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REVIEW ARTICLE

Quantitative parameters of digital occlusal analysis in dental implant supported restorative reconstruction recent 5 years: a systematic review

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ABSTRACT

Objective: The aims of this systematic review were to evaluate the clinical masticatory performance of implant-supported restorations, observe the occlusal force changes in the distribution of the implant restoration and reveal the positive and negative contributing factors of implant design and components based on the outcomes of digital occlusal measurement.

Material and methods: An extensive search was conducted through PubMed and CENTRAL to identify clinical trials on implant-retained restorations using digital occlusal analysis methods. Two researchers assessed the identified studies and data extraction independently, and the data synthesis strategies without meta-analysis that summarizes the effect estimates were adopted.

Results: The search screened 3821 titles and abstracts, then full-text analysis for 26 articles was performed, and 14 studies were included in the quantitative synthesis. Four of six studies for implant-retained overdenture showed statistically significant improved bite force when immediate loading ($p = .00045$, .00005, .00055, and .00005, respectively), and no statistically significant results in the other two studies ($p = .225$, .371, respectively.) However, the results of the favoured intervention were not statistically significant ($p = .104$, .166, respectively) in two studies of single posterior implant restorations. In all three studies, the bite force distributed on the implant prostheses of partially fixed implant-retained restoration increased statistically significantly ($p = .013$, .001, .05, respectively).

Conclusions: The edentulous restoration supported by implants seems to significantly improves bite force and chewing efficiency compared with conventional dentures. Regular quantitative occlusal measurement is recommended to avoid the possible risk of overload. Smaller implants size and relatively small and flexible attachment designs may be more conducive to the stability and retention of the restoration of atrophy of alveolar bone.

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Introduction

Dental implant-supported restorations are extensively used for the oral reconstruction of partial and complete edentulism after evolving from experimental treatment to highly predictable alternative options of missing teeth in the past 50 years [1–3]. Two primary goals of implant treatment are successful treatment results from the rehabilitation of normal oral physiological functions such as chewing, pronunciation, and aesthetics with high predictability and good long-term stability, in addition, it is crucial to reduce the occurrence of complications during healing and subsequent periods [2,4]. Various methods to evaluate the oral health-related outcomes include chewing efficiency, maximum bite force, patient satisfaction, and patient nutritional status [5–8]. Each method has its advantages, but some indicators are subjective and lack comparability among the outcomes due to different observational contents.

Moreover, the clinical evidence is still insufficient because of inevitable limitations, such as selecting subjects, sample size setting, research purposes and significance, appropriate research methods, the objectivity of index evaluation, application of statistical methods, etc. Bite force and occlusal contact area are the critical factors used to evaluate chewing performance [9,10], so the digital presentation of these occlusal indicators could provide an effective way to evaluate the improvement of oral function quantitatively. Meanwhile, even with high success and survival rates (above 95%) [11–14], implant-retained restorations are still not immune to complications [4,15,16] due to physiological differences between the implant and natural tooth, such as displacement of the osseointegrated implant [17,18], tactile sensation of periodontal tissue [19], the elastic modulus of root [20]. Furthermore, the compressibility and deformability of periodontal ligament (PDL) in natural teeth can differ in force adaptation compared with osseointegrated implants under

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loading [18]. Therefore, dental implants may be more prone to occlusal overloading. A considerable number of studies [1,21–24] reported the recommendations and considerations of occlusion in implant dentistry. However, this review mainly summarized the principles and strategies in implant restoration from the perspective of optimal occlusion and expounded the multiple factors that may cause overloading systematically. To the authors' knowledge, no article focuses on the quantitative occlusal parameters, such as occlusal force applied on the implant-retained restorations or individual implant and changes in occlusal characteristics after placement implant-retained constructions in the views of clinical trials. Moreover, with the continuous advancement, quantitative analysis of occlusal parameters is essential objective clinical evidence for considering various designs and components of dental implants.

The primary objective of this systematic review was to evaluate the clinical masticatory performance of implant-supported restorations based on the outcomes of digital occlusal measurement; the secondary aims were to observe the occlusal force changes in the distribution of the implant restoration and reveal the positive and negative contributing factors of implant design and components in line of digital occlusal analysis. The null hypothesis is that no strong clinical evidence indicates that implant-supported restorations' chewing performance is better than conventional rehabilitations.

Materials and methods

This review was registered at the National Institute for Health Research PROSPERO, International Prospective Register of Systematic Reviews (CRD42021236484).

General search strategy

This systematic review was conducted according to the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (http://www.prisma-statement.org) [25].

- Population. Partial or completely edentulous patients.
- Intervention. Partial or full implant-supported restorations.
- Comparison. Conventional complete restorations or prior to placement of implant-retained restoration.
- Outcome. Digital quantitative occlusal parameters, such as occlusal force, contact area, contact time and contact number.

Literature search methodology

All relevant works of literature of implant retained reconstructions using digital occlusal analysis methods were included. The search criteria were set from 1 January 2016 to 31 July 2021. An extensive search was conducted from two online databases: MEDLINE/PubMed and Cochrane library/Embase. The keyword search criteria were as follows: PubMed: ((((('occlusion' OR 'occlusal' OR 'occlude' OR 'bite force' OR 'contact' OR 'pressure' OR 'loading' OR 'chew' OR 'masticatory')) AND (('scan' OR 'scanning' OR 'scanner' OR 'sensor' OR 'transducer' OR 'digital' OR 'digitization' OR 'dynamic' OR 'computerised' OR 'advanced' OR 'quantitative'))) AND (('implant' OR 'implant retained' OR 'implant supported' OR 'implant fixed'))) AND (('crown' OR 'bridge ' OR 'reconstruct ' OR 'reconstruction 'OR 'superstructure ' OR 'restoration ' OR 'restorative ' OR 'prosthesis ' OR 'prostheses ' OR 'denture ')); Cochrane: 'implant' AND ('occlusion' OR 'occlusal' OR 'contact') AND ('scan' OR 'digital' OR 'computerised' OR 'advanced').

Inclusion criteria

- The human study, more than 18 years old.
- Partial or complete dental implant-supported restoration.
- A study evaluating occlusal parameters by digital method solely or combined with other methods.
- Study results presented as quantitative parameters, not qualitative ones. In addition, the quantitative data of each study included at least one occlusal indicator. Primary outcomes: occlusal force. Secondary outcomes: occlusal contact area, occlusal contact time, and occlusal contact number.
- Studies including clinical trial, systematic review (with and without meta-analysis).
- Written in English.
- Both abstract and full article available.

Exclusion criteria

- Laboratory research.
- Case report, short commentary.

Selection of studies

The review team was divided into two groups: TZ and XXL, BM and PM. Two groups independently screened the titles derived from the initial search in consideration for inclusion. After title screening, the abstracts obtained were scanned for inclusion by groups 1 and 2, respectively. Based on the selection of abstracts, articles were then obtained in full text. Disagreements were resolved by discussion. Finally, the selection based on inclusion/exclusion criteria is made for the full-text articles by the authors TZ and BM. For this purpose, materials and methods, results, and discussions of these studies were screened. BB then double-checked the selected articles. Any issues regarding the selection during the screening were discussed within the groups to reach a consensus.

Data extraction and method of analysis

Two researchers (TZ and BM) independently extracted the data of the selected articles using data extraction tables. For standardization purposes, each researcher extracted the data of the same three articles at the beginning of the literature analysis, and then any disagreements were discussed, aiming at a consensus to standardize the subsequent analyses. Finally, all extracted data were double-checked by one senior researcher (BB). Information on the following parameters was extracted:

Item	Yes	No	Unclear
1. Was the spectrum of patients representative of the patients who will receive the test in practice?	( )	( )	( )
2. Were selection criteria clearly described?	( )	( )	( )
3. Is the reference standard likely to correctly classify the target condition?	( )	( )	( )
4. Is the time period between reference standard and index test short enough to be reasonably sure that the target condition did not change between the two tests?	( )	( )	( )
5. Did the whole sample or a random selection of the sample, receive verification using a reference standard of diagnosis?	( )	( )	( )
6. Did patients receive the same reference standard regardless of the index test result?	( )	( )	( )
7. Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)?	( )	( )	( )
8. Was the execution of the index test described in sufficient detail to permit replication of the test?	( )	( )	( )
9. Was the execution of the reference standard described in sufficient detail to permit its replication?	( )	( )	( )
10. Were the index test results interpreted without knowledge of the results of the reference standard?	( )	( )	( )
11. Were the reference standard results interpreted without knowledge of the results of the index test?	( )	( )	( )
12. Were the same clinical data available when test results were interpreted as would be available when the test is used in practice?	( )	( )	( )
13. Were uninterpretable/ intermediate test results reported?	( )	( )	( )
14. Were withdrawals from the study explained?	( )	( )	( )

Figure 1. Quality assessment of diagnostic accuracy studies (QUADAS) tool.

author(s); year of publication; study design; the number of patients; follow-up time; demographic information of patients; features of the implant-retained restorations (implant type and design, number, location, restoration material and design of implants); digital measurement methods; quantitative parameters of occlusal outcomes that obtained from complete denture and implant supported rehabilitation, respectively, or those from partial edentulous patients and patients rehabilitated with implant retained restorations, which including magnitude and distribution of occlusal force, occlusal contact number and area, occlusal time and other occlusal related indicators.

Bias risk assessment

Considering that different digital occlusal measurement tools obtained quantitative parameters, the Quality Assessment of Diagnostic Accuracy Studies (QUADAS) tool [26] was implemented to measure the risk of bias of the included studies. It was achieved by asking 14 questions (Figure 1) for every study. For each question, a score of 1 was given if the answer was 'yes'; a score of 0 was given if the answer was 'no' or 'unclear'. Therefore, the highest possible score is 14, which indicates a lower risk of bias.

Data synthesis and statistic calculation

The data synthesis strategies were adopted without meta-analysis because of the overly diversified characteristics of included studies in terms of research design, research purposes, intervention types and results [27]. According to the hypotheses, the maximum bite force was selected as the main outcome due to the acceptance of an important indicator of masticatory performance [9,10]. At least one quantitative result can be extracted from the experimental group and the control group. Therefore, the mean and standard deviation of maximum bite force were calculated when summarizing effect estimates and calculating the p values. Besides, the changes in occlusal force distributed on the individual implant from the baseline (immediate) to the last follow-up were analysed because this indicator is directly related to overloading evaluation. In addition to the above, other digital-related occlusal outcomes, such as occlusal contact area, occlusal contact time and occlusal contact number were extracted and presented. The effect estimates were calculated by Reviews Manager version 5.4.1 (The Nordic Cochrane Centre, Copenhagen, Denmark), and the one sided p values were used, since these contain information about the direction of effect [28]. If there were multiple subgroups of intervention within a study, summary statistics were obtained by combining multiple subgroups. The average bite force was calculated *via* a within-subgroup standard deviation when the maximum bite

force was expressed as the left and right sides, respectively, for the same subjects [29].

1. The extracted outcome of maximum bite force was the bite force value of the full arch or posterior segment directly obtained via the digital means in the included study.
2. The time points of the compared data were pre-treatment and immediate placement of the implant-supported restorations; the time of occlusal force changes in implant restoration was defined from the baseline (immediate placement) to the last follow-up (the longest follow-up point) during the whole observational period (the intervals in observational period was each year except for 3 and 6 months).
3. The intervention measures were divided into implant-supported complete dentures or partially fixed prostheses according to the research questions addressed when summary statistics were applied. If the control group contained multiple types of dentures, only the traditional standard method (complete removable denture) was selected as the control. For the partially fixed prostheses, the data of pre placement of implant-retained restoration was considered as control.
4. The minimum number of studies for synthesis is two studies for one subgroup (different implant-retained restoration types).
5. If there were discrepancies between the results stated in the article and the raw data provided, the mean and standard deviation were calculated based on the raw data.

Results

Included studies

Fourteen studies [30–43] were included in the present systematic review (Figure 2). A total of 3656 and 193 articles were provided from PubMed and Cochrane Central respectively according to the search strategy, 28 papers were duplicated among those. A total of 3795 papers were excluded in the first (title and abstract) and 26 articles assessed for eligibility in the second (full-text) screening. It should be emphasized that the 0.839 of Kappa agreement coefficient ($p = .000$, 95% CI: 0.811–0.868) was achieved between two groups when initial abstract screening and 90 articles had been discussed before the 26 articles were determined. The characteristics of included studies are summarized in Table 1. The intervention group in the study included a total of 278 subjects with 695 implants, age from 18 to 87 years old, at least 135 females and 104 males. The shortest and longest follow-up dates that provided in the text were the immediate placement of the implant support restoration and 8 years post-placement, respectively. There were no randomized clinical trials; five studies were designed as prospective cohort or comparative studies, three were retrospective clinical trials, four were cross-sectional, and two were crossover clinical trials. Among them, nine studies [31–33,36,37,39,40,42,43] focussed on implant-supported overdentures (IODs) *vs*. full arch removable prostheses before the implant placement, and two studies [32,39] also contained complete dentures supported by all-on-four treatment concept. Five studies [30,34,35,38,41] focussed on fixed partial implant-supported prostheses, the details of implant (design) of those were summarized in Table 1. Four different digital occlusal measuring instruments were applied. Seven studies [30,33–35,38,40,41] used the T-scan (Tekscan, Inc., South Boston, MA), one study [31] adopted the force transducer (three axis force sensor USL06-H5-50N, Tec Gihan Co., Ltd, Kyoto, Japan), two studies [32,37] employed a force sensor (Bite Force Sensor, Hariom electronics, Vadodara, Gujarat, India), four studies [36,39,42,43] applied a digital force gauge (Occlusal Force-Metre GM 10, Nagano Keiki). Each study contained at least one item of the digital occlusal outcome.

Bias risk assessment and details of outcomes

According to QUADAS guidelines, the quality scores ranged from 9 to 12 (out of 14). Due to the diversity of occlusal indicators, the quantitative indicators were classified into the following six categories according to different outcomes of the studies: maximum bite force (arch or segments), relative occlusal force distributed on the individual implant, the specific bite force measured at the moment during the chewing process, duration of the bite force and occlusal contact teeth number or occlusion time. All quantitative digital occlusal parameters and the clinical significance of each research are listed in Table 2. Two studies [32,37] focussed on the comparison of masticatory performance between implant overdentures and complete dentures. Four studies [30,34,38,41] observed the changes in occlusal force distribution after single crowns. Three studies [33,42,43] observed the clinical manifestations of the occlusal force of implant-supported dentures of different designs or components. Four studies [35,36,39, 0] analysed the factors influencing bite force or correlation between bite force and oral health, such as bone resorption, occlusal design and complications. One study [31] measured the ability to adjust occlusal in implant-retained overdenture.

Summarizing the effect estimates of quantitative outcome

The available value of bite force selected from eight studies was analysed to evaluate the chewing efficiency of both experiment and control groups. Six studies [19,32,36,37,40,42] belonged to the implant-retained complete denture and two studies [30,41] to partially fixed implant restorations. The baseline and final data of the occlusal force distributed on the implant restoration from three studies [30,34,38] were obtained and analysed.

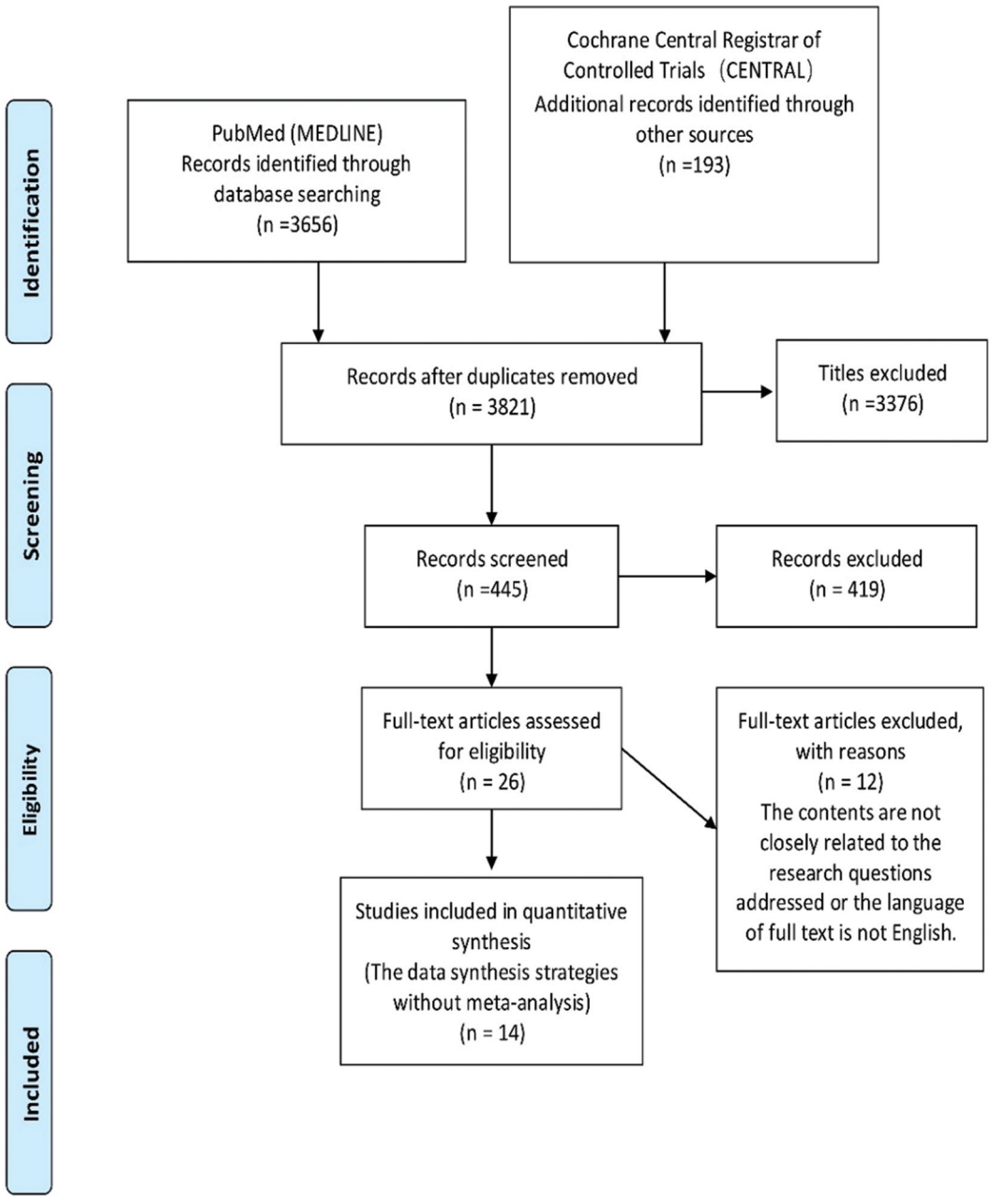

Figure 2. PRISMA 2009 flow diagram.

Summarizing effect estimates of maximum bite force

From Table 3, 95% confidence intervals were seen because of the use of different units of the digital methods. Six studies compared the maximum occlusal force of implant-retained overdentures (1 study contained all-on-four implant-retained restoration) and conventional complete dentures. Among these six studies, the statistically significant favoured intervention results were found in four studies [32,37,40,42], and there was evidence of the benefit of improved bite force for implant-retained overdenture in the above four studies ($p = .00045$, .00005, .00055, .00005, respectively). No statistically significant results in the other two studies [33,36], and the p value was .225 and .371, respectively. Meanwhile, for the two studies [30,41] of single posterior implant restoration, no statistically significant results of the favoured intervention was found, there was no sufficient evidence of masticatory performance benefit for single implant posterior restoration in these two studies ($p = .104$, .166, respectively). The data synthesis strategies were adopted without meta-analysis because of the overly diversified characteristics of included studies in terms of research design, research purposes, intervention types and results [27].

Summarizing effect estimates of changes in occlusal force applied on the individual implant

Statistically significant changes of bite force distributed on the implant restoration were observed in three studies ($p = .013$, .001, .05, respectively).

Table 1. Characteristics of included studies.

Study, year	Study design	Intervention: Implant -retained construction	Subjects/ implant number	Gender (female/ male)	Age (mean/ min, max) years	Compari-son	Follow-up time (mean or range)	Details of implant (design)	Digital methods	Digital occlusal outcome index
Zhou et al. [30]	A prospective clinical study	Single posterior implant-supported restorations	30/32	18/12	Age 27–75 years old	Pre-treatment	Immediate 2 weeks 3 months 6 months	Posterior regions of the maxilla or mandible. Screw-retained.	A T-Scan III computerized occlusal analysis system (Tekscan, Inc., South Boston, MA)	Bite force distributed on implants and teeth. Bite force distributed on segments pre, and post-implant restoration inserted.
Abe et al. [31]	A retrospective clinical controlled study	Implant-supported overdentures (IODs)	7/15	5/2	74.9 ± 6.8	Natural dentition. Conventional full denture.	6.1 ± 3.1 months	Three IODs had a magnetic attachment system, two had a locator attachment system, two had a ball attachment system.	Force transducer (3 axis force sensor USL06-H5-50N, Tec Gihan Co., Ltd., Kyoto, Japan).	Mean value of the occlusal force during the hold phase (hold force); Peak force rate during the split phase (peak force rate); The time required to split test foods (duration); The time required to split test foods (duration). Maximum occlusal force in the split phase (split force).
Soni et al. [32]	A comparative study	1. Complete dentures with implant-supported overdenture. 2. Complete dentures with hybrid denture supported by all-on-four treatment concept.	12/36	No details	Group 1: 55.83 Group 2: 52.6	Conventional full denture	Immediate measurement	No more details	1. A force sensor (Bite Force Sensor, Hariom electronics, Vadodara, Gujarat, India); 2. A computerized surface EMG (Synergy EMG. System, Arena medical care private limited, New Delhi, India).	The bite force of complete denture, overdenture and all-on-four denture, respectively. The chewing efficiency of complete denture, overdenture and all-on-four denture, respectively.
Kabbua et al. [33]	A prospective clinical study	Implant-retained overdenture	31/64	10/21	65.84 ± 7.66	Conventional full denture	Immediate 3 months 6 months 12 months	Low vertical profile attachments (Equator®).	T-scan (T-Scan 8, Software version 8.0.1, Tekscan, Inc.)	Maximum occlusal contact force (MOF). Force distribution. Tooth contact number.
Luo et al. [34]	A prospective clinical study	Single posterior partial fixed implant supported prostheses	33/37	18/15	42.8 (Age 23.9–70 years)	Pre-treatment	Immediate 2 weeks 3 months 6 months 12 months 24 months 36 month	Screw-retained or cement -retained.	T-scan (T-Scan III)	Maximal occlusal force. Occlusion time.
Huang et al. [35]	A retrospective clinical study	Posterior partial fixed implant supported prostheses	13/51	5/8	51.0 (Age 26–68 years old)	No data of pre-treatment	More than 7 years	The oral cancer patients were treated with dental implants in the fibular flap.	T-scan digital occlusal analysis system (T-Scan III v8; Tekscan Inc.).	Total bite force in full arch. Individual bite force of each implant prosthesis.
Schimmel et al. [36]	A cross-sectional study	Edentulous with two-implant overdentures (IOD group);	17/34	10/7	72.6 ± 5.9	Conventional full denture. Partial removable dental prostheses. Fully dentate.	96.8 ± 59.5 months	Retained by two unsplinted spherical attachments on Straumann RN implants located	A digital force gauge was used (Occlusal Force-Metre GM 10, Nagano Keiki; I-30-4 Higashimagome).	Maximum Restraining Lip Force. Maximum Voluntary Bite.

(*continued*)

Table 1. Continued.

Study, year	Study design	Intervention: Implant -retained construction	Subjects/ implant number	Gender (female/ male)	Age (mean/ min, max) years	Compari-son	Follow-up time (mean or range)	Details of implant (design)	Digital methods	Digital occlusal outcome index
Sharma et al. [37]	A within subjects crossover clinical trial	Implant-supported overdentures (IODs)	12/24	No details	60–75 years old	Conventional full denture	4 weeks	2 mm diameter metal balls. Implant grade V titanium with rough microtextured surface treatment and single threaded tapering design.	A force sensor (Bite Force Sensor, Hariom electronics, Vadodara, Gujarat, India);	Masticatory bite force
Madani et al. [38]	A prospective cohort study	Single posterior implant	21/21	10/11	30.81 ± 8.85 (Age 18–48 years old)	No data of pre-treatment	Immediate 3 months 6 months	Cemented-retained.	A T-Scan III computerized occlusal analysis system (Tekscan, Inc., South Boston, MA)	The percentage of applied occlusal force to the implant crowns (POFI). The percentage of applied occlusal force to the contralateral teeth (POFT)
Alzoubi et al. [39]	A cross-sectional study	Edentulous rehabilitated with a fixed implant-supported profile denture (implant-supported overdenture and all-on-four treatment concept)	34/220	22/12	A mean of 61.2 age from 20 to 83 years old	Conventional full denture	Mean of 48.6 months	In the maxilla 10 arches were treated using the All-On-4 approach, 19 arches were treated using bilateral zygoma and two axial implants, and four arches were treated using a quad zygoma concept. In the mandible, 21 arches were treated using the All-on-4 approach.	A digital occlusal force gauge (GM10, Nagano Keiki)	Maximum occlusal force in the anterior region. Maximum occlusal force in the posterior region;
Khuder et al. [40]	A cross-sectional study	Mandibular implant overdentures (IOD)	23/46	17/6.	IOD group: 66.2 ± 8.4. CD group: 64.9 ± 9.7	Conventional full denture	4 ± 1.8 years	Two implants inserted at canine areas in the parasymphyseal region and opposing conventional maxillary complete dentures.	T-scan III (Tekscan Inc., South Boston, MA, USA)	Occlusal force of anterior. Occlusal force of posterior.
Roque et al. [41]	A retrospective cohort study	Single posterior implant-supported restorations	15/15	No mention	No mention	Pre-treatment	Pre- and immediate treatment measurement, no follow-up	Position: 7 premolars and 8 first molars). Cement-retained crown.	A digital occlusal sensor (Tekscan III, Tekscan Inc., South Boston, MA, USA)	Occlusal force distribution of segments (anterior/ posterior). Occlusal force distribution of position (premolar/molar).
Elsyad et al. [42]	A crossover study (within patient comparisons)	Implant overdentures	10/20	5/5	No mention	Conventional full denture	3 months	20 implants. bar overdentures (BOD) or resilient telescopic overdentures (TOD) attachment systems.	A bite force transducer (Occlusal Force-Metre GM10, Nagano Keiki Co. Ltd; Higashimagome, Ohtaku, Tokyo, Japan)	Maximum bite force (MBF) (BOD and TOD). Chewing efficiency (unmixed fraction).
Enkling et al. [43]	Prospective clinical study	Edentulous patients treated with narrow diameter implants (NDIs)	20/80	15/5	41–87 years old, median 65.5 years old	Conventional full denture	4 weeks 8 weeks 12 weeks 26 weeks 52 weeks	80 implants. Four one-piece titanium NDIs (diameter 1.8 mm, length 13 or 15 mm, MDI system 3 M ESPE)	The GM 10 occlusal force metre (Nagano KeikiCo., Ltd. I-30-4 Higashimagome, Ohta-ku, Tokyo, Japan)	Maximum bite force (MBF) at different follow-up times. Chewing efficiency (colour mixing ability). Oral health-related quality of life OHR.

Table 2. Evaluation of risk bias and all quantitative parameters of outcome.

Author, year	Score of risk bias	Outcome index	Quantitative parameters and statistical differences (magnitude/unit)	Research findings and clinical significance
Zhou et al. [30]	12	1. Bite force distributed on implants and teeth. 2. Bite force distributed on segments pre and post-implant restoration inserted.	1. Occlusal bite force on implant mean ± SD (Median). Immediate: 4.46 ± 4.30 (3.270) % 2 weeks: 3.39 ± 2.61 (2.700) % 3 months: 6.90 ± 4.77 (6.280) % 6 months: 7.31 ± 4.60 (7.385) % 2. Occlusal force distributed on posterior segment. Category 1 (unilateral tooth defect) Pre: 36.18 ± 13.96 (36.880)% Post: 39.49 ± 13.11 (41.535)% category 2 (bilateral tooth defects) Pre: 34.37 ± 16.23 (35.700)% Post: 41.20 ± 15.37 (43.230) % – The occlusal force of the posterior segment on the restored side increased significantly ($p = .013$, .001, respectively). – The average bite force distributed on implant restorations significantly ($p = .008$, .013, respectively) changed from 2 weeks to 3 months and 6 months post-insertion.	1. Bite force can be improved with the immediate placement of a single posterior implant restoration. 2. A routine follow-up and occlusal evaluation are strongly needed because of inevitably increased bite force applied on the implant prosthesis after functional loading.
Abe et al. [31]	10	1. Mean value of the occlusal force during the hold phase (hold force). 2. Peak force rate during the split phase (peak force rate). 3. The time required to split test foods (duration). 4. Maximum occlusal force in the split phase (split force).	IODs: implant-retained overdenture. ND: natural dentition. CD: complete dentures 1. Median of hold force. IODs: 1.82 N (peanuts) and 1.59 N (biscuits); ND: 2.42 N (peanuts) and 1.69 N (biscuits); CD: 2.8 N (peanuts) and 1.72 N (biscuits); – No significant different among 3 groups ($p = .261$ for peanuts, $p = .615$ for biscuits) 2. Median of peak force rate. IODs: 195 N/s (peanuts) and 164 N/s (biscuits); ND: 292 N/s (peanuts) and 271 N/s (biscuits); CD: 223 N/s (peanuts) and 186 N/s (biscuits); – For peanuts, the peak force rate of the ND group was significantly higher than that of the IOD ($p = .047$) and CD groups ($p = .031$); However, for biscuits, there was no significant difference among the three groups ($p = .297$); 3. Median of duration. IODs: 0.9 s (peanuts) and 0.71 s (biscuits) ND: 0.63 s (peanuts) and 0.5 s (biscuits) CD: 1. 3 s (peanuts) and 1.09 s (biscuits) – The duration was significantly longer in the CD group than in the ND ($p < .001$) and IOD groups ($p = .016$ and .014) for both test foods. 4. Median of split force. IODs: 29.3 N (peanuts) and 21.0 N (biscuits) ND: 35.6 N (peanuts) and 21.3 N (biscuits) CD: 30.5 N (peanuts) and 22.1 N (biscuits) – There was no significant difference among the three groups.	1. Compared with wearers of natural teeth, the ability to adjust the bite force for IOD wearers is limited, but this is helpful to reduce the overload of implant dentures so that keeping the IOD in good condition for a long time. 2. From the view of the ability of force adjustment, the better treatment outcomes of IODs than traditional complete dentures treatment were revealed.
Soni et al. [32]	9	1. The bite force of complete denture, overdenture and all-on-four denture respectively. 2. The chewing efficiency of complete denture, overdenture, and all-on-four denture respectively.	IODs: implant-retained overdenture. CD: complete dentures 1. Mean and standard deviation of bite force. Group 1: IODs: 78.50 ± 12.15 N (right), 82.00 ± 23.97 N (left) CD: 25.00 ± 14.18 N (right), 25.33 ± 12.40 N (left) Group 2: All on four: 219.17 ± 117.35 N (right), 209.33 ± 84.80 N (left) CD: 51.17 ± 24.57 N (right), 55.67 ± 28.66 N (left) – Intergroup: The biting force of hybrid denture supported by all-on-four treatment concepts was significantly highest followed by overdenture ($p = .016$	The completely edentulous individuals with atrophic<posterior alveolar ridges can be rehabilitated successfully both implants retained overdenture or all-on-four dentures with improved biting force and chewing efficiency.

(*continued*)

Table 2. Continued.

Author, year	Score of risk bias	Outcome index	Quantitative parameters and statistical differences (magnitude/unit)	Research findings and clinical significance
			and .005) and complete denture ($p = .008$ and .002), respectively.	
Kabbua et al. [33]	12	1. Maximum occlusal contact force (MOF). 2. Tooth contact number. 3. Force distribution degree of force difference).	1. Mean and standard deviation of maximum bite force (MOF), tooth contact number and force distribution, respectively. Pre-implant restoration placement: 84.14 ± 5.79%; 6.63 ± 1.95; 3.39 ± 0.75% Post-implant restoration placement: 1 d function: 85.27 ± 5.92%; 5.84 ± 2.30; 2.92 ± 0.99%. 3-month function: 88.22 ± 7.11%; 7.22 ± 2.13; 3.58 ± 0.70%. 6-month function: 87.62 ± 5.63%; 6.58 ± 2.18; 3.32 ± 0.85%. 12-month function: 89.77 ± 4.56%; 7.73 ± 1.66; 3.62 ± 0.65%. – Significant difference of MOF: before implantation and12-month function ($p = .004$); 1-d function and 12-month function ($p = .013$). – Significant difference of tooth contact number: before implantation and 12-month function ($p = .022$);1-d function and 3-month function ($p = .001$); 1-d function and 12-month function ($p < .001$); 6-month function and 12-month function ($p = .009$) – Significant difference of Force distribution: 1-d function and 3-month function ($p = .001$); 1-d function and 12-month function ($p = .003$).	The oral function of the complete denture retained by mini-dental implant has been enhanced because of the function significantly improved in terms of maximum occlusal contact force and tooth contact number.
Luo et al. [34]	12	1. Maximal relative occlusal forces on implant prosthesis. 2. Implant occlusion time (the time from the first occlusal contact of Vimplant prostheses to the MIP) ratios.	1. Mean and standard deviation of maximum relative occlusal forces on implant prostheses (ROFs) and control teeth, respectively. 0.5-month: 7.46 ± 4.21%; 13.78 ± 6.00% 3-month: 9.87 ± 6.79%; 11.43 ± 5.47% 6-month: 10.59 ± 6.59%; 12.67 ± 5.76% 12-month: 13.03 ± 10.61%; 13.14 ± 7.54% 24-month: 14.32 ± 10.99%; 11.4 ± 6.87% 36-month: 19.09 ± 11.76%; 12.5 ± 6.84% – The ROFs of implant prostheses increased significantly ($p < .05$) from 2 weeks (7.46 ± 4.21%) to 3 months (9.87 ± 6.79%), whereas those of control natural teeth decreased significantly ($p < .05$) from 13.78 ± 6.00 to 11.43 ± 5.47%. The ROFs of implant prostheses continued to increase from 6 to 12 months and from 12 to 24 months, with significant differences ($p < .05$). However, they were statistically like those of control natural teeth at 6, 12, 24 and 36 months after restoration. – Implant prosthesis occlusion time ratios also increased significantly between 2 weeks and 3 months and between 3 and 6 months ($p < .05$).	The occlusal force and occlusal contact time of the posterior implant retained fixed partial restorations increased with functional loading. During follow-up inspections, the occlusion of the implant restoration must be carefully monitored, and necessary adjustments should be made.
Huang et al. [35]	11	1. Total bite force in full arch. 2. Individual bite force of each implant prosthesis. 3. The association of the bite force with the implant variables.	1. Average total bite force: 97.3 ± 2.56%. 2. Average individual bite force of each implant prosthesis: 38.9 ± 32.8%. 3. Linear regression for bite force of the variance derived from dental implant rehabilitation. Fibular length/Mandibular length: −0.08 Implant prosthetic dentition (length/Mandibular dentition length): − 4.24 Implant prosthetic dentition (length/Maxillary dentition length): − 4.27 Mandibular dentition (length/Maxillary dentition length): 6.95 Individual bite force Crown/Implant: −2.22 -No statistical significance ($p > 0.05$) was	1. The increased crown-implant ratio might decrease the bite force. 2. Increasing the length of implant rehabilitative dentition and fibular flap might have the tendency to weaken the occlusal force. 3. The restored dental arch should be expanded to be if possible to attain comparability and better functional considerations.

(*continued*)

Table 2. Continued.

Author, year	Score of risk bias	Outcome index	Quantitative parameters and statistical differences (magnitude/unit)	Research findings and clinical significance
			found among the association of the bite force with the implant variables.	
Schimmel et al. [36]	9	Maximum voluntary bite force (MBF).	CRDP: complete removable dental prostheses IOD: implant- retained overdentures PRDP: Kennedy Class I partial removable dental prostheses. 1. Mean and standard deviation of maximum voluntary bite force. CRDP group): 78.11 ± 5.00 N IOD group): 82.4 ± 53.08 N PRDP group): 119.94 ± 76.97 N Fully dentate (control group): 376.75 ± 180.50 N - MBF was different among the four study groups ($p < 0.0001$). Detailed comparisons revealed significantly higher forces in the control group than in all other groups ($p < 0.0001$). 2. Regression between MBF and Model to Predict Masticatory Performance (VOH). – MBF was significant predictors in the linear backward selection model; (Estimate: −0.0003; $p = 0.02693$).	1. Tooth loss significantly affects MBF and masticatory performance. 2. Distal edentulous extensions with a rotational axis in two-implant IODs and Kennedy Class I PRDPs may limit MBF and consequently chewing efficiency. 3. CRDP design should facilitate perioral muscular function.
Sharma et al. [37]	10	Masticatory bite force.	1. Mean and standard deviation of masticatory bite force. CD (conventional complete dentures) group: mean (min/max): 64.16 (31.18-85.07) N right side: 63.25 ± 18.15 N; left side: 62. 56 ± 15.63 N IODs (Implant-retained overdenture) group: mean (min/max): 132.01 (68.78-191.68) N right side: 133.76 ± 38.010 N; left side: 128.10 ± 39.04 N	The significant improved chewing efficiency and masticatory bite force can be achieved with a mandibular overdenture rehabilitation due to the bite force percentage of implant-supported overdentures was nearly 2 times compared with conventional dentures.
Madani et al. [38]	10	1. The percentage of applied occlusal force to the implant crowns (POFI). 2. 2. The percentage of applied occlusal force to the contralateral teeth (POFT).	1. Mean and standard deviation of applied occlusal force to the implant crowns and contralateral teeth. baseline: POFI: 4.0 ± 0.19%; POFT: 9.47 ± 0.28%. 3 months: POFI: 4.52 ± 0.20%; POFT: 8.71 ± 0.35%. 6 months: POFI: 5.0 ± 0.28%; POFT: 8.23 ± 0.30% – The POFT values at 3- and 6-month follow-up appointments were significantly lower than those at baseline ($p < .001$). However, there were no significant differences between the POFT values at 3- and 6-month follow-up ($p = .061$).	After placement of the implant restoration, the density of contacts between the prosthesis and the opposite tooth gradually increased, so it is necessary to adjust the occlusion regularly to prevent potential overload caused by changes in the position of the teeth.
Alzoubi et al. [39]	10	1. Maximum occlusal force in the anterior region. 2. Maximum occlusal force in the posterior region.	1. Mean (min/max) of maximum occlusal force. maximum occlusal force in the anterior region: a mean of 108 Ncm (provisional = 103 Ncm, definitive = 112 Ncm; SD = 44) ranged from 38 to 223 Ncm; maximum occlusal force in the posterior region: a mean of 205 Ncm (provisional = 192 Ncm, definitive = 215 Ncm; SD = 81) ranged from 57 to 423 Ncm – The higher the maximum occlusal force in the anterior region, the greater the complications (Spearman correlation coefficient = −0.276; $p < .05$). – A significant difference was also noticed between sexes regarding maximum occlusal force both in the anterior and posterior regions ($p < .01$).	1. The quality of life seems to improve when completely edentulous patients are treated with a fixed implant-supported prosthesis. 2. Impact on quality of life was also correlated with posterior maximum occlusal force. 3. Complications detected were positively correlated with anterior maximum occlusal force but not posterior maximum occlusal force.
Khuder et al. [40]	12	1. Occlusal force of anterior (IOD and CD). 2. Occlusal force of Posterior (IOD and CD).	IOD: implant-retained overdenture. CD: complete dentures Mean and standard deviation of occlusal force: occlusal force of anterior: IOD: 16 ± 16%; CD: 37 ± 24%	The results implied that the type of prostheses has no influence on the bone reduction in the anterior maxilla, but for each 1% increase in occlusal force

(*continued*)

Table 2. Continued.

Author, year	Score of risk bias	Outcome index	Quantitative parameters and statistical differences (magnitude/unit)	Research findings and clinical significance
			occlusal force of posterior: IOD: 84 ± 16%; CD: 63 ± 24% – Multivariate linear regression analyses showed that in the anterior maxillary ($p < .0001$) and in the posterior mandibular ($p = .023$) ridges, the bone change was significantly associated with the percentage of occlusal force distribution.	distribution, the increased by 0.3% bone resorption at maxillary anterior ridge and 0.2% in the posterior mandibular ridge were observed. However, prosthetic factors were also believed to be related to the bone resorption in the mandible.
Roque et al. [41]	10	1. Occlusal force distribution of segments (anterior/posterior). 2. Occlusal force distribution of position (premolar/molar).	1. Mean (standard error) of occlusal force distribution. Occlusal force distribution of segments: pre-treatment: occlusal force of anterior 15.8 (2.70)% posterior of restored side: 39 (2.9)% posterior of contralateral side: 44.3 (2.96)% post-treatment: occlusal force of anterior: 14.4 (2.25)% posterior of restored side: 43.18 (3.07)% posterior of contralateral side: 41.4 (2.71)% – Posterior occlusal force significantly increased ($p = .019$) in the restored side of implant restoration insertion, whereas it significantly decreased ($p = .047$) in the contralateral side. 2. Average changes of occlusal force distribution based on position. Restorations at the first premolar position (PM1): an average increase of 4.74% in the sextant containing the restoration; an average increase of 4.03% in the anterior sextant of PM1 restorations; an average decrease of 7.65% of total occlusal pressure in the sextant contralateral to PM1 restorations. Restorations at the second premolar position (PM2): an average increase of 8.37% of total occlusal pressure; an average decrease of 3.0% in the anterior sextant of PM2 restorations; a decrease of 0.08% in the contralateral sextant to PM2 restorations. Molar restorations (M): an average increase of 6.34% in the containing sextant; the anterior sextant of M restorations registered an average decrease of 1.77%; sextants contralateral to M restorations registered an average decrease of 1.97%.	1. Posterior occlusal force increased significantly in the restored side whereas significantly decreased in the contralateral side. 2. The pressure on the anterior dentition increased or decreased with placement of restorations more nearly to anterior or posterior, respectively.
Elsyad et al. [42]	12	Maximum bite force (MBF). conventional complete dentures (CD) bar overdentures (BOD) resilient telescopic overdentures (TOD)	Mean and standard deviation of maximum bite force (MBF): CD group: 68.0 ± 5.4 N (range from 60.0 to 75.0 N). BOD group: 90.17 ± 7.15 N (range from 80.0 to 100.0 N). TOD group: 98.57 ± 6.85 N (range from 90.0 to 110.0 N). – MBF differs significantly between the three tested dentures with TOD recorded the highest MBF, followed by BOD, and the CD recoded the lowest MBF. – There was a significant negative correlation between MBF, and unmixed fraction (UF) was measured using chewing gum (Spearman correlation = −0.806, $p < .001$)	Resilient telescopic attachments are associated with increased chewing efficiency and MBF compared bar attachments when used to retain overdentures to the implants in patients with atrophic mandibles.
Enkling et al. [43]	10	1. Maximum bite force (MBF) in edentulous patients treated with narrow diameter implants (NDIs)	Median of maximum bite force (MBF) at different follow-up times: baseline (pre- treatment): 46.6 N. week 4 postoperatively: 56.6 N. week 8 postoperatively: 68.8 N. week 12 postoperatively: 69.8 N. week 26 postoperatively: 85.8 N.	1. Maximum bite force increased continuously during the observational period of 1 year. 2. The use of NDIs could be a minimally invasive

(*continued*)

Table 2. Continued.

Author, year	Score of risk bias	Outcome index	Quantitative parameters and statistical differences (magnitude/unit)	Research findings and clinical significance
			week 52 postoperatively: 103.9 N. – Increase of the maximum voluntary bite force MBF (N) over the study period of 52 weeks (w52), categorized in patients age $<$ 65 years and patients age $\geq$ 65 years: younger patients showed higher MBF values than older patients ($p = .002$).	and economical approach to improve oral function especially in elderly patients with limited bone support.

Discussion

Although four studies performed the benefit of improved bite force for implant-retained overdenture ($p = .00045$, .00005, .00055, .00005, respectively) among six studies in comparison with the conventional complete denture, however, there was no sufficient evidence of masticatory performance benefit for single implant posterior restoration in the two include studies ($p = .104$, .166, respectively). Besides, substantial evidence of increased bite force distributed on the implant prostheses of partially fixed implant-retained restoration in all three studies ($p = .0065$, .0005, .025, respectively). As a proper meta-analysis cannot be performed, there are too many potential biases, including the timing of loading, implant-supported configuration and different populations, so there is no sufficient evidence to reject the null hypothesis.

Digital occlusal measurement device

The digital occlusal measurement tools used in fourteen studies mainly include:

- A T-scan (Tekscan, Inc., South Boston, MA).
- A force transducer (3 axis force sensor USL06-H5-50N, Tec Gihan Co., Ltd, Kyoto, Japan).
- A force sensor (Bite Force Sensor, Hariom electronics, Vadodara, Gujarat, India).
- A digital force gauge (Occlusal Force-Metre GM 10, Nagano Keiki).

Obvious advantages were recognized, such as directly obtaining the quantitative value of the bite force, the visible distribution of bite force in different arch segments (or calculation from the ratio through the measurement results), and the correlation between force and time to make it possible for in-depth study. However, in addition to the different measurement units, the outcomes are also limited by the thickness of the instruments, material sensitivity, as well as the accuracy and precision of mechanical characteristics of the bite force recording system, especially under the clinical oral operating environment [44–46]. Therefore, the summarized effect results from 10 studies (Table 3) also reflected these characteristics of different methods. It can be noticed that quantitative occlusal parameters represented multiple meanings, not only for comparison of chewing performance but also to reveal the correlations between occlusal features of implant restoration and oral related health according to the outcomes of all 14 studies. Hence, it is not difficult to infer that the appropriate choice of digital occlusion measurement method is mainly determined by the purpose and significance of the research or actual clinical conditions.

Maximum bite force and masticatory efficiency

Masticatory efficiency is defined academically as 'the effort required for achieving a standard degree of comminution' [44]. The cumulative contribution of multiple factors such as bite force, the severity of malocclusion, occlusal contact area, loss of tooth body, type of posterior restoration, craniomaxillofacial morphology, and other functional activities bite force is one of the key factors [9,45]. Among six studies, the result of four studies indicated that the bite force of implant overdentures was significantly higher than conventional complete dentures when immediate placement [32,37,40,42], the other two studies [33,36] failed to demonstrate effects on chewing efficiency. An important reason for the former study [33] was that the selected time point was immediate placement instead of the 1-year follow-up in the original study; the possible reason for the latter study [36] was that the performance of bite force was greatly determined by the characteristics of the subjects due to a cross-sectional study design. The following views could explain the results of improved bite force: first, the ability of wear to comminute food during chewing is determined by the increment of retention and stability of the mandibular denture [46,47] rather than the degree of retained by implants or alveolar mucosa; in addition, the loss of teeth in elderly patients usually accelerate atrophy of the jaw closure muscles [48] leading to pain and instability during chewing, the usage of implants has a positive training effect [5,49] on masseter so that stabilizing the mandibular denture by reducing vertical and horizontal denture movement and lowering the pain threshold during biting and chewing. Although the index of maximum bite force was not presented in AbeM's study [31], the implanted overdenture displayed a significantly shorter duration (the required time to split test foods) than the conventional full mouth denture during the chewing process (Table 2). This result was also consistent with the above viewpoints due to the differences in mucosal movement and stability between the two dentures. On the contrary, none of the studies [30,41] supported the significant improvement of bite force for partially fixed implant prostheses included, even if the actual research results indicated that the occlusal force changes of pre-and post-treatment were statistically significant *via* corresponding statistical methods. On the one

Table 3. Summary statistics of available data for the representative outcomes from each study.

				Summary statistics							
Study, year	Score of BRA	Represen-tative outcome	Intervention/ comparable comparison	Available data* mean (SD) Experimental	*N*	Control	*N*	Units	Stand. metric MD (95% CI)	Available data* (2-sided *p* value)	Stand. metric (1-sided *p* value)
Soni et al. [32]	9	Maximal bite force of each side (right and left respectively)	Subgroup 1 Implant-supported overdenture/ complete dentures	78.50 (12.15) 82.00 (23.97) Average 80.25 (17.35)	6 6 6	25.00 (14.18) 25.33 (12.40) Average 25.17 (12.16)	6 6 6	N N N	/	/	/
			Subgroup 2 hybrid denture supported by all on four/complete dentures	219.17 (117.35) 209.33 (84.80) Average 214.25 (93.46)	6 6 6	51.17 (24.57) 55.67 (28.66) Average 53.42 (24.37)	6 6 6	N N N			
			Combining Subgroup	147.25 (94.89)	12	39.30 (23.55)	12	N	107.96 (52.64∼163.27)	$p = .0009$ $N = 24$	.00045
Kabbua et al. [33]	12	Maximum occlusal contact force	Implant-retained overdenture/ complete dentures	85.27 (5.92)	31	84.14 (5.79)	31	%	1.13 (−1.79∼4.05)	$p = .450$ $N = 62$	.225
Schimmel et al. [36]	9	Maximum voluntary bite force	Implant overdentures /complete dentures	82.4 (53.08)	17	78.11 (5.00)	17	N	4.29 (−21.05∼29.63)	$p = .742$ $N = 34$	.371
Sharma et al. [37]	10	Masticatory bite force of each side	Implant-supported overdentures /complete dentures	132.01 (36.15)	12	64.16 (16.69)	12	N	67.85 (45.32∼90.38)	$p < .0001$ $N = 24$	.00005
Khuder et al. [40]	12	Occlusal force of Posterior	implant overdentures (IOD)/ complete dentures	84.0 (16.0)	23	63.0 (24.0)	23	%	21.00 (9.21∼32.79)	$p = .0011$ $N = 46$	.00055
Elsyad et al. [42]	12	Maximum bite force (MBF)	Subgroup 1(BOD Bar overdentures) /complete dentures	90.17 (7.15)	5	68.0 (5.4)	10	N	/	/	/
			Subgroup 2(TOD) resilient telescopic overdentures /complete dentures	98.57 (6.85)	5						
			Combining Subgroup	94.37 (7.95)	10				26.37 (20.41∼32.33)	$p < .0001$ $N = 20$	.00005
Zhou et al. [30]	12	Maximal occlusal force of Posterior segment	single posterior implant-supported restorations /pre-treatment	Category 1 39.49 (13.11)	14	36.18 (13.96)	14	%	/	/	/
				Category 2 41.20 (15.37)	13	34.37 (16.23)	13	%			
			Combining Subgroup	40.31 (13.99)	27	35.31 (14.83)	27	%	5.00 (−2.68∼12.69)	$p = .208$ $N = 54$	.104
Roque et al. [41]	10	Occlusal force distribution of posterior segments	Single posterior implant-supported restorations /pre-treatment	43.18 (11.89)	15	39.0 (11.23)	15	%	4.18 (−4.10∼12.46)	$p = .331$ $N = 30$	.166
				Baseline (immediate loading)	N	Final (the last follow-up)	N		Change Mean	Available data* (2-sided *p* value)	Stand. metric (1-sided *p* value)
Zhou et al. [30]	12	Maximal occlusal forces on implant prosthesis	single posterior implant-supported restorations /6-month follow up	3.39 (2.61)	17	7.31 (4.60)	18	%	−3.92	$p = .013$	.0065
Luo et al. [34]	12	Maximal relative occlusal forces on implant prosthesis	single posterior implant-supported restorations /36-month follow up	7.46 (4.21)	37	19.09 (11.76)	22	%	−11.63	$p = .001$	.0005
Madani et al. [38]	10	The percentage of applied occlusal force to the implant crowns	Single posterior implant-supported restorations /6-month follow up	4.0 (0.19)	21	5.0 (0.28)	21	%	−1.0	$p = .05$	.025

*The 'available data' column indicates the data that were directly reported, or were calculated from the reported statistics, in terms of: effect estimate, confidence interval, precise *p* value, or statement regarding statistical significance (either statistically significant, or not). BRA: bias risk assessment; CI: confidence interval; MD: mean difference; Stand.: standardized. 'N' in unit column = newton.

hand, this indicated that the few numbers of missing teeth might have only a slight effect on chewing performance. On the other hand, only two partial dentures that single posterior implant restorations were analysed, and the primary purposes of these studies were to evaluate the redistribution of bite force in the prothesis and each segment. Therefore, the maximum bite force data for comparison were only before and after immediate treatment. T-scan was used to measure the percentage of bite force rather than the absolute value of bite force. It might be challenging to achieve both sides' equality because the individual bite force of the patient was still regarded as a fixed whole and measured by a percentage even though the actual bite force value has increased.

Risk factors of overloading and complications

Overloading refers to stress around the implant components and bone–implant interface that is not both technically and biologically acceptable, which is often regarded as one of the potential causes for peri-implant bone loss and failure of the implant/implant prosthesis [50–52], as well as the range of overload that biologically acceptable is also unknown [53–55]. Three include studies [30,34,38] reported the changes in the occlusal force distribution on implants prostheses, the results from those showed the tendency of a significantly increased occlusal force of prostheses, which suggested that implants may face the risk of overloading over time. It has been reported that a variety of contributing factors including the wear of natural teeth and occlusal surface of restorations, extrusion of the opposing occluding teeth and craniomaxillofacial growth [56–58], recurring bone remodelling [59,60], the geometry and design of occlusal surface [61,62] could result in the changes of occlusal force distributed on implant restorations over time. For other included studies, Huang et al. [35] revealed that occlusal force on each implant prosthesis could be reduced with increased crown-implant ratio to avoid potential overloading. The study of Alzoubi et al. [39] found that the distribution of anterior segmental occlusal force was proportional positively to the occurrence of complications such as incisal acrylic teeth chipping. Similarly, Khuder et al. [40] pointed out that for each 1% increase in bite force distribution, the increased bone resorption of the maxillary anterior and the posterior mandibular ridges increased by 0.3% and 0.2%, respectively. These factors have been described and emphasized as possible overloading factors in the relevant review of occlusion [1,18,22–24]. These data may have vital guiding significance for clinical research because the quantitative correlations between the influencing factors and the changes for individualized subjects were presented intuitively.

Consideration of occlusal design and component

The essential considerations of occlusal design and components for edentulous implant-retained restoration are sufficient stability and retention, especially in ageing patients with alveolar ridge atrophy. A better choice is mini-implant-retained mandibular overdenture for the elderly with alveolar ridge absorption, chronic diseases, fear of surgery and economical choice. Mini implants have apparent advantages such as more accessible access to sufficient bone–implant width, lesser surgical invasion and pain, and shorter healing time than the standard implants [63,64]. Kabbua et al. [33] demonstrated an average of 5.63% significant improvement in occlusal force post-1-year treatment using mini-IODs. It also did not impair the balancing occlusion, which has been designed, and better clinical performance was obtained with an increase in the number of occlusal contact teeth and patient satisfaction for 1-year follow-up (Table 2). However, it must be noticed that disintegration of the mini-dental implants could result from excessive occlusal forces, such as using the anterior part of the denture only. Besides, in the included study [43] of lower complete prostheses supported with four interforaminal NDIs (narrow dental implants), the results showed the maximum bite force improved from 46.6 N (pre-treatment) to 56.6 N (immediate post-treatment) and finally to 103.9 N (1 year follow up). Hence, the authors inferred that a lower complete prosthesis retained with four interforaminal NDIs could be a minimally invasive and economical approach to improve oral function, especially in elderly patients with limited bone support (Table 2).

Furthermore, the attachment system of implant-retained overdentures was highly concerned [65,66] because the type of attachment system influences the retention and stability of the complete denture. In the present review, one study [33] used the Equator® attachment and emphasized the advantages, including its smaller size than other attachment systems and fewer prosthetic complications than ball attachments. One study [42] concluded that resilient telescopic attachment was associated with increased chewing efficiency and maximum bite force compared to bar attachments when used to retain overdentures to the implants in patients with atrophic mandibles.

The limitations of this systematic review are as follows:

- The studies' diversities in terms of research purposes, design, and multiple outcomes bring about the heterogeneity and the limited effect summarized methods among the studies.
- The low level of evidence of the included studies is a bias, for the reasons of no randomized clinical trials, five prospective cohort or comparative studies, three retrospective, four cross-sectional and two crossover clinical trials.
- The quality assessment used in this study is closely related to the results reporting, so well-conducted research may be scored lowly in the quality assessment if the methods and results are not reported in sufficient detail.
- The study only retrieved the data of published papers but did not collect and analyse the results from unpublished articles.
- The partial denture analysed in this review was the single fixed posterior restoration only. The reasonably narrow inclusion of partially fixed prostheses significantly

increased the bias of result judgement based on the null hypothesis.

Conclusion

Given the limitations of this study, the following conclusions can be drawn:

Based on the limited evidence, the edentulous restoration supported by implants seems to significantly improve bite force and chewing efficiency when compared with the conventional dentures; however, the limitations of type and number included in this study might conceal the effect of improved chewing efficiency of partial fixed implant prostheses. With the continuous advancement that designs and components of dental implants, the research findings could supply strategies and considerations for reference from the perspective of how to maximize oral function. For the further studies, the sample size should be increased and the randomized controlled trials should be considered, and in addition to the time of immediate loading, at least 1 year or long-term observational time points are required.

Regularly quantitative occlusal measurement is recommended because potential overload factors such as increased occlusal force distributed on the restoration and excessive occlusal force applied in the anterior were observed.

The less dimensional implant and relatively small and elastic attachment design may be more beneficial to the stability and retention of the restoration for edentulous with alveolar bone atrophy.

Disclosure statement

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