing function, muscle activity, lip force, speech and articulation, oral tactile sensitivity, oral diadochokinesis, and salivary flow) in completely edentulous patients.

Based on our aim, the population intervention comparison outcome time (PICOT) focus question set for this systematic review was: "What are the short- to long-term benefits in completely edentulous patients rehabilitated with implant-retained/supported fixed- or removable-dental prostheses when compared to those rehabilitated with conventional complete removable dental prostheses, with regard to oral function?"

2 | MATERIALS AND METHODS

This systematic review was performed and reported adhering to the PRISMA (preferred reporting items for systematic reviews and meta-analysis) guidelines (Page, McKenzie, et al., 2021; Page, Moher, et al., 2021). The protocol of this systematic review and meta-analysis was registered with PROSPERO: International prospective register of systematic reviews (CRD42021290852).

2.1 | Eligibility criteria and information sources

The complete list of inclusion and exclusion criteria used for this systematic review along with the sources of information for identifying the relevant records are detailed in Table 1. The last search update was performed on February 28, 2022.

2.2 | Search strategy and selection process

The search terms were identified based on the PICOT (population intervention comparison outcome and time) criterion and an initial search strategy was developed by the first author (MS). The search terms were either medical subject headings (MeSH) or other relevant terms in the "all fields" category, and were combined using appropriate Boolean operators (OR, AND, NOT) to structure the initial strategy, which was discussed with all co-investigators (PK, LA, and FM) and modified to develop the final search strategy. PK ran the search in all the listed databases to check for accuracy. Errors identified were corrected and then the search strategy was appropriately modified for final implementation. The complete list of search terms and the final implemented strategy are described in Table 1.

The results of the search strategy in each of the online databases were imported into a web-based collaboration software

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

Focus question	**What are the short- to long-term benefits in completely edentulous patients rehabilitated with implant-retained/supported fixed- or removable-dental prostheses when compared to those rehabilitated with conventional complete removable dental prostheses, with regard to oral function?**	
Criteria	Inclusion criteria	• Studies reporting on oral function in completely edentulous human subjects • Patients must be rehabilitated with implant-retained/supported dental prostheses (fixed or removable) • Dental implant type: micro-rough surface, root form dental implants • Patients must have been clinically examined during recall. • Minimum follow-up period: ≥ 6 months after implant loading
	Exclusion criteria	• Sample size of less than 10 cases • Animal studies • Invitro- and proof-of-concept experiments.
Information sources	Electronic databases	Medline (PubMed), Embase, the Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science
	Journals	All peer reviewed journals available online in databases: Medline (PubMed), Embase, the Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science
	Others	Popular online internet search engines (e.g., Google, Yahoo, Bing), Online internet research community websites (https://www.researchgate.net/), reference crosschecks, personal communications, hand-searches.
Search Terms (*PICOT*)	Population	**#1:** [MeSH]: jaw, edentulous OR mouth, edentulous **#2:** [All fields]: edentulous OR edentulous maxilla OR edentulous mandible OR completely edentulous mouth OR completely edentulous jaw
	Intervention or exposure	**#3:** [MeSH]: dental implants OR dental implantation, endosseous OR dental prosthesis, implant-supported OR denture, overlay **#4:** [All fields]: implant retained removable dental prosthesis OR implant-supported removable dental prosthesis OR overdenture OR implant overdentures OR implant retained overdentures OR implant-supported overdentures OR implant assisted overdentures OR implant-retained fixed dental prosthesis OR implant-supported fixed dental prosthesis OR implant-supported dental prosthesis
	Comparison	**#5:** [MeSH]: denture, complete OR dental prosthesis **#6:** [All fields]: conventional complete denture OR traditional complete denture OR complete removable dental prosthesis OR removable dental prosthesis
	Outcome	**#7:** [MeSH]: mastication OR chewing OR bite force OR speech OR phonetics OR salivation OR deglutition OR swallowing OR swallowing function **#8:** [All fields]: oral function OR chewing capability OR chewing efficiency OR chewing performance OR masticatory efficiency OR chewing function OR masticatory function OR masticatory performance OR eating capability OR food oral processing OR comminution OR maximum bite force OR maximum voluntary bite force OR jaw muscle activity OR masseter muscle thickness OR salivary flow rate OR stimulated salivary flow rate OR resting salivary flow rate OR tongue pressure OR tongue force OR tongue function OR lip function OR lip force OR maximum lip force OR swallowing threshold OR mandibular movement OR mandibular movement coordination OR Oral stereognosis OR oral diadochokinesis OR oral tactile sensitivity OR intra-oral sensitivity OR jaw kinematics
	Time	Minimum: 6 months post implant loading Maximum: no limit
Filters	Language	Not applied
	Species	Not applied
	Ages	Not applied
	Journal categories	Not applied
Search Builder	Search combination	(#1 OR #2) AND (#3 OR #4) AND (#5 OR #6) AND (#7 OR #8)

TABLE 1 (Continued)

Focus question	What are the short- to long-term benefits in completely edentulous patients rehabilitated with implant-retained/supported fixed- or removable-dental prostheses when compared to those rehabilitated with conventional complete removable dental prostheses, with regard to oral function?	
Search query as performed in the electronic databases	PubMed (Medline), Embase, CENTRAL, Web of Science	(jaw, edentulous OR mouth, edentulous OR edentulous OR edentulous maxilla OR edentulous mandible OR completely edentulous mouth OR completely edentulous jaw) AND (dental implants OR dental implantation, endosseous OR dental prosthesis, implant-supported OR denture, overlay OR implant retained removable dental prosthesis OR implant-supported removable dental prosthesis OR overdenture OR implant overdentures OR implant retained overdentures OR implant-supported overdentures OR implant assisted overdentures OR implant-retained fixed dental prosthesis OR implant-supported fixed dental prosthesis OR implant-supported dental prosthesis) AND (denture, complete OR dental prosthesis OR conventional complete denture OR traditional complete denture OR complete removable dental prosthesis OR removable dental prosthesis) AND (mastication OR chewing OR bite force OR speech OR phonetics OR salivation OR deglutition OR swallowing OR swallowing function OR oral function OR chewing capability OR chewing efficiency OR chewing performance OR masticatory efficiency OR chewing function OR masticatory function OR masticatory performance OR eating capability OR food oral processing OR comminution OR maximum bite force OR maximum voluntary bite force OR jaw muscle activity OR masseter muscle thickness OR salivary flow rate OR stimulated salivary flow rate OR resting salivary flow rate OR tongue pressure OR tongue force OR tongue function OR lip function OR lip force OR maximum lip force OR swallowing threshold OR mandibular movement OR mandibular movement coordination OR Oral stereognosis OR oral diadochokinesis OR oral tactile sensitivity OR intra-oral sensitivity OR jaw kinematics)
Search dates	January 1953 to 28 February 2022	A final confirmatory online search was performed on 28 February 2022. No further online searches were conducted after this date

platform that streamlines the production of systematic and other literature reviews (Covidence Systematic Review Software, Veritas Health Innovation, available at: www.covidence.org, last accessed on 22.10.2022). The software removed all the duplicate records as an initial step and then two investigators initially swept through the search results in the web-based software performing a thorough title and abstract screening. After the initial sweep, the shortlisted studies were included for a full-text analysis only after a mutual agreement between the two investigators. Disagreements, if present, were resolved by a consensus meeting with the first author. If multiple publications existed on the same cohort by the same research group, only the most recent publication was included in the review.

2.3 | Data collection process, data items, and missing data

Information relating to oral function including bite force, chewing efficiency, masticatory performance, jaw muscle activity (electromyography [EMG]), tongue function (tongue pressure and force), mandibular movement and chewing pattern, lip function (lip force), swallowing function, masseter thickness, oral stereognosis, oral diadochokinesis, oral sensitivity (tactile sensitivity), and phonetics (speech) were extracted, when present, from the identified records. The data extraction was performed by two investigators, who were reciprocally blinded to each other's data extraction. If any information was missing or not clear in the included record, the corresponding authors were contacted by email. The extracted parameters from the included studies are detailed in Tables 2–16. For any missing information from the included studies relevant to this systematic review, direct email contact was made with the corresponding author. Email reminders were sent to the authors in case of a nonresponse. Further emails were sent if the received information required further clarity. A nonresponse from the author or if the received information was not relevant, or inadequate, ultimately lead to the exclusion of the study.

2.4 | Study risk of bias assessment

The risk of bias of the included randomized controlled trials (RCTs) was assessed using the Cochrane tool for the assessment of risk of bias (Higgins et al., 2011), while the Newcastle–Ottawa tools were used for the prospectively designed cohort and case–control studies (Wells et al., 2014).

2.5 | Summary measures and synthesis of results

For each investigated parameter, mean and standard deviations along with sample sizes were extracted. A standardized

TABLE 2 Studies included in the meta-analysis reporting on bite force.

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Bite force (mean ± SD in *N*)	*n*	Method	Conclusion
Bakke et al. (2002)	CD/CD					115.5 ± 73.1	12	Strain gauge transducer (Miniature Bite-Force Recorder, Kleven)	Bite forces in the IOD group improved significantly compared to the CD group.
	CD/IOD	0/2	-/Astra Tech	-/ball or bar	12	189.2 ± 72.2	12		
	CD/IOD	0/2	-/Astra Tech	-/ball or bar	60	193.4 ± 54.7	12		
da Silva et al. (2011)	CD/CD					40 ± 5 Right side	16	Digital dynamometer, model IDDK (Kratos, Cotia, São Paulo, Brazil)	Bite forces in the IOD group improved significantly compared to the CD group.
	CD/IOD	0/2	-/Neodent-Titamax, Curitiba, SC, Brazil	-/ball	3	70 ± 9 Right side	16		
	CD/IOD	0/2	-/Neodent-Titamax, Curitiba, SC, Brazil	-/ball	15	71 ± 8 Right side	16		
	CD/CD					50 ± 7 Left side	16		
	CD/IOD	0/2	-/Neodent-Titamax, Curitiba, SC, Brazil	-/ball	3	76 ± 9 Left side	16		
	CD/IOD	0/2	-/Neodent-Titamax, Curitiba, SC, Brazil	-/ball	15	77 ± 9 Left side	16		
Enkling et al. (2019)	CD/CD					58.1 ± 41.3	20	GM 10® occlusal force meter (Nagano Keiki Co. Ltd, 1-30-4 Higashimagome, Ohtra-ku, Tokyo, Japan)	Overall, bite forces in the IOD group improved significantly compared to the CD group. However, older participants showed less improvement compared to the younger cohort after the first-year post-loading
	CD/IOD	0/4	-/Mini dental implant, MDI® system 3M ESPE	-/ball	12	112.5 ± 63.3	20		
	CD/IOD	0/4	-/Mini dental implant, MDI® system 3M ESPE	-/ball	60	150.1 ± 97.1	19		

TABLE 2 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Bite force (mean ± SD in *N*)	*n*	Method	Conclusion
Fontijn-Tekamp et al. (1998)	CD/CD					139.9 ± 42.2 Men	4	Miniature strain gauge bite-force transducer	The IOD group had significantly higher bite forces than the CD group. Women had significantly lower bite forces than men.
	CD/IOD	0/2	-/?	-/bar	28.8–62.4	235.2 ± 110 Men	5		
	CD/CD					70.6 ± 28.9 Women	13		
	CD/IOD	0/2	-/?	-/bar	28.8–62.4	148.2 ± 91.2 Women	22		
Lindquist and Carlsson (1985)	CD/CD					64.4 ± 26.94 SD was calculated from SEM	24	Steel bite fork with strain gauge transducer	Bite forces in the IFD group improved significantly compared to the CD group.
	CD/IFD	0/?	-/?	-/?	36	190.7 ± 77.89 SD was calculated from SEM	24		
Maniewicz et al. (2019)	CD/CD					48.1 ± 24.6	16	Occlusal Force-Meter GM10® (Nagano Keiki Co. Ltd., Tokyo, Japan)	The IOD group had significant higher bite forces than the CD group.
	CD/IOD	0/2	-/Straumann Standard Tissue Level Implants, Institute Straumann, Basel, Switzerland)	-/stud	3–12	111.3 ± 60.7	16		
	CD/CD					72.5 ± 45.3	16		
	CD/IOD	0/2	-/Straumann Standard Tissue Level Implants, Institute Straumann, Basel, Switzerland)	-/stud	≥24	145.9 ± 90.7	16		

(Continues)

TABLE 2 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Bite force (mean ± SD in *N*)	*n*	Method	Conclusion
Melo et al. (2018)	CD/CD					39.23 ± 17.65 Mean and SD were calculated from kg-force to *N*	29	Digital gnathodynamometer (IDDK, Kratos, São Paulo, Brazil)	Bite forces in the IOD group improved significantly compared to the CD group after immediate post-rehabilitation and 3-to-5-year follow-up period. There was no statistically significant difference in bite forces considering facial type (brachyfacial, mesofacial, and dolichofacial).
	CD/IFD	0/5	-/Neoporos, Neodent, Curitba, Brazil	-/?	36–60	150.04 ± 89.24 Mean and SD were calculated from kg-force to *N*	24		
van der Bilt et al. (2010)	CD/CD					183 ± 110	14	Bite-force transducer	Bite forces in the IOD group improved significantly compared to the CD group.
	CD/IOD	0/2	-/Frialit-2, Friadent, Friedrichsfeld, Germany	-/ball or bar	8–14	337 ± 137	14		
	CD/IOD	0/2	-/Frialit-2, Friadent, Friedrichsfeld, Germany	-/ball or bar	120	341 ± 136	14		

Note: -, not applicable;?, not specified in the article.

Abbreviations: CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; L, lower; *n*, sample size; SEM, standard error of mean; SD, standard deviation; U, upper.

TABLE 3 Studies included in the meta-analysis reporting on masticatory performance and efficiency by comminution tests (sieving methods).

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Masticatory performance (mean ± SD)	*n*	Method	Conclusion
Outcome: X50 (median particle size, the less value, the better efficiency)						Standardized in mm			
Marcello-Machado et al. (2018)	CD/CD					5.29 ± 1.15	23	Chewing artificial food Optocal (17 cubes, 5.6 mm) for 40 strokes	Masticatory performance (X50) in the IOD group improved significantly compared to the CD group.
	CD/IOD	0/2	-/NeoPoros, Neodent, Curitiba, PR, Brazil	-/stud	3	4.38 ± 1.37	23		
	CD/IOD	0/2	-/NeoPoros, Neodent, Curitiba, PR, Brazil	-/stud	6	4.44 ± 1.2	23		
	CD/IOD	0/2	-/NeoPoros, Neodent, Curitiba, PR, Brazil	-/stud	12	4.31 ± 1.21	23		
van der Bilt et al. (2010)	CD/CD					4.6 ± 0.7	14	Chewing artificial food Optocal for 15 strokes	Masticatory performance (X50) in the IOD group improved significantly compared to the CD group.
	CD/IOD	0/2	-/Frialit-2, Friadent, Friedrichsfeld, Germany	-/ball or bar	8–14	3.7 ± 0.5	14		
	CD/IOD	0/2	-/Frialit-2, Friadent, Friedrichsfeld, Germany	-/ball or bar	120	3.7 ± 0.7	14		
	CD/CD					3.4 ± 0.6	14	Chewing artificial food Optocal for 30 strokes	
	CD/IOD	0/2	-/Frialit-2, Friadent, Friedrichsfeld, Germany	-/ball or bar	8–14	2.4 ± 0.4	14		
	CD/IOD	0/2	-/Frialit-2, Friadent, Friedrichsfeld, Germany	-/ball or bar	120	2.5 ± 0.7	14		
Outcome: %weight of test material that was passed through the sieve (the more value, the better efficiency)						Standardized in %weight of passed test material			
Borges Tde et al. (2011)	CD/CD					14.33 ± 14.42	16	Chewing artificial food Optocal for 40 strokes, then using 2.8-mm sieve	Masticatory performance (%weight of passed test material) in the IOD group improved significantly compared to the CD group.
	CD/IOD	0/2	-/Conexão Prosthesis System Limited, São Paulo, SP, Brazil)	-/bar	3	26.68 ± 17.85	16		
	CD/IOD	0/2	-/Conexão Prosthesis System Limited, São Paulo, SP, Brazil)	-/bar	6	27.70 ± 17.46	16		

(Continues)

TABLE 3 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Masticatory performance (mean ± SD)	*n*	Method	Conclusion
Garrett et al. (1998)	CD/CD					39.8 ± 12.5 Peanut	28	Chewing peanuts (3 g) for 20 strokes, then using 1.7-mm sieve. Chewing carrots (3 g) for 40 strokes, then using 4.0-mm sieve	The IOD group had no significant advantage over the CD group for improving the ability to comminute food.
	CD/IOD	0/2	-/IMZ	-/bar	6	40.2 ± 14.6 Peanut	50		
	CD/CD					42 ± 11.2 Peanut	19		
	CD/IOD	0/2	-/IMZ	-/bar	24	40.5 ± 13 Peanut	30		
Pera et al. (1998)	CD/CD					8.2 ± 3.1	11	Chewing artificial food Optosil (17 cubes, 5.6 mm) for 60 strokes, then using 5.6-mm sieve	Masticatory performance (%weight of passed test material) in the IOD group improved significantly compared to the CD group.
	CD/IOD	0/2	-/?	-/ball	12	19.3 ± 5.8	12		
Sun et al. (2014)	CD/CD					47.41 ± 7.23	50	Chewing peanuts (4 g) for 20 s	Masticatory performance (%weight of passed test material) in the IOD group improved significantly compared to the CD group.
	CD/IOD	0/2	-/Strauman Company, Waldenburg, Switzerland	-/stud or magnetic	6	62.58 ± 6.64	49		
Outcome: $N_{1/2}$ (the number of chewing strokes necessary to reduce the value of X50 to half the initial particle size, the less value, the better efficiency)						Standardized in number of chewing cycles			
van der Bilt et al. (2010)	CD/CD					52 ± 25	14	Chewing artificial food Optocal for 15 and 30 strokes	Masticatory performance ($N_{1/2}$) in the IOD group improved significantly compared to the CD group.
	CD/IOD	0/2	-/Frialit-2, Friadent, Friedrichsfeld, Germany	-/ball or bar	8–14	24 ± 7	14		
	CD/IOD	0/2	-/Frialit-2, Friadent, Friedrichsfeld, Germany	-/ball or bar	120	27 ± 12	14		

TABLE 3 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Masticatory performance (mean ± SD)	*n*	Method	Conclusion
Outcome: C_i (Chewing efficiency index (Ci, 1 = good, 5 = poor))									
Lindquist and Carlsson (1985)	CD/CD					3.5 ± 1.22 SD was calculated from SEM	24	Almonds and a sieve-system	Masticatory performance (C_i) in the IFD group improved significantly compared to the CD group.
	CD/IFD	0/?	-/?	-/?	36	2.1 ± 0.69 SD was calculated from SEM	24		

Note: -, not applicable;?, not specified in the article.

Abbreviations: CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; L, lower; *n*, sample size; SEM, standard error of mean; SD, standard deviation; U, upper.

difference in means was calculated at 95% confidence intervals (95% CI). Inter-investigator reliability was assessed using Cohen's unweighted kappa (**κ**) (Landis & Koch, 1977). The meta-analysis was performed for prospectively designed studies reporting on and comparing cohorts rehabilitated with conventional complete removable dental prostheses (CRDPs) in both jaws (CD/CD) with cohorts rehabilitated with conventional maxillary CRDPs opposing a mandibular implant-retained/supported removable or fixed prostheses (CD/IOD or IFD) for the following outcomes: bite force, chewing efficiency or masticatory performance, muscle activity, mandibular movement and chewing pattern, and salivary flow rate. Lip force could not be included in the meta-analysis and was reported qualitatively. In this review individual subgroups in the studies were considered independent. Confidence intervals (CIs) were set to 95%, and standardized mean differences were calculated for each outcome parameter using comprehensive meta-analysis software, version 3.0 (Biostat). I-squared statistics (I^2-statistics) was used to assess the heterogeneity across the included studies, and accordingly, random-effects or fixed-effects models were used (DerSimonian & Laird, 1986).

The current review did not distinguish between: the types of implant rehabilitations (fixed or removable), or the number of implants employed for the rehabilitation, as well as the different types of attachments employed for the IODs. The meta-analyses were categorized for different time points and grouped by the outcome parameters. The different time points used in this meta-analyses were: 6–12 months, 12–36 months, and more than 36 months, after the insertion of the implant-supported prostheses.

2.6 | Publication biases and additional analyses

Descriptive analysis was performed on all studies to report their intervention groups, number of participants, number of implants, implant details, attachment systems, follow-up period, outcome parameters, methods applied for measuring outcomes, and conclusions. Publication bias was assessed across the studies with Egger's statistics, and were explored graphically with funnel plots (Sterne & Egger, 2001).

3 | RESULTS

3.1 | Study selection and study characteristics

The initial search identified 5507 records (Medline [PubMed]: $n = 2581$; Embase: $n = 1302$; CENTRAL: $n = 187$; Web of science: $n = 1437$). The automated removal of duplicates by the software resulted in 2205 records being eliminated. A total of 3302 records were screened and 30 relevant records qualified for data extraction and final analysis. The overall kappa (**κ**) scores for the study search, identification, and inclusion processes ranged between

TABLE 4 Studies included in the meta-analysis reporting on masticatory performance by mixing ability tests (color methods).

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Masticatory performance (mean ± SD)	*n*	Method	Conclusion
Outcome: VOH (variance of hue, the less value, the better efficiency)									
de Resende et al. (2021)	CD/CD					~0.543 ± ~0.157 Mean and SD were estimated from diagram using ImageJ2 software (version 2.9.0/1.53t)	23	Chewing a two-color chewing gum (Vivident Fruitswing Karpuz/Asai Üzümü, Perfetti van Melle, Turkey) for 20 strokes. The ViewGum© software (dHAL Software, Greece, www.dhal.com) was used to measure the variance of the hue (VOH)	Masticatory performance (VOH) in the 1-IOD group improved significantly compared to the CD group after 6-month and 1-year follow-up. While masticatory performance (VOH) in the 2-IOD group improved significantly compared to the CD group after 1-year follow-up.
	CD/IOD	0/1	-/Straumann® Standard Plus SLActive®	-/ball	6	~0.512 ± ~0.114 Mean and SD were estimated from diagram using ImageJ2 software (version 2.9.0/1.53t)	23		
	CD/IOD	0/1	-/Straumann® Standard Plus SLActive®	-/ball	12	~0.402 ± ~0.104 Mean and SD were estimated from diagram using ImageJ2 software (version 2.9.0/1.53t)	22		
	CD/CD					~0.466 ± ~0.144 Mean and SD were estimated from diagram using ImageJ2 software (version 2.9.0/1.53t)	24		
	CD/IOD	0/2	-/Straumann® Standard Plus SLActive®	-/ball	6	~0.485 ± ~0.121 Mean and SD were estimated from diagram using ImageJ2 software (version 2.9.0/1.53t)	24		
	CD/IOD	0/2	-/Straumann® Standard Plus SLActive®	-/ball	12	~0.423 ± ~0.112 Mean and SD were estimated from diagram using ImageJ2 software (version 2.9.0/1.53t)	24		

TABLE 4 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Masticatory performance (mean ± SD)	*n*	Method	Conclusion
Enkling et al. (2019)	CD/CD					0.78 ± 0.22	20	Chewing a two-color chewing gum for 20 strokes. The ViewGum© software was used to measure the variance of the hue (VOH)	The color-mixing ability revealed no difference in chewing efficiency (VOH) during the first year of function but was found to be improved at the 5-year follow-up relative to baseline and to 1 year.
	CD/IOD	0/4	-/Mini dental implant, MDI® system 3 M ESPE	-/ball	12	0.86 ± 0.18	20		
	CD/IOD	0/4	-/Mini dental implant, MDI® system 3 M ESPE	-/ball	60	0.66 ± 0.22	19		
Hartmann et al. (2020)	CD/CD					0.604 ± 0.14 20-stroke value	14	Chewing a two-color chewing gum (Vivident Fruitswing Karpuz/Asai Üzümü, Perfetti van Melle, Turkey) for 20 and 50 strokes. The ViewGum© software (dHAL Software, Greece, www.dhal.com) was used to measure the variance of the hue (VOH)	Masticatory performance (VOH) in the 1-IOD group, the 2-IOD group and the IFD group improved significantly compared to the CD group after 6-month and 1-year follow-up, considering both the tests for 20 and 50 cycles. There was no significant difference among the 1-IOD group, the 2-IOD group and the IFD group. It was also evident a small increase in VOH values from 6- to 12-month follow-ups, suggesting a slight declining in chewing function after 1 year for the 1-IOD group, the 2-IOD group and the IFD group.
	CD/IOD	0/1	-/Titamax TI Cortical, Neodent, Brazil	-/ball	6	0.356 ± 0.14 20-stroke value	11		
	CD/IOD	0/1	-/Titamax TI Cortical, Neodent, Brazil	-/ball	12	0.5 ± 0.16 20-stroke value	11		
	CD/CD					0.634 ± 0.09 20-stroke value	17		
	CD/IOD	0/2	-/Titamax TI Cortical, Neodent, Brazil	-/ball	6	0.388 ± 0.14 20-stroke value	13		
	CD/IOD	0/2	-/Titamax TI Cortical, Neodent, Brazil	-/ball	12	0.427 ± 0.14 20-stroke value	13		
	CD/CD					0.584 ± 0.09 20-stroke value	15		
	CD/IFD	0/4	-/Titamax TI Cortical, Neodent, Brazil	-/?	6	0.347 ± 0.11 20-stroke value	13		
	CD/IFD	0/4	-/Titamax TI Cortical, Neodent, Brazil	-/?	12	0.42 ± 0.14 20-stroke value	13		

(Continues)

TABLE 4 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Masticatory performance (mean ± SD)	*n*	Method	Conclusion
Maniewicz et al. (2019)	CD/CD					0.83 ± 0.11	16	Chewing a two-color chewing gum (Hubba Bubba® Tape Gum, The Wrigley Company Ltd., England) for 20 strokes. The ViewGum© software was used to measure the variance of the hue (VOH)	No significant change (VOH) was observed in the IOD group compared to the CD group.
	CD/IOD	0/2	-/Straumann Standard Tissue Level Implants, Institute Straumann, Basel, Switzerland)	-/stud	3–12	0.73 ± 0.16	16		
	CD/CD					0.8 ± 0.11	16		
	CD/IOD	0/2	-/Straumann Standard Tissue Level Implants, Institute Straumann, Basel, Switzerland)	-/stud	≥24	0.66 ± 0.21	16		

TABLE 4 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Masticatory performance (mean ± SD)	*n*	Method	Conclusion
Nogueira et al. (2019)	CD/CD				6	~0.642 ± ~0.109 20-stroke value, Mean and SD were estimated from diagram using ImageJ2 software (version 2.9.0/1.53t)	19	Chewing a two-color chewing gum (Vivident Fruitswing Karpuz/Asai Üzümü, Perfetti van Melle, Turkey) for 20 and 50 strokes. The ViewGum© software (dHAL Software, Greece, www.dhal.com) was used to measure the variance of the hue (VOH)	The masticatory performance (VOH) of edentulous patients rehabilitated with mandibular CD improved significantly after a 12-month follow- up period, irrespective of the stabilization of the mandibular denture with a single implant or not. However, the greater improvement in the mixing ability of the IOD group after 6 months suggests that the use of an implant to retain the mandibular denture may result in a different pattern of changes in masticatory performance compared to patients rehabilitated with a CD.
	CD/IOD	0/1	-/Straumann® Standard Plus SLActive®, Institut Straumann AG, Basel, Switzerland	-/ball	6	~0.567 ± ~0.088 20-stroke value, Mean and SD were estimated from diagram using ImageJ2 software (version 2.9.0/1.53t)	15		
	CD/CD				12	~0.454 ± ~0.119 20-stroke value, Mean and SD were estimated from diagram using ImageJ2 software (version 2.9.0/1.53t)	19		
	CD/IOD	0/1	-/Straumann® Standard Plus SLActive®, Institut Straumann AG, Basel, Switzerland	-/ball	12	~0.509 ± ~0.134 20-stroke value, Mean and SD were estimated from diagram using ImageJ2 software (version 2.9.0/1.53t)	15		

(Continues)

TABLE 4 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Masticatory performance (mean ± SD)	*n*	Method	Conclusion
Outcome: mixing ability index (the more value, the better efficiency)									
Khalid et al. (2020)	CD/CD					−0.32 ± 0.69	23	Chewing a paraffin wax cube for 10 strokes. The masticated wax cubes were removed, and color mixing was analyzed on a scanner	Masticatory performance (mixing ability index) in the IOD group improved significantly compared to the CD group after 3-month and 3-year follow-up.
	CD/IOD	0/2	-/?	-/stud or telescopic	3	0.67 ± 0.48	23		
	CD/IOD	0/2	-/?	-/stud or telescopic	36	0.62 ± 0.66	22		
Yunus et al. (2014)	CD/CD					−0.2 ± 0.56	17	Chewing temperature-controlled two-color wax cubes for 10 strokes. The masticated wax cubes were scanned and analyzed by the digital image analyzer (Luzex-FS)	Masticatory performance (mixing ability index) in the IOD group improved significantly compared to the CD group after 3-month and 1-year follow-up.
	CD/IOD	0/2	-/Ankylos, Dentsply Friadent	-/telescopic	3	0.66 ± 0.44	17		
	CD/IOD	0/2	-/Ankylos, Dentsply Friadent	-/telescopic	12	0.86 ± 0.43	17		

Note: -, not applicable;?, not specified in the article.

Abbreviations: CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; L, lower; *n*, sample size; SEM, standard error of mean; SD, standard deviation; U, upper.

TABLE 5 Studies included in the meta-analysis reporting on swallowing threshold.

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Masticatory performance (mean ± SD)	*n*	Method	Conclusion
Outcome: number of chewing cycles required to chew test food until ready to swallow (the less value, the better efficiency)						Standardized in strokes			
Garrett et al. (1998)	CD/CD				6	46.1 ± 24.4 Carrot value	28	Chewing carrots (3 g) and peanuts (3 g) until ready to swallow	The IOD group had no significant advantage over the CD group for improving the ability to comminute food.
	CD/IOD	0/2	-/IMZ	-/bar	6	43 ± 19 Carrot value	50		
	CD/CD				24	41.8 ± 14.3 Carrot value	19		
	CD/IOD	0/2	-/IMZ	-/bar	24	36.3 ± 12.5 Carrot value	30		
	CD/CD				6	41.8 ± 19.3 Peanut value	28		
	CD/IOD	0/2	-/IMZ	-/bar	6	44.1 ± 23.1 Peanut value	50		
	CD/CD				24	44.3 ± 14.7 Peanut value	19		
	CD/IOD	0/2	-/IMZ	-/bar	24	39.7 ± 11.9 Peanut value	30		
Lindquist and Carlsson (1985)	CD/CD					56.8 ± 57.81 SD was calculated from SEM	24	Chewing 1 almond until ready to swallow	Masticatory performance (swallowing threshold stroke) in the IFD group improved significantly compared to the CD group.
	CD/IFD	0/?	-/?	-/?	36	29.7 ± 12.25 SD was calculated from SEM	24		

(Continues)

TABLE 5 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Masticatory performance (mean ± SD)	*n*	Method	Conclusion
Marcello-Machado et al. (2018)	CD/CD					75.83 ± 54.72	23	Chewing artificial food Optocal (17 cubes, 5.6 mm) until ready to swallow	No significant change (swallowing threshold stroke) was observed in the IOD group compared to the CD group after 3-to-12-month follow-up.
	CD/IOD	0/2	-/NeoPoros, Neodent, Curitiba, PR, Brazil	-/stud	3	65.78 ± 34.97	23		
	CD/IOD	0/2	-/NeoPoros, Neodent, Curitiba, PR, Brazil	-/stud	6	67.84 ± 37.43	23		
	CD/IOD	0/2	-/NeoPoros, Neodent, Curitiba, PR, Brazil	-/stud	12	59.17 ± 24.51	23		
Outcome: time required to chew test food until ready to swallow (the less value, the better efficiency)						Standardized in seconds			
Garrett et al. (1998)	CD/CD	0/0	-/–	-/–	6	34.2 ± 23.7 Carrot value	28	Chewing carrots (3 g) and peanuts (3 g) until ready to swallow	The IOD group had no significant advantage over the CD group for improving the ability to comminute food.
	CD/IOD	0/2	-/IMZ	-/bar	6	29.9 ± 12.1 Carrot value	50		
	CD/CD				24	27.5 ± 9.9 Carrot value	19		
	CD/IOD	0/2	-/IMZ	-/bar	24	25 ± 9.9 Carrot value	30		
	CD/CD				6	30.1 ± 14.1 Peanut value	28		
	CD/IOD	0/2	-/IMZ	-/bar	6	31.1 ± 14.5 Peanut value	50		
	CD/CD				24	28.5 ± 10.6 Peanut value	19		
	CD/IOD	0/2	-/IMZ	-/bar	24	28 ± 9.3 Peanut value	30		

TABLE 5 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Masticatory performance (mean ± SD)	*n*	Method	Conclusion
Lindquist and Carlsson (1985)	CD/CD					~48.541 ± ~22.946 Mean and SD were estimated from diagram using ImageJ2 software (version 2.9.0/1.53t)	24	Chewing 1 almond until ready to swallow	Masticatory performance (swallowing threshold time) in the IFD group improved significantly compared to the CD group.
	CD/IFD	0/?	-/?	-/?	36	~21.258 ± ~4.717 Mean and SD were estimated from diagram using ImageJ2 software (version 2.9.0/1.53t)	24		
Marcello-Machado et al. (2018)	CD/CD					75.78 ± 54.53	23	Chewing artificial food Optocal (17 cubes, 5.6 mm) until ready to swallow	No significant change (swallowing threshold time) was observed in the IOD group compared to the CD group after 3-to-12-month follow-up.
	CD/IOD	0/2	-/NeoPoros, Neodent, Curitiba, PR, Brazil	-/stud	3	57.7 ± 27.64	23		
	CD/IOD	0/2	-/NeoPoros, Neodent, Curitiba, PR, Brazil	-/stud	6	63.84 ± 36.38	23		
	CD/IOD	0/2	-/NeoPoros, Neodent, Curitiba, PR, Brazil	-/stud	12	57.8 ± 30.21	23		

Note: -, not applicable;?, not specified in the article.

Abbreviations: CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; L, lower; *n*, sample size; SEM, standard error of mean; SD, standard deviation; U, upper.

TABLE 6 Studies included in the meta-analysis reporting on electromyography (EMG).

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	EMG (mean ± SD)	*N*	Method	Conclusion
Berretin-Felix et al. (2008)	CD/CD					30.21 ± 18.16 Masseter and chewing rubber value	15	μV RMS measured on masseter, submental muscles, and superior orbicularis by an EMG device (NeuroEducator® 3 Electromyography System, Therapeutic Alliances Inc., Fairborn, OH, USA) while chewing a 2-cm piece of natural rubber, swallowing food paste and swallowing water	Statistical analysis showed that only the masseter muscle had a significant loss in electromyographic activity, with a tendency of similar response for the submental muscles. Moreover, there was an increase in the activity of the orbicularis oris muscle during rubber chewing after treatment, yet without statistically significant difference. The IFD group revealed a decrease in electromyographic amplitude for the masseter muscles during swallowing, which may indicate adaptation to new conditions of stability provided by fixation of the complete denture in the mandibular arch.
	CD/IFD	0/5	-/?	-/?	3	30.8 ± 12.74 Masseter and chewing rubber value	15		
	CD/IFD	0/5	-/?	-/?	6	24.03 ± 13.32 Masseter and chewing rubber value	15		
	CD/IFD	0/5	-/?	-/?	18	24.41 ± 11.53 Masseter and chewing rubber value	15		

TABLE 6 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	EMG (mean ± SD)	N	Method	Conclusion
da Silva et al. (2011)	CD/CD					0.2 ± 0.05 Right masseter at rest	16	µV normalized mean measured on masseter and temporalis by an EMG device (Myosystem-Br1 apparatus, DataHominis Ltda, Uberlândia, MG, Brazil) while at rest, mandibular protrusion, right and left lateral mandibular movement	A decrease in EMG during the rest, lateral and protrusion movements after 15 months with IOD was observed.
	CD/IOD	0/2	-/Neodent-Titamax, Curitiba, SC, Brazil	-/ball	3	0.22 ± 0.04 Right masseter at rest	16		
	CD/IOD	0/2	-/Neodent-Titamax, Curitiba, SC, Brazil	-/ball	15	0.11 ± 0.01 Right masseter at rest	16		
	CD/CD					0.25 ± 0.05 Left masseter at rest	16		
	CD/IOD	0/2	-/Neodent-Titamax, Curitiba, SC, Brazil	-/ball	3	0.17 ± 0.02 Left masseter at rest	16		
	CD/IOD	0/2	-/Neodent-Titamax, Curitiba, SC, Brazil	-/ball	15	0.15 ± 0.01 Left masseter at rest	16		

Note: -, not applicable;?, not specified in the article.

Abbreviations: CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; L, lower; *n*, sample size; SEM, standard error of mean; SD, standard deviation; U, upper.

0.5 and 1.00, which can be considered as moderate to excellent agreement. The entire search and inclusion process is shown in a flow diagram (Figure 1). Of the included 30 studies, 20 studies (Tables 2–8) provided data for meta-analysis for the various investigated parameters of oral function (Bakke et al., 2002; Benzing et al., 1994; Berretin-Felix et al., 2008; Borges Tde et al., 2011; da Silva et al., 2011; de Resende et al., 2021; Enkling et al., 2019; Fontijn-Tekamp et al., 1998; Garrett et al., 1998; Hartmann et al., 2020; Khalid et al., 2020; Lindquist & Carlsson, 1985; Maniewicz et al., 2019; Marcello-Machado et al., 2018; Melo et al., 2018; Nogueira et al., 2019; Pera et al., 1998; Sun et al., 2014; van der Bilt et al., 2010; Yunus et al., 2014).

Ten studies (Tables 9–14) provided information for descriptive analysis (De Rossi et al., 2014; Geckili et al., 2011, 2012; Geertman et al., 1994; Jacobs & van Steenberghe, 1993; Manzon et al., 2021; Müller et al., 2012; Schimmel et al., 2017; Suzuki et al., 1999; Vieira et al., 2014).

In this review, studies were identified which compared the parameters of oral function in edentate subjects who were rehabilitated with conventional CRDPs in both jaws with edentate individuals rehabilitated with conventional maxillary CRDPs and mandibular implant-supported prostheses. The systematic review was unable to identify purpose-designed studies with maxillary implant-supported prostheses that satisfied the scope and inclusion criteria of the current review.

This systematic review could identify records for meta-analysis of the following listed outcomes: bite force, masticatory performance (sieve method, colorimetric method, swallowing threshold), stimulated salivary flow rate, mandibular movement, and chewing pattern (area of the chewing pattern, opening and closing velocity, masticatory cycle/second, and the vertical height) (Figure 1).

The review further identified a single record for lip force, but was not included in the meta-analysis because it was of a retrospective design (Schimmel et al., 2017).

Although this review also identified studies for evaluating the effect of implant-supported rehabilitation on the masseter muscle thickness (Amaral et al., 2019; Maniewicz et al., 2019; Müller et al., 2012; 2013), this parameter was excluded from this review since it is not oral function and will be presented in one of the other ITI consensus papers (De Souza et al., 2023).

The review further identified records for the effect of implant-supported prostheses on speech (Fonteyne et al., 2021; Jacobs et al., 2001; Meira et al., 2021) and oral tactile threshold (active and passive) (Luraschi et al., 2012), but these outcome measures were excluded either because the follow-up periods were less than 6 months, or that there were no conventional CRDP control groups or had an insufficient sample size (<10 cases).

This review, however, failed to locate records for evaluating the effect of implant-supported prostheses on the following parameters of oral function: tongue function (tongue pressure and force), swallowing function, oral stereognosis, and oral diadochokinesis.

TABLE 7 Studies included in the meta-analysis reporting on jaw kinematics (mandibular movement and chewing pattern).

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Mandibular movement and chewing pattern (mean ± SD)	*n*	Method	Conclusion
Outcome: masticatory cycle per second						Standardized in cycles/s			
Benzing et al. (1994)	CD/CD					1.46 ± 0.3	15	Sirognathograph (Siemens, Bensheim, Germany) while chewing Gummy bear	No significant change (masticatory cycle per second) was observed in the IOD group compared to the CD group.
	CD/IOD	0/2	-/IMZ	-/bar	6–41	1.4 ± 0.4	15		
Outcome: opening and closing velocity						Standardized in mm/s			
Benzing et al. (1994)	CD/CD					48.71 ± 13.33 Opening velocity value	15	Sirognathograph (Siemens, Bensheim, Germany) while chewing Gummy bear	No significant change (opening and closing velocity) was observed in the IFD group compared to the CD group.
	CD/IOD	0/2	-/IMZ	-/bar	6–41	49.32 ± 12.76 Opening velocity value	15		
	CD/CD					36.91 ± 11.61 Closing velocity value	15		
	CD/IOD	0/2	-/IMZ	-/bar	6–41	37.27 ± 11.7 Closing velocity value	15		
Outcome: area of chewing pattern in the frontal plane						Standardized in mm^2			
Benzing et al. (1994)	CD/CD					138.67 ± 46.18	15	Sirognathograph (Siemens, Bensheim, Germany) while chewing Gummy bear	No significant change (area of chewing pattern in the frontal plane) was observed in the IOD group compared to the CD group.
	CD/IOD	0/2	-/IMZ	-/bar	6–41	149.42 ± 49.17	15		
Pera et al. (1998)	CD/CD					27.6 ± 14.2	12	Sirograph (Siemens Inc., Erlangen, Germany) while chewing artificial food (Optosil) during the first 10 s	Area of chewing pattern in the frontal plane in the IOD group increased significantly compared to the CD group.
	CD/IOD	0/2	-/?	-/ball	12	71.9 ± 31.7	12		

TABLE 7 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Mandibular movement and chewing pattern (mean ± SD)	*n*	Method	Conclusion
Outcome: vertical length of chewing pattern in the frontal plane						Standardized in mm			
Benzing et al. (1994)	CD/CD					19.33 ± 5.25	15	Sirognathograph (Siemens, Bensheim, Germany) while chewing Gummy bear	No significant change (vertical length of chewing pattern in the frontal plane) was observed in the IOD group compared to the CD group.
	CD/IOD	0/2	-/IMZ	-/bar	6–41	18.49 ± 2.67	15		
Pera et al. (1998)	CD/CD					24 ± 8.7	12	Sirograph (Siemens Inc., Erlangen, Germany) while chewing artificial food (Optosil) during the first 10 s	Vertical length of chewing pattern in the frontal plane in the IOD group increased significantly compared to the CD group.
	CD/IOD	0/2	-/?	-/ball	12	32.3 ± 8.7	12		

Note: -, not applicable;?, not specified in the article.

Abbreviations: CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; L, lower; *n*, sample size; SEM, standard error of mean; SD, standard deviation; U, upper.

TABLE 8 Studies included in the meta-analysis reporting on salivary flow rate.

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Salivary flow rate (mean ± SD in ml/min)	*n*	Method	Conclusion
Maniewicz et al. (2019)	CD/CD					0.340 ± 0.210 Unstimulated salivary flow rate	16	Splitting and collecting for 2 min and chewing paraffin, then collecting for 2 min	No significant change (salivary flow rate) was observed in the IOD group compared to the CD group.
	CD/IOD	0/2	-/Straumann Standard Tissue Level Implants, Institute Straumann, Basel, Switzerland)	-/stud	3–12	0.395 ± 0.265 Unstimulated salivary flow rate	16		
	CD/CD					1.00 ± 0.635 Stimulated salivary flow rate	16		
	CD/IOD	0/2	-/Straumann Standard Tissue Level Implants, Institute Straumann, Basel, Switzerland)	-/stud	3–12	0.930 ± 0.610 Stimulated salivary flow rate	16		
	CD/CD					0.385 ± 0.305 Unstimulated salivary flow rate	16		
	CD/IOD	0/2	-/Straumann Standard Tissue Level Implants, Institute Straumann, Basel, Switzerland)	-/stud	≥24	0.515 ± 0.355 Unstimulated salivary flow rate	16		
	CD/CD					1.32 ± 0.725 Stimulated salivary flow rate	16		
	CD/IOD	0/2	-/Straumann Standard Tissue Level Implants, Institute Straumann, Basel, Switzerland)	-/stud	≥24	0.985 ± 0.715 Stimulated salivary flow rate	16		

Note: -, not applicable;?, not specified in the article.

Abbreviations: CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; L, lower; *n*, sample size; SEM, standard error of mean; SD, standard deviation; U, upper.

TABLE 9 Descriptive analysis of studies not included in the meta-analysis reporting on masticatory performance and efficiency by comminution tests (sieving methods).

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Masticatory performance (mean ± SD)	*n*	Method	Conclusion
Outcome: weight of test material that was retained on the sieve (the less value, the better efficiency)									
Vieira et al. (2014)	CD/CD					2.27 ±? Weight (g) of retained test material, 5.6-mm sieve	14	Chewing artificial food Optocal (17 cubes, 3 cm^3) for 20 and 40 strokes, then using 5.6-mm to 0.5-mm sieves	Masticatory performance (weight of retained test material) in the IOD group improved significantly compared to the CD group.
	CD/IFD	0/?	-/?	-/?	8	0.55 ±? Weight (g) of retained test material, 5.6-mm sieve	14		
Outcome: $N_{1/2}$ (the number of chewing strokes necessary to reduce the value of X50 to half the initial particle size, the less value, the better efficiency)						Standardized in number of chewing cycles			
Geertman et al. (1994)	CD/CD					68 ±?	28	Chewing artificial food Optocal (17 cubes, 5.6 mm) for 10, 20, 40 and 60 strokes	The IOD group had significantly better masticatory performance ($N_{1/2}$) than the CD group.
	CD/IOD	0/2	-/IMZ	-/bar	12	52 ±?	29		

Note: -, not applicable;?, not specified in the article.

Abbreviations: CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; L, lower; *n*, sample size; SEM, standard error of mean; SD, standard deviation; U, upper.

TABLE 10 Retrospective studies included in the review reporting on bite force.

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Bite force (mean ± SD in *N*)	*n*	Method	Conclusion
Geckili et al. (2011)	CD/CD					64.2 ± 64.2	23	A device with two strain gauges (Measurements Group Inc., Micro-Measurements Division, Type EA-06-125 MW-120, Raleigh, NC, USA) connected to a strain gauge measurement system (Vishay Micro-Measurements, Strain Indicator and Recorder, Model P3, Serial No: 159606, Raleigh)	Bite forces in the IOD group improved significantly compared to the CD group. The IOD-ball group showed no significant bite force compared to the IOD-bar group.
	CD/IOD	0/3	-/Osseospeed, Astra Tech	-/ball or bar	36	118.1 ± 118.1	23		
Geckili et al. (2012)	CD/CD					53.09 ±?	50	A device with two strain gauges (Measurements Group Inc., Micro-Measurements Division, Type EA-06-125 MW-120, Raleigh, NC, USA) connected to a strain gauge measurement system (Vishay Micro-Measurements, Strain Indicator and Recorder, Model P3, Serial No: 159606, Raleigh)	The IOD group had significantly higher bite forces than the CD group.
	CD/IOD	0/2	-/Astra Tech, Mˆlndal, Sweden	-/stud	48	127.23 ±?	50		

TABLE 10 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Bite force (mean ± SD in *N*)	*n*	Method	Conclusion
Manzon et al. (2021)	CD/CD	0/0	-/–	-/–	≥12	~74.63 ± ~29.15 Mean and SD were estimated from diagram using ImageJ2 software (version 2.9.0/1.53t)	40	Digital dynamometer (KRATOS Equipment model IDDKv4, seral number o7175142) with a bite fork	Bite forces in the IOD group improved significantly compared to the CD group. Both IOD and CD groups had significant lower bite forces compared to the Full Dentate group.
	IOD/IOD	4/4	?/?	telescopic/ telescopic	≥12	~213.59 ± ~60.16 Mean and SD were estimated from diagram using ImageJ2 software (version 2.9.0/1.53t)	40		
Müller et al. (2012)	CD/CD					61.4 ± 57.8	20	Occlusal Force-Meter GM 10 (Nagano Keiki Co. Ltd; 1-30-4 Higashimagome, Ohtaku, Tokyo, Japan)	Bite forces in CD < IOD < IFD < Full Dentate. The pairwise results were statistically significant, except between CD versus IOD and IFD versus Full Dentate.
	CD/IOD	0/2 or 4	-/Straumann implants, Basel, Switzerland	-/ball, stud or bar	≥12	88.1 ± 61.2	20		
	IFD/IFD	8–16	Nobels, Biocare, Gothenburg, Sweden or Straumann implants, Basel, Switzerland	?/?	≥12	270 ± 211.66	20		
Schimmel et al. (2017)	CD/CD					78.11 ± 5	17	Digital force gauge (Occlusal Force-Metter GM 10, Nagano Keiki, 130-4 Higashimagome)	Bite forces in CD < IOD < Kennedy Class I partially removable dental prosthesis < Full Dentate. The pairwise results were non-significant, except the Full Dentate group showed significantly higher bite forces than other groups.
	CD/IOD	0/2	-/Straumann RN	-/ball	≥6	82.4 ± 53.08	17		

(Continues)

TABLE 10 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Bite force (mean ± SD in N)	*n*	Method	Conclusion
Suzuki et al. (1999)	CD/CD					242 ± 125.3	40	Dental Prescale films (50H R-type)	The IFD group showed significant higher bite forces than the CD group. No significant difference was seen in occlusal force balance between the left and right sides.
	CD/IFD	0/?	-/Steri-Oss OR Calcitek OR 3i	-/?	4.8–64.8	342.1 ± 163.6	40		

Note: -, not applicable;?, not specified in the article.

Abbreviations: CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; L, lower; *n*, sample size; SEM, standard error of mean; SD, standard deviation; U, upper.

3.2 | Synthesis of results: Meta-analyses of the searched outcomes

The meta-analysis of the included studies revealed an overall significant improvement in the oral function for CD/IOD or IFD groups when compared with the CD/CD groups at 6–12 months (Overall: $Z=-4.895$, $p<.001$), at 12–36 months (Overall: $Z=-4.886$, $p<.001$), and for 36+ months (Overall: $Z=-9.108$, $p<.001$) after insertion of the implant-supported prostheses.

3.2.1 | Bite force

There was a significant improvement in the maximum bite force for all time points (6–12 months: $Z=-3.788$, $p<.001$, Figure 2; 12–36 months: $Z=-4.041$, $p<.001$, Figure 3; more than 36 months: $Z=-8.061$, $p<.001$, Figure 4; Table 2).

3.2.2 | Masticatory performance and efficiency

The studies reporting on the effect of implant rehabilitation on the masticatory performance assessed this outcome in a number of ways. Masticatory performance was assessed using the comminution tests by sieve methods (Table 3), mixing ability tests using the bi-color chewing gum technique (Table 4), and swallowing threshold method (Table 5). Different studies employed different techniques for the measured the sieve method which included: median particle size (X50), the number of strokes required to achieve the X50 median particle size, the percentage (%) of weight of the test material that passed through the sieves, and the chewing efficiency index. Studies using the chewing gums for the colorimetric techniques reported using the variance of hue (VoH), or the mixing ability index. The masticatory performance was also reported by measuring the number of chewing strokes required before swallowing and the time required to chew before swallowing.

The masticatory performance was significantly better at the 6–12 months timepoint for the implant-supported prosthesis group when measured with the median particle size ($Z=-4.264$, $p<.001$; Figure 2), number of strokes required for reducing the particle size to X50 mm ($Z=-3.552$, $p<.001$; Figure 2), and colorimetric methods (VoH: $Z=-2.635$, $p=.008$; Figure 2). The masticatory performance improved significantly for the implant-supported prosthesis group at 12–36 months after prosthesis delivery when measured by median particle size ($Z=-2.702$, $p=.007$; Figure 3), chewing efficiency index ($Z=-4.378$, $p<.001$; Figure 3), colorimetric methods (VoH: $Z=-2.283$, $p=.022$; mixing ability index: $Z=-4.711$, $p<.001$; Figure 3), and in swallowing threshold measuring the number of strokes required before swallowing ($Z=-2.838$, $p=.005$; Figure 3). Masticatory performance, when assessing with comminution tests, was significantly better for the implant-supported groups beyond 36 months as well (median particle size: $Z=-3.282$, $p=.001$; number of chewing strokes: $Z=-3.075$, $p=.002$, Figure 4).

TABLE 11 Retrospective studies included in the review reporting on masticatory performance by mixing ability tests (color methods).

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Masticatory performance (mean ± SD)	*n*	Method	Conclusion
Outcome: VOH (variance of hue, the less value, the better efficiency)									
Schimmel et al. (2017)	CD/CD					?±?	17	Chewing a two-color chewing gum for 20 strokes. The ViewGum© software was used to measure the variance of the hue (VOH)	No significant change (VOH) was observed in the IOD group compared to the CD group. The Full Dentate group showed the best masticatory performance compared to the CD group, the IOD group and the partially removable prostheses group. The partially removable prostheses group had significantly better masticatory performance than the CD group.
	CD/IOD	0/2	-/Straumann RN	-/ball	≥6	?±?	17		

Note: -, not applicable;?, not specified in the article.

Abbreviations: CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; L, lower; *n*, sample size; SEM, standard error of mean; SD, standard deviation; U, upper.

TABLE 12 Retrospective studies included in the review reporting on electromyography (EMG).

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	EMG (mean ± SD)	*n*	Method	Conclusion
De Rossi et al. (2014)	CD/CD					15.6 ± 2.6 Masseter at rest value	21	Percentage of Maximum Voluntary Contraction (MVC) value (μV*100/μV) on masseter and temporalis by an EMG device (Myosystem-Br1 portable electromyograph, DataHominis Tecnologia Ltda, Uberlândia, MG, Brazil) while at rest, paraffin chewing, peanut chewing, and cotton roller contraction	All groups presented symmetric muscular activity. The IFD and Full Dentate groups had a similar EMG pattern, that is, a higher EMG activity of masseter than temporalis muscles, differing from those of denture group. Not one statistical difference was found between the IFD and the Full Dentate groups.
	IFD/IFD	4/4	Nobel Biocare, Goteborg, Sweden/ Nobel Biocare, Goteborg, Sweden	?/?	≥6	25.4 ± 8.3 Masseter at rest value	21		
	CD/CD					17.2 ± 2 Masseter at rest value	21		
	IFD/IFD	4/4	Nobel Biocare, Goteborg, Sweden/ Nobel Biocare, Goteborg, Sweden	?/?	≥6	21.9 ± 3.7 Masseter at rest value	21		
Jacobs and van Steenberghe (1993)	CD/CD					0.17 ± 0.05	16	The amplitude range (AMP) and the mean power frequency (MPF) on masseter by an EMG device (Dantec Medical and Scientific Equipment, Skovlunde, Denmark) while clenching at the selected level for as long as possible until fatigue prevented them from further clenching	EMG indicated an increased myoelectrical output level for implant-supported reconstructions compared with the CD group.
	CD/IOD	0/2	-/?	-/bar	48	0.33 ± 0.21	20		
	CD/IFD or IFD/CD	0/5–6 or 5–6/0	-/? or? /0	-/? or? /–	72	0.32 ± 0.21	9		

Note: -, not applicable;?, not specified in the article.

Abbreviations: CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; L, lower; *n*, sample size; SEM, standard error of mean; SD, standard deviation; U, upper.

TABLE 13 Retrospective studies included in the review reporting on lip force.

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	Lip force (mean ± SD)	*n*	Method	Conclusion
Schimmel et al. (2017)	CD/CD					?±?	17	Measured as the maximum withstood pulling force with three sized (small, medium and large) of oral screens by a digital force gauge (ZP50-N, Imada)	Maximum lip force depended on the screen size and increased in the CD group, especially in challenging tasks such as restraining the smallest screen.
	CD/IOD	0/2	-/Straumann RN	-/ball	≥6	?±?	17		

Note: -, not applicable;?, not specified in the article.

Abbreviations: CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; L, lower; *n*, sample size; SEM, standard error of mean; SD, standard deviation; U, upper.

3.2.3 | Muscle activity (EMG)

There were no differences detected between the edentate individuals rehabilitated with conventional prostheses in both jaws and those rehabilitated with implant-supported protheses at the 6–12 months ($Z = 1.053$, $p = .292$; Figure 2) but significantly higher muscular activity during chewing was observed in the 12–36 months period for the conventional prosthesis group ($Z = 7.696$, $p < .001$; normalized mean; Figure 3) but no difference detected between the groups when reported with root mean square ($Z = 1.035$, $p = .301$; Figure 3; Table 6).

3.2.4 | Mandibular movements and chewing patterns

There were no differences detected between the edentate individuals rehabilitated with conventional prostheses and those rehabilitated with implant-supported protheses for the mandibular movements and chewing patterns when measuring masticatory cycles/seconds ($Z = -.464$, $p = .643$; Figure 3), opening and closing velocity ($Z = -.150$, $p = .881$; Figure 3), area of chewing pattern in the frontal plane ($Z = -1.246$, $p = .213$; Figure 3), and for vertical length of chewing pattern in the frontal plane ($Z = -1.457$, $p = .147$) (Table 7).

3.2.5 | Salivary flow rate

Rehabilitations with implant-supported prostheses did not improve the stimulated salivary flow rate when compared with rehabilitation with conventional CRDPs ($Z = -1.271$, $p = .204$; Figure 3) (Table 8).

3.3 | Synthesis of results: Descriptive analysis of the studies not included in the meta-analysis

All prospectively designed studies excluded from the meta-analyses are reported descriptively in Tables 9 and include the parameters of masticatory performance and efficiency by comminution tests. Retrospective studies that provided valuable information on bite force, masticatory performance, muscle activity (EMG), and lip force are presented in Tables 10–13. Although excluded from this review because of the predefined inclusion and exclusion criteria, studies which report on speech and articulation as well as oral tactile threshold are presented in Table 14 because these are the only studies which exist in current literature that provide valuable information on these outcomes.

3.4 | Risk of bias and quality assessment of the included studies in the meta-analysis

The quality assessments of the studies included in the meta-analysis revealed a low to moderate risk of bias and are presented in Tables 15 and 16.

TABLE 14 Descriptive analysis of studies not included in the review that report on tactile threshold, and phonetics (speech articulation).

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	*n*	Method	Conclusion	Reason for exclusion
Outcome: Tactile threshold									
Luraschi et al. (2012)	CD/CD					7	Three active tactile thresholds (absolute, 50% and 100%) were evaluated by means of copper foils of decreasing thickness (12 foils:700–5 μm). The passive thresholds were measured in six different sites per quadrant using a custom-made computer-supported strain gauge. MBF was evaluated electronically using the central-bearing point method	IFD/IFD are a valuable treatment option for restoring edentulous patients. Limitations concerning their physiological integration into the orofacial system are mainly related to a poor passive rather than active tactile sensitivity or maximum bite force.	Sample size of <10 cases
	IFD/IFD	6 or 8/6 or 8	-/Straumann® or Nobel Biocare®	-/?	46.8–75.6	7			
Outcome: Speech and articulation problems									
Fonteyne et al. (2021)	CD/CD					18	Assessments were taken by speech therapists and included evaluation of oromyofunctional behavior and articulation which focus on different speech sounds ex. stridens, simplex by picture naming and reading	There was no significant impact of the treatment on speech nor on the results of oromyofunction.	Follow-up period of less than 6 months
	CD/IOD	0/2	-/?	-/bar	3	19			

TABLE 14 (Continued)

First author (year)	Study group (U/L)	Implant number (U/L)	Implant detail (U/L)	Attachment system	Follow-up period (months)	*n*	Method	Conclusion	Reason for exclusion
Meira et al. (2021)	CD/CD					21	Articulation disorders were analyzed by audio and video recordings, which focuses on motor aspect ex. substitution, omission, distortion, anterior and/or lateral tongue protrusion, anterior and/or lateral lisp, exaggerated or reduced articulatory movement, anterior or lateral jaw trajectory deviation and exaggerated or reduced lip mobility	No difference in articulation disorders was found between the CD group and the IOD group.	Follow-up period of <6 months
	CD/IOD	0/1	-/Titamax-TiCortical, Neodent, São Paulo, Brazil	-/stud	2	15			

Note: -, not applicable;?, not specified in the article.

Abbreviations: CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; L, lower; *n*, sample size; SEM, standard error of mean; SD, standard deviation; U, upper.

TABLE 15 Results of the quality assessment of the included RCTs using the Cochrane collaboration tool for the assessment of risk of bias.

Study	Sequence generation	Allocation concealment	Blinding	Incomplete outcome data	Selective reporting	Other bias	Summary
Garrett et al. (1998)	Low	Unclear	Unclear	Low	Low	Unclear	Medium
Maniewicz et al. (2019)	Low	Low	Low	Low	Low	Unclear	Low
Nogueira et al. (2019)	Low	Low	Low	Low	Low	Unclear	Low

3.5 | Publication biases

The analyses for the time point of 6–12 months revealed a publication bias (Egger's $p = .026$, Figure 5), but no biases were detected in other analyses (12–36 months: Egger's $p = .106$, Figure 6; +36 months: Egger's $p = .778$, Figure 7).

4 | DISCUSSION

4.1 | Principal findings

Oral function is one of the most essential criteria that needs to be re-established in completely edentulous patients. This systematic review demonstrated that completely edentulous patients rehabilitated with implant-supported dental prostheses had significantly improved oral function compared to those rehabilitated with conventional CRDPs. The effect can be acknowledged from the follow-up period of more than 6 months, which is the optimal period of denture adaptation (Müller & Barter, 2016). The oral function consists of various aspects. Hence, a single objective assessment cannot represent the overall outcome. This review included purpose-designed studies assessing outcomes of oral function through measurement of bite force, masticatory performance, muscle activity (EMG), mandibular movement and chewing pattern, salivary flow rate, and lip force. These improvements could be a reflection of an efficient implant assisted rehabilitation with good retention, stability, and support.

4.1.1 | Bite force

Bite force is an objective assessment representing the ability of force generation by masticatory muscles, which is a vital feature in food mastication. It was shown that bite force reduced dramatically after tooth loss (Müller et al., 2012; Schimmel et al., 2017); thus, dental prostheses rehabilitation helps regain this ability. This review showed that rehabilitation with implant-supported dental prostheses significantly increased the bite force in edentate patients when compared to those rehabilitated with conventional complete dentures. The effect can be recognized from 6 months after implant-supported rehabilitation and maintained until more than 36 months of the follow-up period. These findings corresponded with the majority of previous studies evaluating bite force between implant-supported dental prostheses and conventional complete dentures (Fontijn-Tekamp et al., 1998; Maniewicz et al., 2019; Melo et al., 2018; Müller et al., 2012; Schimmel et al., 2017; van der Bilt et al., 2006). Even if the follow-up period was less than 6 months after the rehabilitation, the significantly increased effect could be achieved by implant support in many studies (Amaral et al., 2019; Kashyap et al., 2021; Sharma et al., 2017; Soni et al., 2020; van Kampen et al., 2002). These findings could be implied that dental implants assisted the prostheses in gaining the ability to generate bite force since the early stage of denture adaptation. In edentulous patients with mucosa-born CRDPs, the maximum bite force is limited by pain arising from the periosteum or due to the dislodging of the CRDP. Hence CRDP wearers limit their maximum forces to avoid pain and embarrassment caused by denture loosening, in particular in a social context. CD/IODs or CD/IFDs transfer bite force and chewing load to the osseointegrated implants, thus avoiding pressure on the sensitive edentulous tissues. The implants also preclude denture dislodgement, as they mechanically retain the IOD in place and do not rely on a suction effect on the denture bearing tissues. This is a mechanical improvement, which explains the immediacy of the improvement after IOD placement.

4.1.2 | Masticatory performance

Masticatory performance is a general term representing the harmony and coordination of the masticatory organs to mix or comminute food bolus (Elgestad Stjernfeldt et al., 2017). The masticatory organs consist of teeth, tongue, salivary glands, orofacial nerves, and muscles of mastication. Masticatory performance could be objectively evaluated by various methods, such as sieving comminuted food, color-changing chewing gum, or swallowing threshold methods.

The sieving methods can be briefly performed by making patients chew brittle foods or by making artificial test-bolus by mixing condensation silicone with other materials, for an assigned number of chewing strokes (Pocztaruk Rde et al., 2008). Then the masticated foods are collected and run through a series of sieves. The food particle size, or percentage of food weight passed or retained on the sieves, can be used to represent a masticatory performance by the sieving methods. In this meta-analysis, the time frame of 6–12 months, 12–36 months, and more than 36 months was fixed; only one study could be fitted in the outcome of X50, $N_{1/2}$, and C_i

TABLE 16 Results of the Newcastle–Ottawa quality assessment scale for prospectively designed studies used in the meta-analysis

	Selection				Comparability	Outcome		
First author (Year)	Representativeness of the exposed cohort	Selection of the non-exposed cohort	Ascertainment of exposure	Outcome of interest not present at start of the study	Comparability of cohorts	Assessment of outcome	Sufficient follow-up time	Adequacy of follow-up of cohorts
Bakke et al. (2002)	*	*	*			*	*	*
Benzing et al. (1994)		*	*			*	*	*
Berretin-Felix et al. (2008)	*	*	*			*	*	*
Borges Tde et al. (2011)		*	*			*	*	*
da Silva et al. (2011)	*	*	*			*	*	*
de Resende et al. (2021)	*	*	*			*	*	*
Enkling et al. (2019)	*	*	*			*	*	*
Fontijn-Tekamp et al. (1998)	*	*	*		*	*	*	*
Hartmann et al. (2020)	*	*	*			*	*	*
Khalid et al. (2020)		*	*			*	*	*
Lindquist and Carlsson (1985)		*	*			*	*	*
Marcello-Machado et al. (2018)	*	*	*			*	*	*
Melo et al. (2018)	*	*	*			*	*	*
Pera et al. (1998)		*	*			*	*	*
Sun et al. (2014)		*	*			*	*	*
van der Bilt et al. (2010)		*	*			*	*	*
Yunus et al. (2014)		*	*			*	*	*

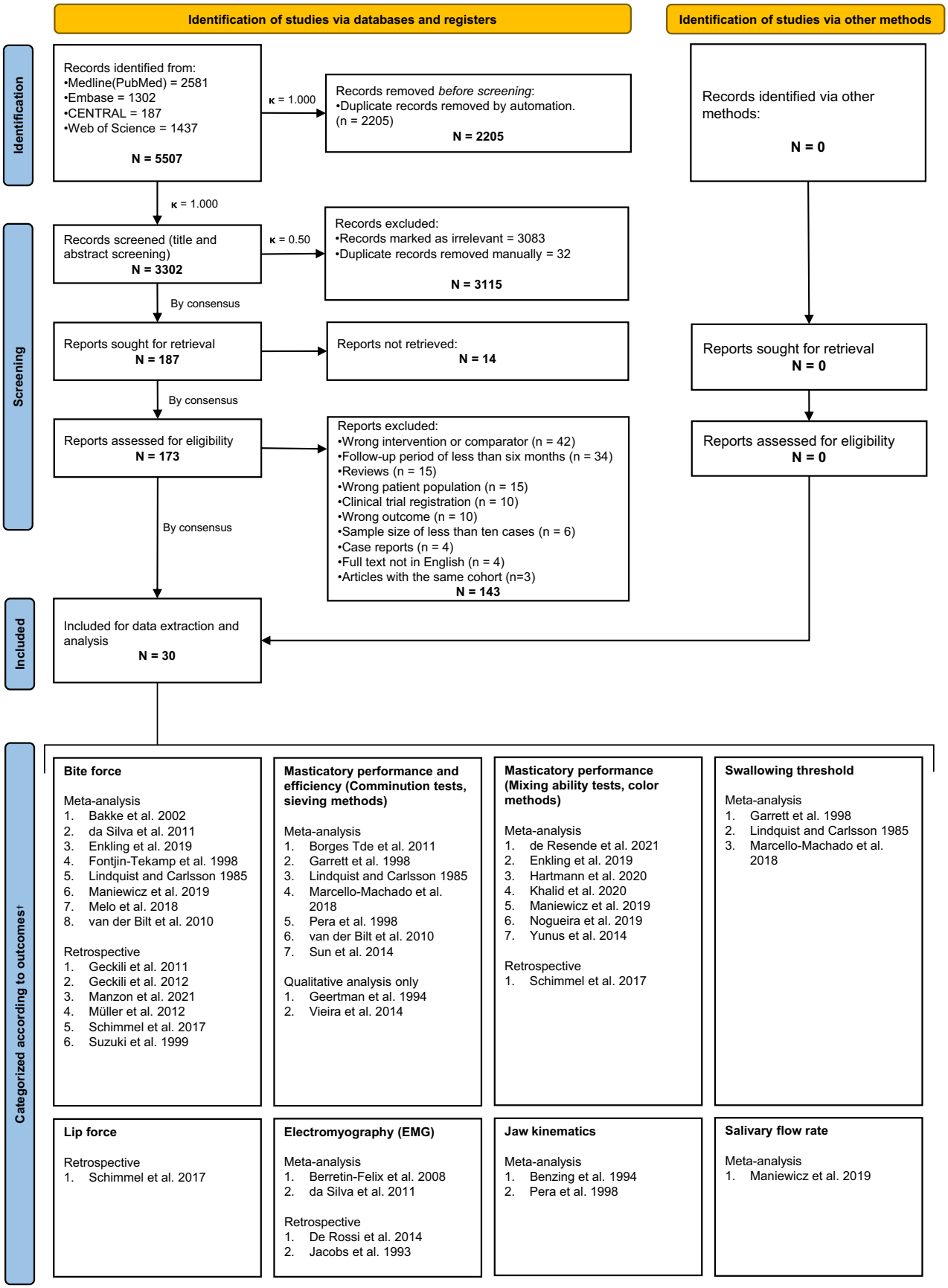

FIGURE 1 Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) flow diagram showing the entire identification, inclusion process, and studies categorized according to outcomes. *N*, number; κ, Cohen's Kappa value; †, multiple studies report on more than one outcome parameter.

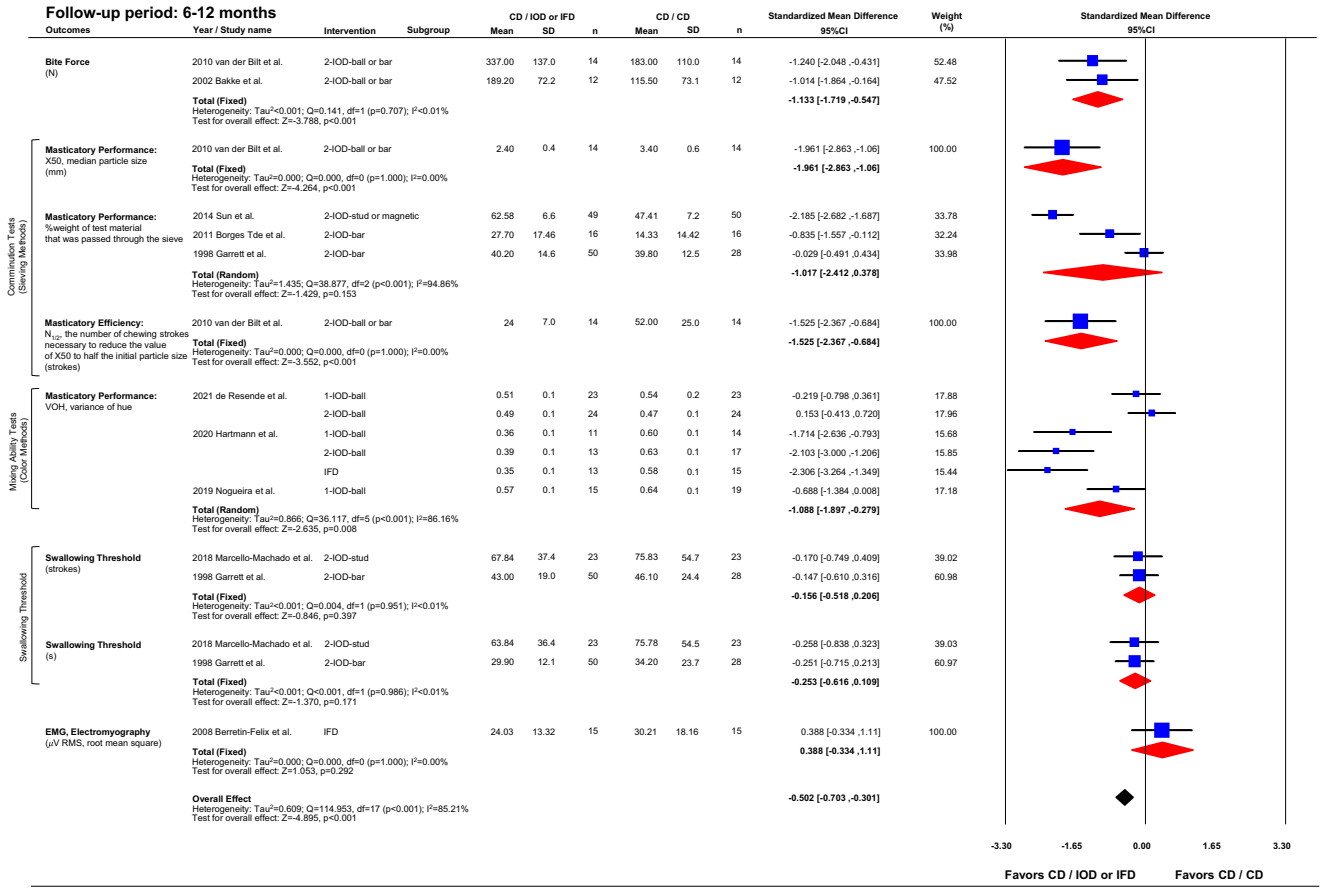

FIGURE 2 Forest plots showing outcomes of 6–12 months follow-up period. CI, confidence interval; CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; *n*, sample size; SD, standard deviation.

parameters. Therefore, the meta-analysis yielded the same results of significantly improved masticatory performance when rehabilitated with implant-supported dental prostheses, as found in the original articles (Lindquist & Carlsson, 1985; Marcello-Machado et al., 2018; van der Bilt et al., 2010). However, when the percentage of food weight passed through the sieve measurement technique was used to assess the masticatory performance, the meta-analysis showed no significant effect in masticatory performance between implant-supported dental prostheses and complete dentures for the follow-up period of 6–36 months. These findings contradicted the previous studies from Borges Tde et al. (2011), Pera et al. (1998), and Sun et al. (2014), which showed significantly improved masticatory performance when rehabilitation with implant-supported dental prostheses (Borges Tde et al., 2011; Pera et al., 1998; Sun et al., 2014). The authors assumed this inconsistent trend came from the heterogeneity in the sieving methods and the different foods used in the tests (Borges Tde et al., 2011; Garrett et al., 1998).

The color methods can be briefly performed by giving patients two-color chewing gum or wax for assigned chewing strokes. Then the mixed-color gum is collected, and the variance of hue (VOH) or mixing ability index is measured as a representative parameter of masticatory performance (Khalid et al., 2020; Schimmel et al., 2017). The meta-analysis indicated a significant improvement in masticatory performance when rehabilitation with implant-supported prostheses for a follow-up period of 6–36 months. These findings corresponded with previous studies (de Resende et al., 2021; Hartmann et al., 2020; Khalid et al., 2020; Nogueira et al., 2019; Yunus et al., 2014). In contrast, Müller et al. (2013) and Maniewicz et al. (2019) demonstrated no significant change in masticatory performance by the color methods (Maniewicz et al., 2019; Müller et al., 2013). This may also be caused by a non-renewal of the occlusal surfaces in this geriatric study where existing lower CRDPs were converted to IODs without changing the denture teeth.

The swallowing threshold methods can be briefly performed by giving patients chewing foods until they desire to swallow. The time or number of chewing strokes is used to represent masticatory performance. The meta-analysis revealed no significant improvement in masticatory performance for a follow-up period of 6–12 months, which corresponded to previous studies (Garrett et al., 1998; Marcello-Machado et al., 2018). In contrast, the meta-analysis result of 12–36 months showed significant improvement in reducing strokes required to chew foods until ready to swallow, which resembled a previously published study (Lindquist & Carlsson, 1985). The swallowing threshold methods could be considered partially subjective assessments as the feeling of readiness to swallow could be varied individually.

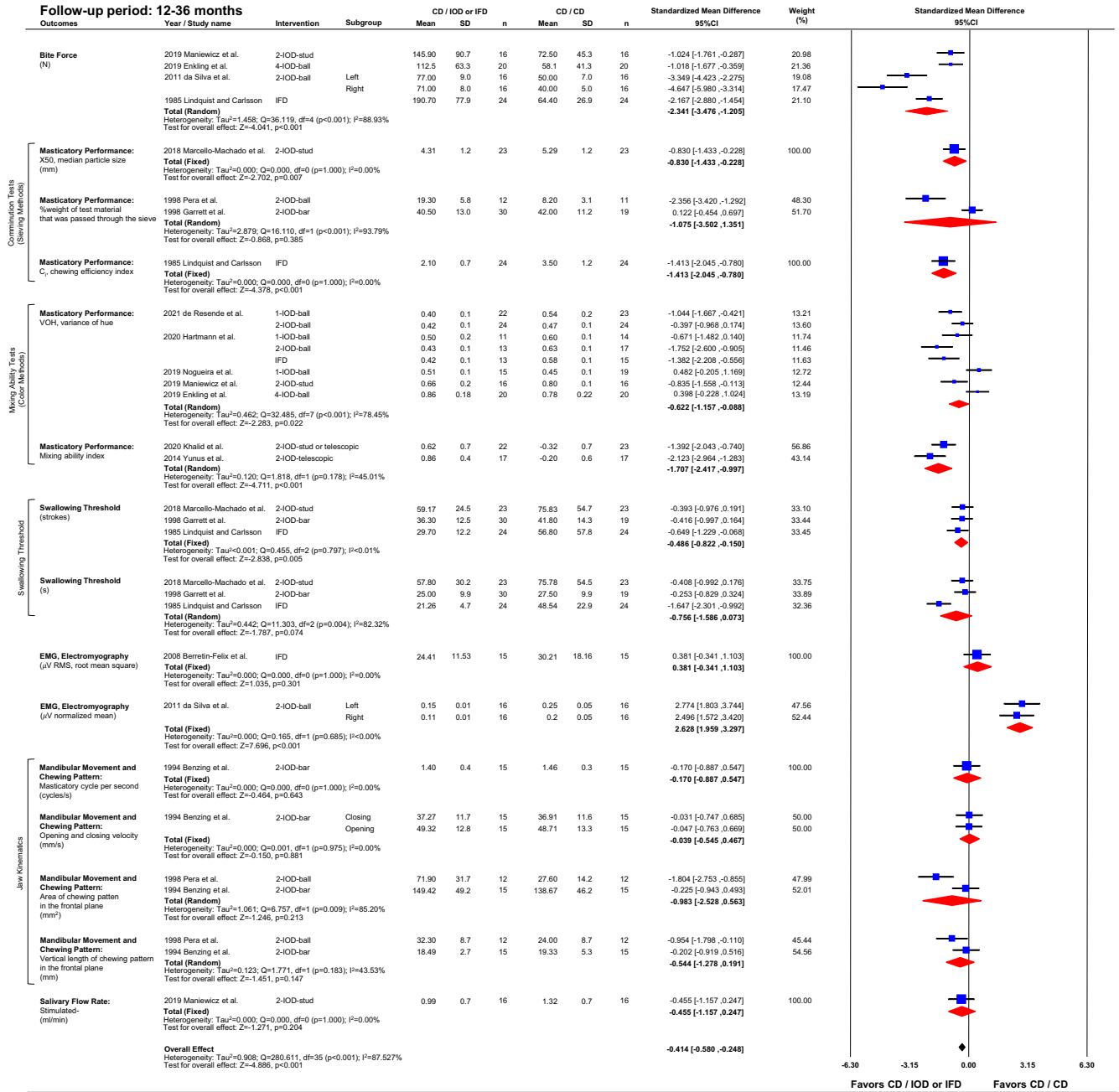

FIGURE 3 Forest plots showing outcomes of 12–36 months follow-up period. CI, confidence interval; CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; *n*, sample size; SD, standard deviation.

4.1.3 | Muscle activity (EMG)

EMG is a measurement of electrical activities in various units, such as μV, μV amplitude, μV RMS, μV normalized mean, or surface under the rectified and integrated curve. For muscles of mastication, the measurements are usually taken from the masseter and temporalis muscles, during different test conditions, for instance, hard food chewing, soft food chewing, cotton-roll clenching, maximum clenching, or rest (ElSyad et al., 2019; Soni et al., 2020). Fully edentulous patients notably produced lower EMG results than dentate patients, implying less neuromuscular activities and bite force (Heckmann et al., 2009). In this meta-analysis, the time frame of follow-up periods was fixed; only one study could be suited to the parameter of μV RMS and μV normalized mean. Consequently, the meta-analysis yielded the same results of no significant change in EMG (μV RMS) results, while it showed significant decreased EMG (μV normalized mean) when rehabilitated with implant-supported dental prostheses, as found in the original articles (Berretin-Felix et al., 2008; da Silva et al., 2011). These findings are surprising, given the significant increase in maximum bite force with IODs. However, the lower muscle activity combined with a better chewing performance might be explained by a more efficient comminution of the food. Hence

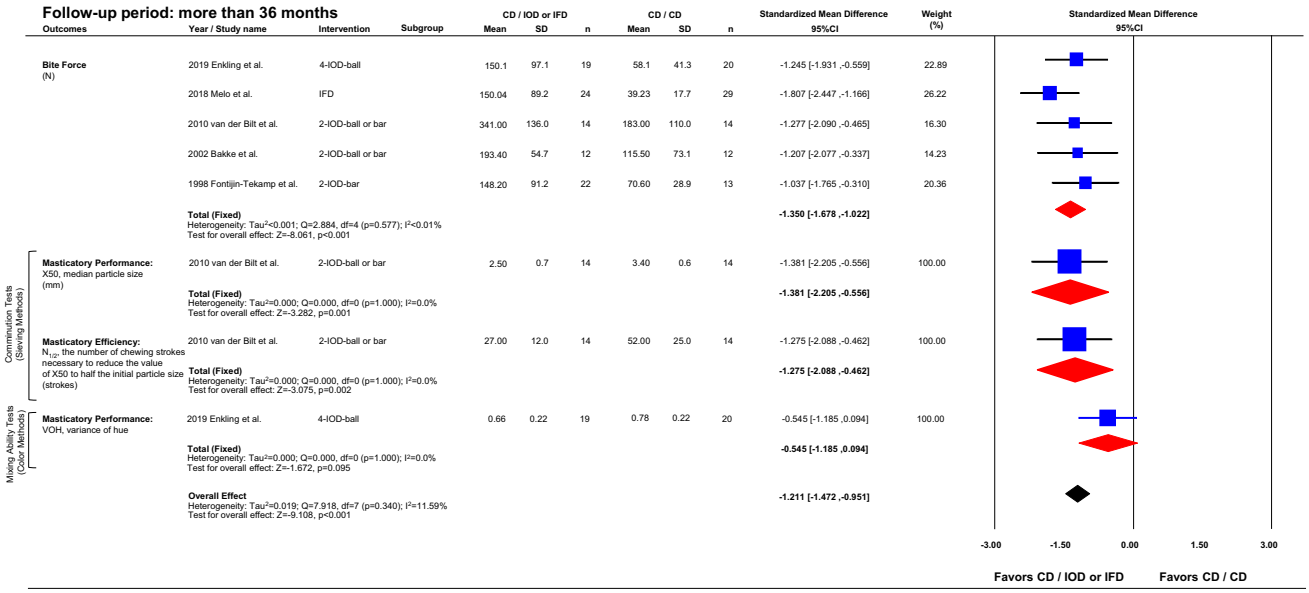

FIGURE 4 Forest plots showing outcomes of more than 36 months follow-up period. CI, confidence interval; CD, conventional removable complete denture; IFD, implant-supported fixed dental prostheses; IOD, implant-supported removable complete overdenture; *n*, sample size; SD, standard deviation.

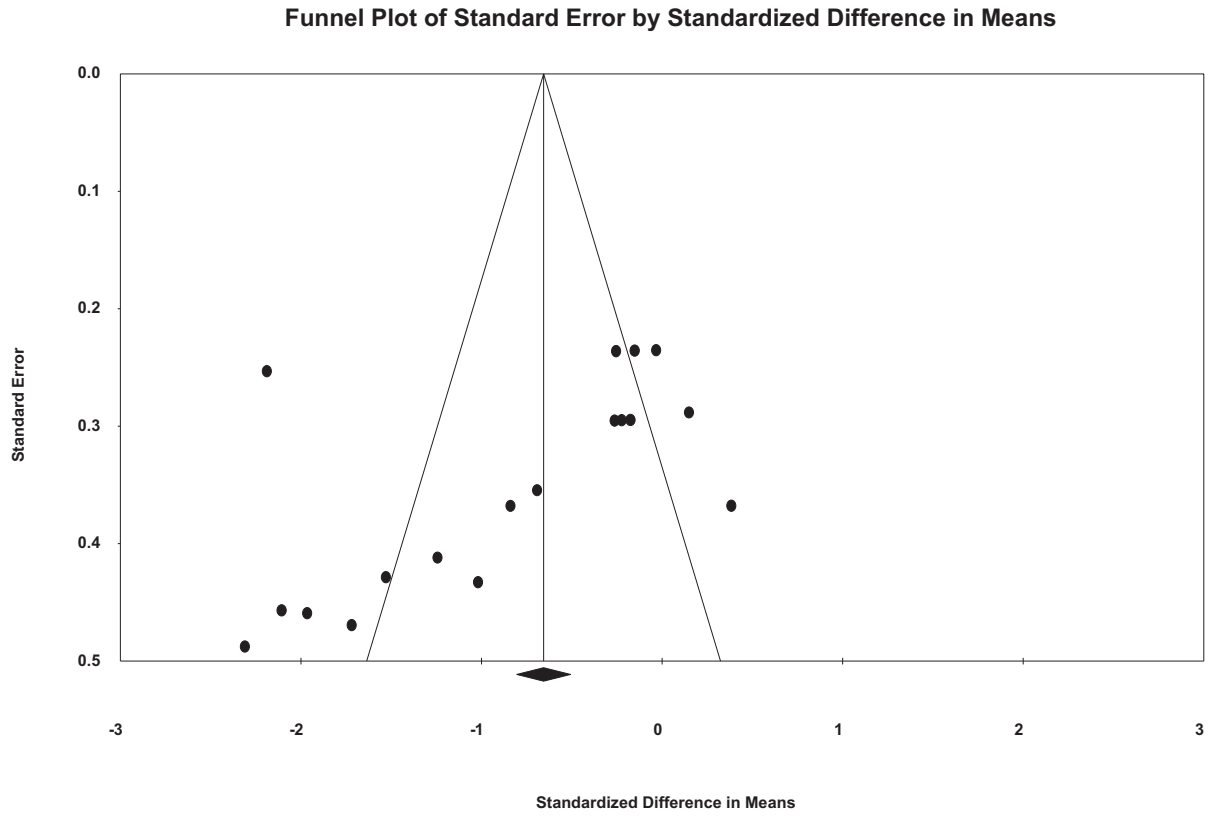

FIGURE 5 Funnel plot exploring the publication bias for the meta-analysis of the studies included for the 6–12 months timepoint (Egger's $p = .026$).

less force may be needed to achieve the same particle size with a high-performance IOD. The patients may be attempting to compensate the low chewing efficiency of conventional CRDPs by recruiting more muscle activity.

4.1.4 | Mandibular movement and chewing pattern

Mandibular movement and chewing patterns can be assessed by a jaw-tracking or video devices. Various parameters represent this

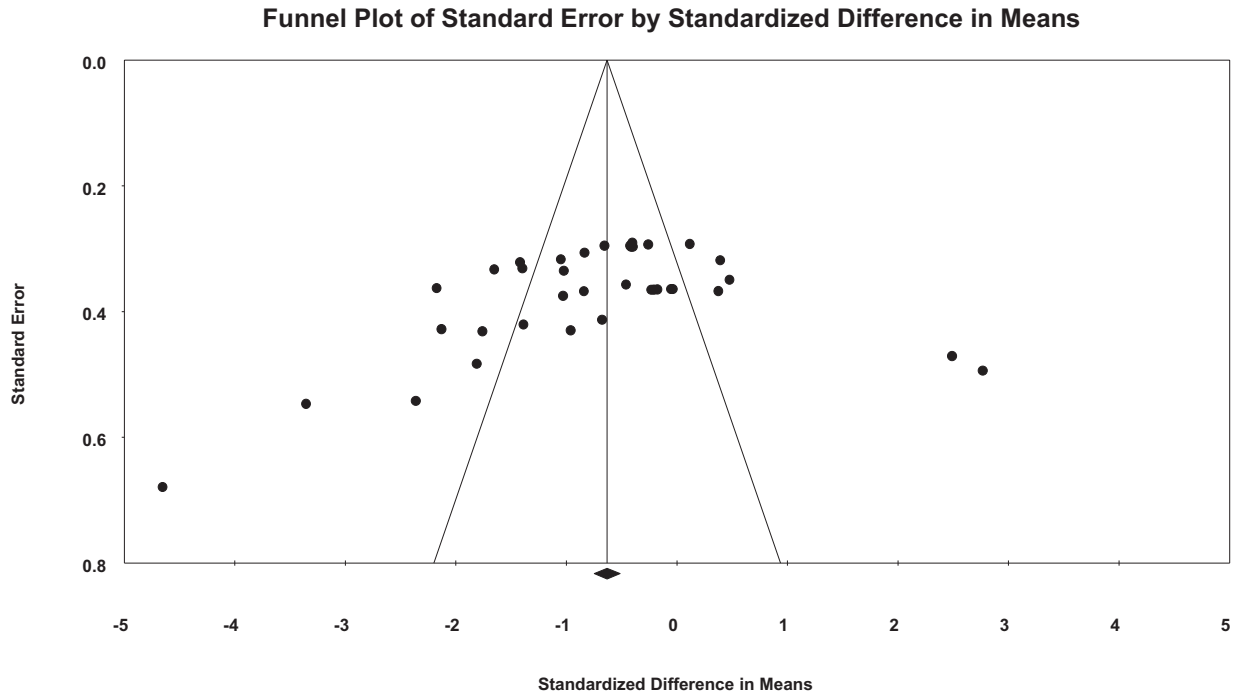

FIGURE 6 Funnel plot exploring the publication bias for the meta-analysis of the studies included for the 12–36 months timepoint (Egger's $p = .106$).

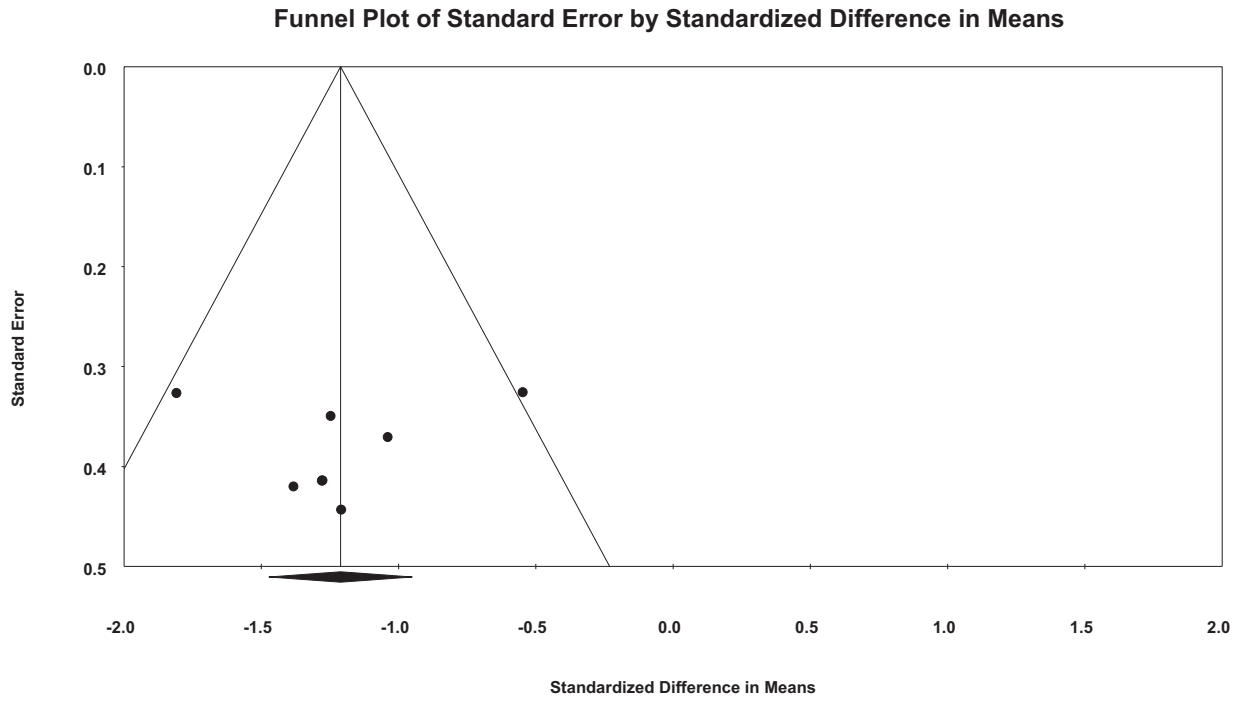

FIGURE 7 Funnel plot exploring the publication bias for the meta-analysis of the studies included for the more than 36 months timepoint (Egger's $p = .778$).

outcome; for illustration, opening and closing jaw velocity, vertical length of chewing cycles in the frontal plane, area of chewing cycles in the frontal plane, or number of masticatory cycles per second. When compared to dentate subjects, the chewing cycles of edentulous CRDP wearers show less excursion in a vertical and lateral plane, with almost unchanged movement speed (Proschel & Hofmann, 1982). An increase in these parameters would indicate an improved adaptation of the movement parameters and neuromuscular system, resulting in higher masticatory efficiency (Heckmann et al., 2009). However, this review showed no significant change in mandibular movement and

chewing pattern after rehabilitation with implant-supported dental prostheses for a follow-up period of 12–36 months. These findings corresponded with a former published study (Benzing et al., 1994). Chewing movements are programmed by a central pattern generator in the brain stem. While the chewing rhythm remains mostly consistent over a lifetime, the mandibular displacement may vary based on the food consistency and texture, as well as the type of dentition/prosthesis. The absence of increased mandibular displacement reported in the present review may be caused by methodological shortcomings, such as different test foods used. Patients might have also required some adaptation time to change their chewing habits.

4.1.5 | Salivary flow rate

Salivary function is measured in two distinctly different conditions, at rest and under stimulation (Sreebny, 2000). In this meta-analysis, only one study could be fitted in the stimulated salivary flow rate parameter; thus, the meta-analysis yielded the same results of no significant change after rehabilitation with implant-supported dental prostheses, as per evidence present in literature (Maniewicz et al., 2019; Müller et al., 2013). The salivary flow from the parotid gland is stimulated by unilateral mastication via the periodontal receptors. Increased bite force and improved masticatory efficiency would therefore suggest increased salivary flow rates. However, this very clear physiological reflex may become less visible in geriatric cohorts with substantial intake of medications and a high prevalence of hyposalivation.

4.2 | Strengths and limitations of this review

The review was successful in identifying a number of studies which assessed oral functions in edentulous patients rehabilitated with implant-supported/retained prostheses. However, not all outcome measures were suitable for meta-analyses, hence the review provides various levels of evidence relating to the effect of implant therapy for the chosen parameters of oral function. Although the systematic review was conducted with sound methodology and reported as prescribed by the PRISMA guidelines, limitations may still exist. Numerous studies were excluded for a variety of reasons due to the rigorous inclusion criteria. This may have affected the results of the review. The excluded studies along with the reasons for exclusion are presented in Appendix S1. However, some of the excluded studies, were considered to contain some valuable information and therefore for the sake of scientific interest, although excluded from the analysis, are still presented in Appendix S2, therefore, eliminating marginally the errors of inclusion bias.

4.3 | Clinical relevance of findings of this systematic review

Implant therapy can be recommended for edentulous adults to alleviate the shortcomings of conventional complete removable dental prostheses. The availability of this treatment modality should also be promoted in edentulous communities with limited access and means.

4.4 | Implication for research

The current review reveals a notable knowledge gap regarding implant therapy and certain parameters of oral function such as lip force, salivary flow, oral tactile sensitivity, and oral diadochokinesis. Moreover, this review identified that the assessment of masticatory performance was found to be the most heterogenous. Various methods with different measurement techniques exist currently for this parameter. Interpretation of the results were sometimes difficult and were not universally comparable. Therefore, a global consensus should be achieved for choosing a simplified universal technique to measure this parameter; or a technique to unify the different measurements to correspond to a single standard. Furthermore, a consensus needs to be also achieved to define standard protocols for reporting other parameters related oral functions based on the findings of this systematic review.

5 | CONCLUSIONS

This systematic review concluded that the oral function of completely edentate adults significantly improved with implant-supported/retained prostheses, even when only one jaw received implant therapy. Therefore, implant therapy should be promoted for edentulous adults to alleviate the shortcomings of conventional complete removable dental prostheses.

AUTHOR CONTRIBUTIONS

Murali Srinivasan and Frauke Müller conceived the ideas; Porawit Kamnoedboon and Lea Angst collected the data; Murali Srinivasan and Porawit Kamnoedboon analyzed the data and led the writing and the preparation of the initial draft. Murali Srinivasan, Porawit Kamnoedboon, Lea Angst, and Frauke Müller edited and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

None.

DATA AVAILABILITY STATEMENT

Data will be made available on request.

PROSPERO REGISTRATION

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SUPPORTING INFORMATION

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

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