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SYSTEMATIC REVIEW

Bite force of children and adolescents: a systematic review and meta-analysis

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Abstract

This systematic review aimed to assess bite force measurements in children and adolescents and to study the various devices that measure Maximum Voluntary Bite Force (MVBF). This systematic review included observational studies and experimental studies in children and adolescents (upto 19 years of age) which evaluated MVBF using a bite force measuring device. Studies on participants with systemic conditions were excluded. Databases such as PubMed, Embase, LILACS, and the Cochrane library were searched until September 2022, for which screening and quality assessment were performed. Newcastle-Ottawa, modified Newcastle-Ottawa and ROBINS-I tools were used to assess the Risk-of-bias. All observational studies reporting overall bite force values of participants were included for meta-analyses. A total of 8864 participants (3491 males and 3623 females) were included from 61 studies. Meta-analyses were conducted to evaluate mean average bite force value for each included dentition using R software v2.4-0. Estimation was done to derive an average BF value for variables such as age (dentition), gender, side, site, device and ethnicity. MVBF values were reported as mean average in the form of MLN with 95% CI (Confidence Interval). Using a random-effects model, 29 forest plots were generated. I^2 values varied between 90% and 100%. Bite force ranged from 246.22 N (220.47; 274.98) to 311.72 N (255.99; 379.59) and 489.35 N (399.86; 598.87) in primary, mixed, and permanent dentitions, respectively. Six different sites for recording bite force and 11 different types of devices were reported with portable occlusal bite force gauge being the most common device. Outcomes of this review provide useful baseline reference values of bite force for clinicians and researchers.

Keywords

Bite force; Children; Device; Dentition; Occlusion

1. Introduction

Bite force (BF) can be defined as "the capacity of the mandibular elevation muscles to perform a maximum force of lower teeth against the upper teeth, under favorable conditions" [1, 2]. The measurement of these balanced forces such as Maximum Bite Force (MBF) or Maximum Voluntary Bite Force (MVBF) and their dispersion could be an index for assessment of the level of normality or deviation from the normal in oral health. In any compromised dentition, the assessment of occlusion and the forces applied within the stomatognathic system when in occlusion may aid in the quantification of the clinical complications in an individual. BF measurements have been studied in various subjects with a wide range of devices for either the diagnosis or assessment of multiple conditions such as dental decay [3, 4], temporomandibular joint or muscle disorders [5, 6], malocclusion [7, 8], influence of Body Mass Index (BMI) [9], and early loss of teeth, which can disturb normal occlusion.

BF values can be obtained directly or indirectly from an individual [10, 11]. Among the many parameters used for assessing BF by clinical measures are Masticatory Efficiency or Performance [12], Electromyographic (EMG) activity [13], and measurement of MVBF [14, 15]. However, unlike MVBF, masticatory performance and EMG are not quantifiable as numerical data. Additionally, reports in the literature have associated MVBF and its impact on quality of life directly through multiple studies in children [16–18]. A wide range of MVBF values has been recorded, and numerous devices for recording them have been reported in the literature thus far. A recent review on BF measuring devices [19] listed nine different types of equipment commonly used in gauging MVBF in children, adolescents, and adults.

Uncertainty prevails regarding the calibrated values of MVBF, measured in children and adolescents due to multiple devices, varying sites and units used to evaluate BF. Also, the absence of a baseline value in primary, mixed and permanent dentitions necessitates a strong need for quantitative evaluation

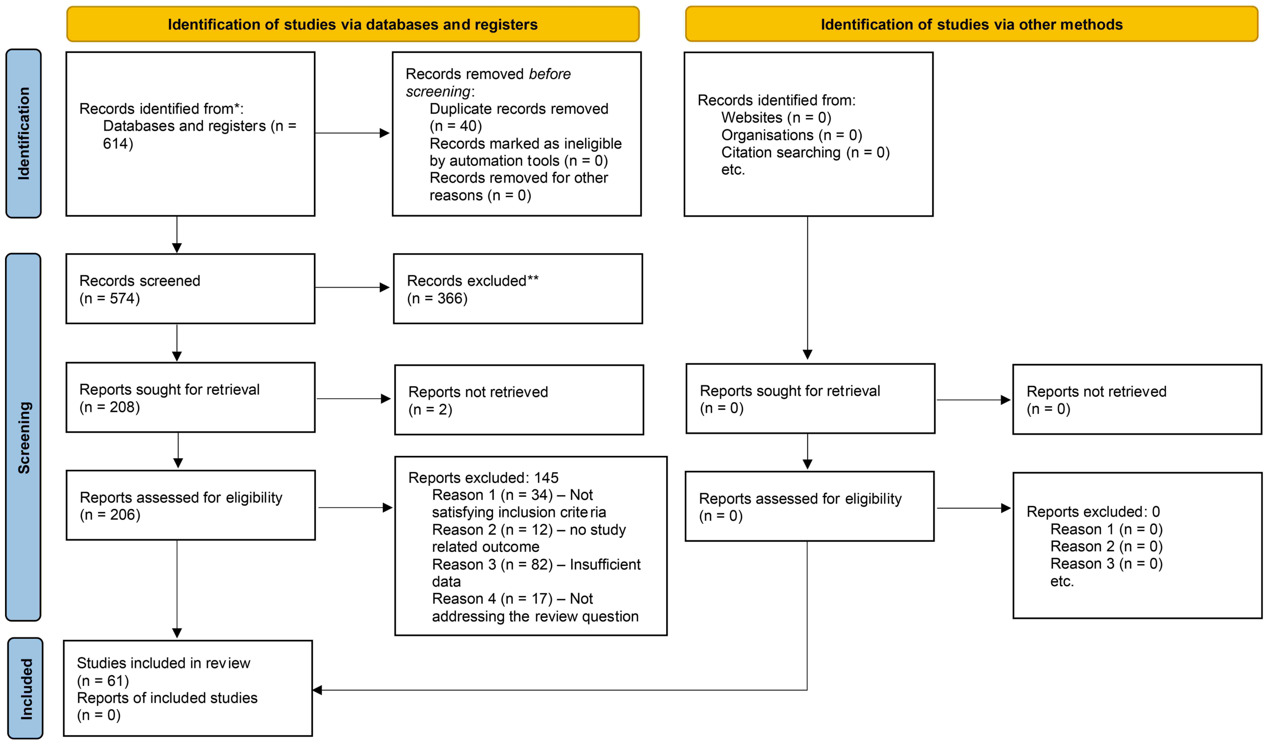

FIGURE 1. Flow diagram for study selection according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Total of 57 studies that satisfied the eligibility criteria were included in this systematic review.

of the average BF value. Values that may serve as standard baseline measurements to detect various dental-related abnormalities concerning age/dentition, gender, side, site, device and ethnicity are required. Therefore, this systematic review is primarily intended to compile BF measurements in children and adolescents and investigate various devices that measure MVBF. Additionally, this systematic review aimed to document changes in BF after various methods of oral rehabilitation, significant to diagnose any clinical deviations from the baseline value.

2. Methods

This systematic review was performed to review BF measurements in children and adolescents and reported according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [20]. The study protocol was registered in PROSPERO (The International Prospective Register of Systematic Reviews) no: CRD42020150464.

2.1 Selection criteria

This systematic review included observational studies (cross-sectional, case-control, and cohort studies) and experimental studies evaluating MVBF using a BF measuring device. Children and adolescents (according to WHO (World Health Organization criteria)) [21] comprised the study population. Study designs such as reviews, protocols for trials, and conference abstracts were excluded. Any studies that measured MVBF in adults (>19 years), children with special health care needs, with cleft lip/palate, and medically compromised patients were excluded. Records published in languages other than English and unpublished records were excluded.

2.2 Search strategy

The search aimed to find published data with no limit on the date of publication up to September 2022 from PubMed, Embase (Excerpta Medica Database), LILACS (Latin American & Caribbean Health Sciences Literature), and Cochrane library. Two authors (PJ and GFP) independently identified potential references through hand searches of journals (Journal of Dental Research, Paediatric Dentistry, Journal of Dentistry for Children, International Journal of Pediatric Dentistry, International Journal of Orthodontics, Journal of Clinical Orthodontics, Journal of Prosthodontics, and Journal of Prosthetic Dentistry), cross-references, and grey literature (NTIS (National Technical Information Services), Ovid, PsycEXTRA, and Shodhganga) for relevant articles. Search terms were a combination of MeSH and free text such as "bite force", "masticatory efficiency", "occlusal force distribution", "child", "children", "adolescents", "device", "method", and "measurement".

2.3 Data collection

Two reviewers (PJ and GFP) independently performed an initial title and abstract screening to select the articles according to the eligibility criteria. The consensus was sought from a third investigator (MS Muthu) in cases of disagreement about the eligibility of a study to be retained. All studies excluded at this stage are documented with reasons for exclusion (not satisfying inclusion criteria, no study-related outcome, insufficient data despite attempts to contact the author, and not addressing the review question). Two authors (PJ and GFP) independently extracted data from each included study. The customized spreadsheets included the details on author/s, year of publication, demographic information of the participants (age, gender, ethnicity), dentition, index test (masticatory efficiency/bite force/occlusal force distribution) used, instrument/device used, and unit of measurement along with side and site of bite registration. Further information was sought from the authors of the studies wherever necessary.

2.4 Assessment of risk-of-bias

The risk-of-bias in the included studies was assessed by PJ and GFP independently. Assessing the risk-of-bias among included cohort and case-control studies was done using the Newcastle-Ottawa scale (NOS) [22] and the modified Newcastle-Ottawa scale (M-NOS) [23] for cross-sectional studies. The risk-of-bias was categorized as high (≥7 stars), moderate (5–6 stars), and low (<5 stars) based on the NOS and M-NOS scales. Additionally, the ROBINS-I (Risk of Bias in Non-randomised Studies-of Interventions) tool [24] judged the quality among included non-randomized clinical trials as critical, serious, or low. The third author (MSM) resolved any differences in methodological quality assessments. We sought further information from the authors of the studies wherever data were inadequate.

2.5 Statistical analysis

The data extracted were entered into customized spreadsheets. Studies that reported average MVBF values and standard deviation were categorized into primary (3–6 years), mixed (6–12 years), permanent (12–19) and overlapping dentitions (all children, whatever their age or dentition development stage) and pooled for meta-analysis utilizing the R Software metafor package v2.4-0 (Wolfgang Viechtbauer, Boston, MA, USA) [25]. Forest plots were generated for parameters of concern, to represent the estimated effect of mean BF across dentitions. Subgroup analysis was done for BF values based on gender, side, site, measuring devices and ethnicity. Random effects model measured the average differences in the investigated outcome. Statistical heterogeneity was estimated by the chi-square test ($p < 0.05$) and the I-square index (I^2). The classification of I^2 values were, over 50% as high, 25–50% moderate, and <25% as low [26].

3. Results

Subsequent to a literature search, 614 unique records were identified for this systematic review. Following the elimination of 40 duplicates, 574 studies were appraised for abstracts, of which 366 studies (studies that did not match the inclusion criteria such as, participants beyond 19 years of age, medically compromised and special children, TMJ and muscle disorders, animal studies and finite element analysis) were excluded, resulting in 208 articles for full-text reading. Two publications from a supplement journal could not be retrieved, leading to a total of 206 records. After scrutiny, 145 articles from the 206 records were excluded for the aforementioned reasons—not satisfying inclusion criteria (n = 34), no study-related outcome (n = 12), insufficient data despite attempts to contact the author (n = 82), and not addressing the review question (n = 17). Therefore, 61 studies that satisfied the eligibility criteria were included in this systematic review (Fig. 1).

3.1 Study characteristics (Supplementary Table 1)

Among the 61 included studies, publications dating from 1986 to 2022 were included. Study designs were divided into cohort (n = 2), case-control (n = 1), cross-sectional (n = 48), and clinical trials (n = 10). Of the data points extracted, 22 unique world regions were identified (Brazil, Croatia, Colombia, Denmark, Ireland, Greece, Japan, Jordan, Kingdom of Saudi Arabia, Iran, Iraq, India, Netherlands, South Korea, Switzerland, Istanbul, Taiwan, Thailand, UK, Poland, Sweden, and the US), with the largest contributions from Brazil, Japan, and Jordan. Ages ranged from 3 to 19 years, with a total of 8864 included participants. Of the 61 included studies, only 26 studies had BF information based on gender, both males (n = 3491) and females (n = 3623), while the one study [27] had information on males only (n = 34). The remaining 34 studies included 2124 participants with no mention of gender ratio.

3.2 Quality of reviewed studies

Table 1 and Fig. 2 represents the risk-of-bias for the included observational studies and clinical trials respectively. The majority had a low risk-of-bias (n = 31), with moderate risk in 16 publications and four reports with high risk-of-bias according to the NOS and M-NOS scales. Among the ten clinical trials, based on the ROBINS-I tool, seven studies had critical risk and three had serious risk. The studies scored with a high risk-of-bias had inadequate information in multiple domains, such as sample size and ascertainment of exposure.

3.3 Data categorization

Quantitatively assessment of 42 eligible reports included studies measuring BF in either one of the dentitions exclusively or in combinations of two or more dentitions. In total, 13, 18, and 11 studies reported BF values distinctively for the primary, mixed, and permanent dentitions, respectively. **Supplementary Table 1** tabulates the MVBF measurements assessed by various devices and reports the maximum BF values (mean average) in the form of MLN (log-transformed mean) with 95% CI. I^2 values varied between 90% and 100%, indicating substantial heterogeneity, resulting in 29 forest plots (Figs. 3,4,5) through random effects model.

3.3.1 Primary dentition (ages 3 to 6 years)

Of 13 studies included for quantitative synthesis, 12 primary dentition studies computed the average BF as 246.22 (220.47; 274.98) Newtons (N) from 2,155 children. For gender assessment (Fig. 4A–B), the molar BF reported in 751 boys—222.30 (187.90; 263.01) N, showed a slight increase in BF values compared to 759 girls (202.43 (182.78; 224.19) N). The average BF values of the right and the left sides were 169.79 (129.31; 222.93) N and 163.88 (125.22; 214.48) N,

TABLE 1. Risk of bias assessment table for observational studies.

(A) Risk of bias for cross sectional studies

S. No	Author Name (Year)	Selection (Max 5 stars)			Comparability (Max 2 stars)	Outcome (Max 3 stars)		No. of Stars Risk of Bias
1	Zwir [6] (2018)	*	*	**	**	**	*	9 Low
2	Takeshima [83] (2019)	*	*	*	**	*	*	7 Low
3	Abu Alhaija [30] (2018)	*	*	*	**	*	*	7 Low
4	Kiriishi [27] (2018)	*	*	_	-	**	*	5 Moderate
5	Heydari [31] (2018)	*	*	-	**	*	*	6 Moderate
6	Jeong [70] (2019)	*	*	*	**	*	*	7 Low
7	Pereira [75] (2018)	*	*	-	*	*	*	5 Moderate
8	Diaz Serrano [65] (2017)	*	*	**	*	**	*	8 Low
9	Hama [68] (2017)	*	-	**	*	*	*	6 Moderate
10	Kaya [54] (2017)	*	*	*	**	**	*	8 Low
11	Awawdeh [55] (2017)	*	*	*	**	*	*	7 Low
12	Marquezin [73] (2016)	*	*	**	-	**	*	7 Low
13	Araujo [52] (2016)	*	*	**	**	**	*	9 Low
14	Szymanska [82] (2015)	*	*	**	**	**	*	9 Low
15	Sun [9] (2016)	*	*	**	**	*	*	8 Low
16	Al Quassar [61] (2017)	*	*	*	*	*	*	6 Moderate
17	Sato [79] (2011)	*	-	-	-	*	*	3 High
18	Varga [15] (2011)	-	-	**	*	*	*	5 Moderate
19	Mountain [29] (2010)	*	*	**	*	*	*	7 Low
20	Castelo [57] (2010a)	*	-	**	**	*	*	7 Low
21	Castelo [64] (2010b)	*	*	**	*	-	*	6 Moderate
22	Oueis [74] (2009)	*	*	**	*	*	*	7 Low

TABLE 1. Continued.

(A) Risk of bias for cross sectional studies

S. No	Author Name (Year)	Selection (Max 5 stars)			Comparability (Max 2 stars)	Outcome (Max 3 stars)		No. of Stars Risk of Bias
22	Oueis [74] (2009)	*	*	**	*	*	*	7 Low
23	Thongudomporn [84] (2009)	*	*	**	**	*	*	8 Low
24	Usui [32] (2007)	*	*	*	**	*	*	7 Low
25	Pereira [76] (2007)	*	*	*	**	*	*	7 Low
26	Duarte Gaviao [51] (2006)	*	*	*	**	*	*	7 Low
27	Sakashita [78] (2006)	*	*	*	*	*	*	6 Moderate
28	Bonjardim [63] (2005)	*	*	*	**	-	*	6 Moderate
29	Sonnensan [81] (2005)	*	*	*	*	*	*	7 Low
30	Kamegai [41] (2005	*	*	-	*	*	*	5 Moderate
31	Maki [72] (2001)	*	*	-	*	*	*	5 Moderate
32	Kampe [14] (1987)	*	-	-	*	*	*	4 High
33	Fields [67] (1986)	*	-	-	*	*	*	4 High
34	Gaviao [76] (2007)	-	*	*	*	*	*	5 Moderate
35	Medhat [53] (2018)	*	*	*	**	*	*	7 Low
36	Marquezin [58] (2017)	*	*	**	**	*	*	8 Low
37	Haritha [69] (2012)	*	-	*	*	*	*	5 Moderate
38	Lemos [71] (2006)	*	-	*	**	*	*	6 Moderate
39	Karibe [28] (2003)	*	-	-	*	*	*	4 High

TABLE 1. Continued.

(A) Risk of bias for cross sectional studies

S. No	Author Name (Year)	Selection (Max 5 stars)			Comparability (Max 2 stars)	Outcome (Max 3 stars)		No. of Stars Risk of Bias
40	Rentes [77] (2002)	*	-	*	*	*	*	5 Moderate
41	Sonnensen [56] (2001)	*	*	*	**	*	*	7 Low
42	Su [17] (2009)	*	*	**	**	-	*	7 Low
43	Alam [62] (2020)	*	*	*	**	*	*	7 Low
44	Sonnaville [80] (2021)	*	*	**	*	*	*	7 Low
45	Guo [86] (2021)	*	*	*	*	**	*	7 Low
46	Aishwaryaa [87] (2021)	*	*	-	**	*	*	6 Moderate
47	Prabahar [88] (2021)	*	*	*	**	**	*	8 Low
48	Gudipaneni [85] (2020)	*	*	**	*	**	*	8 Low

(B) Risk of bias for case control study

S.No	Author Name (Year)	Selection (Max 4 stars)				Comparability (Max 2 stars)	Exposure (Max 3 stars)			No. of Stars Risk of Bias
49	Ferraira [10] (2016)	*	-	*	*	**	*	*	-	7 Low

(C) Risk of bias for cohort studies

S.No	Author Name (Year)	Selection (Max 4 stars)				Comparability (Max 2 stars)	Outcome (Max 3 stars)			No. of Stars Risk of Bias
50	Roldan [8] (2016)	*	-	-	*	**	*	*	*	7 Low
51	Ohira [12] (2012)	*	*	*	*	**	*	*	*	9 Low

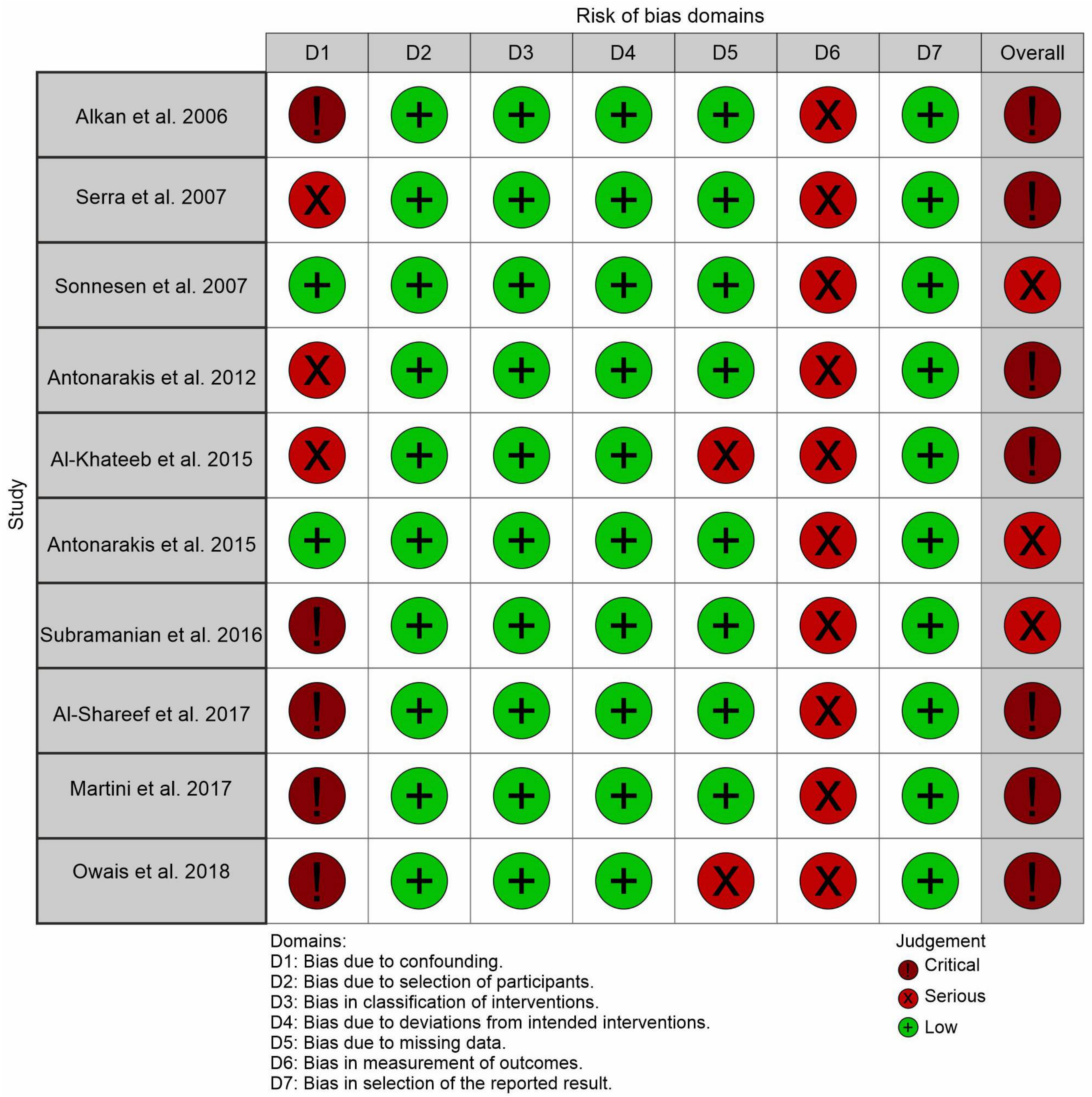

FIGURE 2. Risk-of-bias assessment for clinical trials. Among the 10 clinical trials, based on the ROBINS-I tool, seven studies had critical risk and three had serious risk.

respectively [28–31].

A total of 7 different devices assessed the BF at the primary molar site. Quantitative analysis included two studies with devices comprising similar sites and units. From studies using the portable occlusal bite force (OBF) gauge (n = 4), BF averaged 195.33 (188.44; 202.47) N and from studies testing BF using the pressurized transducer (n = 3), the BF value estimated to 265.57 (233.94; 301.57) N (Fig. 5A).

Considering ethnicity, both Japan and Brazil reported an equal number of studies (n = 6) computing 204.58 (177.24; 236.13) N and 265.56 (233.94; 301.46) N, respectively (Fig. 5D).

3.3.2 Mixed dentition (ages 6 to 12 years)

In total, 18 authors recorded BF in the mixed dentition from 2,736 participants, which averaged 311.72 (255.99; 379.59) N. No clinically significant differences were observed in the molar BF of males (n = 763), 256.27 (156.91; 418.54) N, and females (n = 781), 241.45 (146.00; 399.28) N. The estimations on right and left molars averaged 160.42 (106.61; 241.39) N and 143.95 (94.92; 218.30) N, respectively.

BF values measured in kilograms (kg) (n = 208) and kilogram-force (kgf) (n = 140) showed that males had increased masticatory pressure compared with the females of the same group (Maki *et al*. [72] 2001). MVBF of males (n = 102) computed to 24.59 (20.29; 29.79) kg, and that

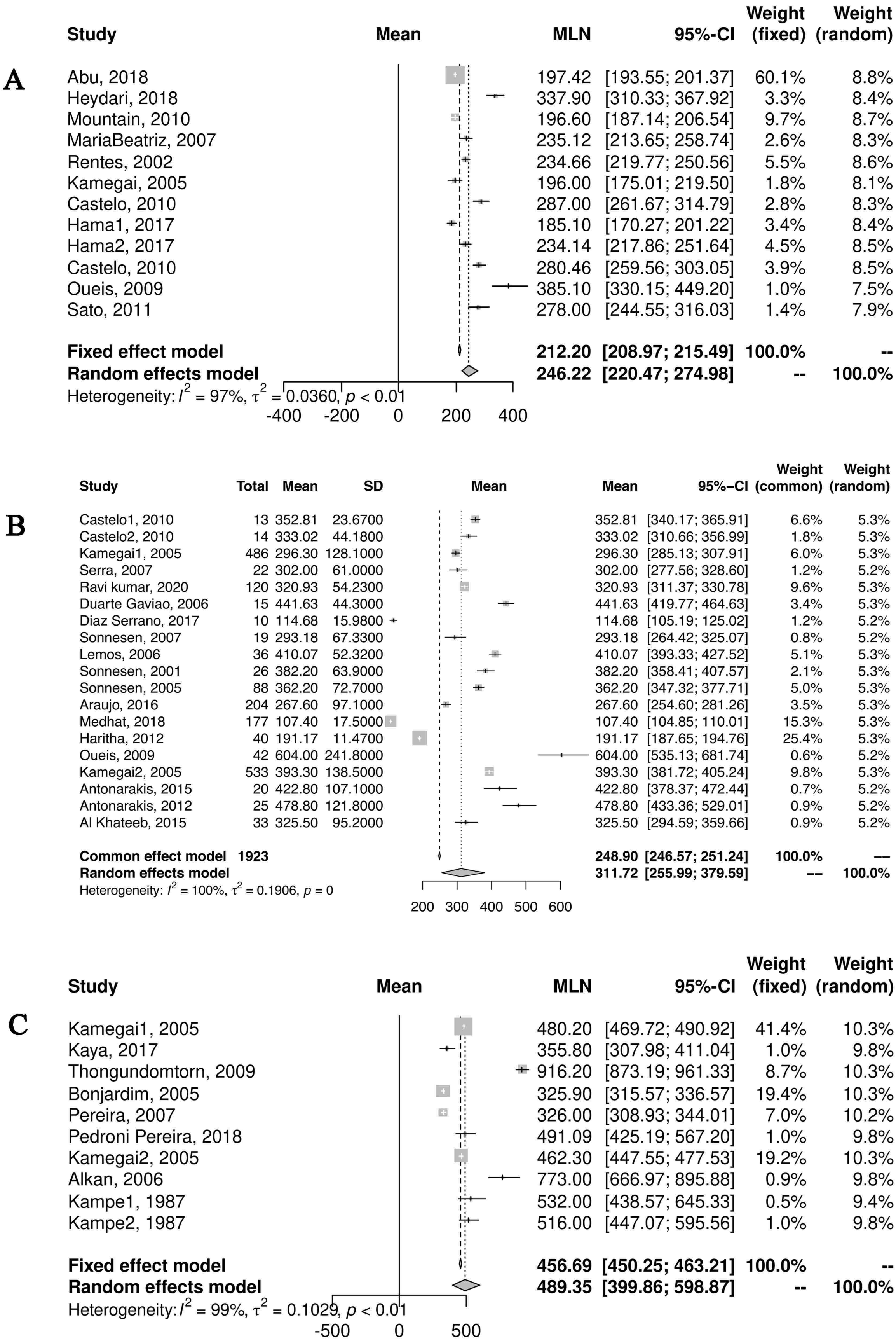

FIGURE 3. Forest plots comparing the bite force values of all the three dentitions based on the random-effects model. (A) Primary dentition—3 to 6 years, (B) Mixed dentition—6 to 12 years, and (C) Permanent dentition—12 to 19 years. Based on the random-effects model, 3 forest plots were generated for primary, mixed and permanent dentitions. MLN: Log transformed mean; CI: Confidence Interval; SD: Standard Deviation.

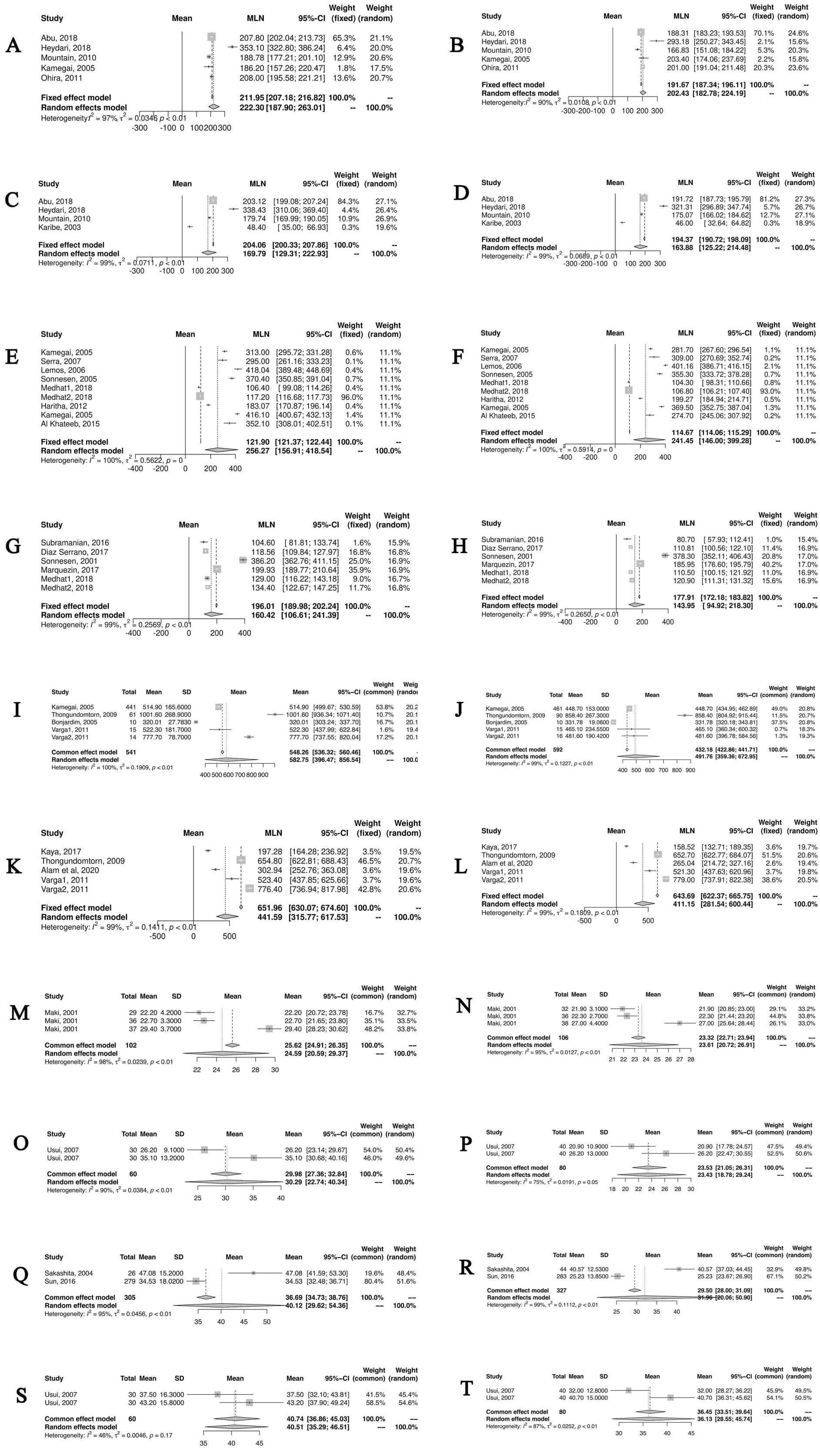

FIGURE 4. Forest plots comparing the bite force values between dentition, gender and side. (A) Primary male, (B) Primary female, (C) Primary right, (D) Primary left, (E) Mixed male, (F) Mixed female, (G) Mixed right, (H) Mixed left, (I) Permanent male, (J) Permanent female, (K) Permanent right, (L) Permanent left, (M) Mixed male, (N) Mixed female, (O) Mixed male, (P) Mixed female, (Q) Permanent male, (R) Permanent female, (S) Permanent male, and (T) Permanent female. MLN: Log transformed mean; CI: Confidence Interval; SD: Standard Deviation.

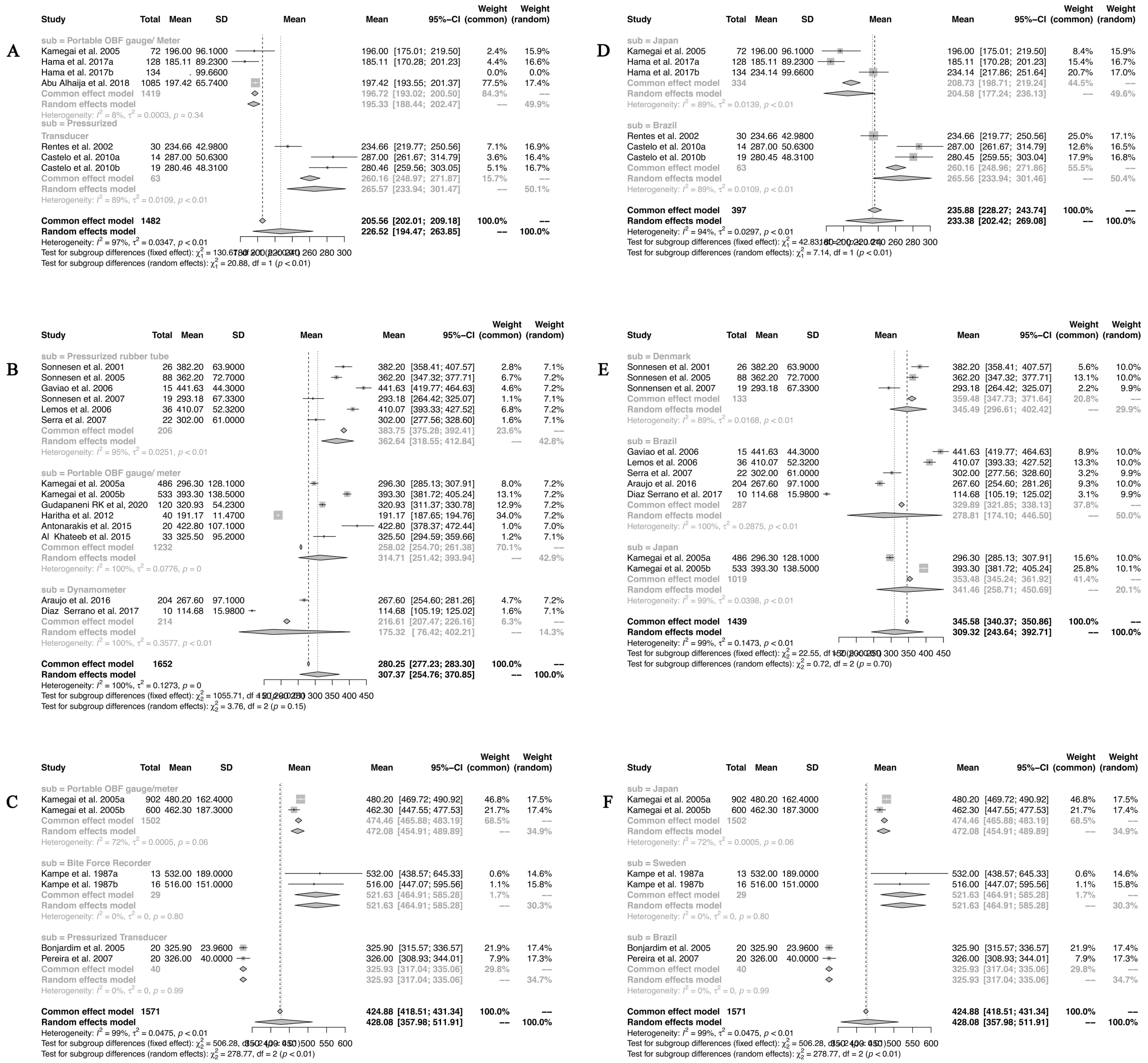

FIGURE 5. Forest plots comparing the bite force values between site of measurement, device and ethnicity for each included dentition. (A–C), Site of measurement and device, where A corresponds to Primary dentition, B—mixed dentition and C—Permanent Dentition. (D–F), Site of measurement and ethnicity, where D corresponds to Primary dentition, E—mixed dentition and F—Permanent Dentition. MLN: Log transformed mean; CI: Confidence Interval; SD: Standard Deviation.

among females (n = 106) computed to 23.61 (20.87; 26.70) kg. MVBF of males (n = 60) measured in kgf averaged 30.29 (22.74; 40.34), and that among females (n = 80) measured in kgf averaged 23.43 (18.78; 29.24).

Six studies tested BF using a pressurized rubber tube in the mixed dentition at the permanent 1st molar site which equated to 362.64 (318.55; 412.84) N while portable OBF gauges averaged 314.71 (251.42; 393.94) N from six included studies. The dynamometer studies by Araujo *et al.* [52], 2016 and Diaz Serrano *et al.* [65] 2017 resulted in an average BF of 175.32 (76.42; 402.21) N (Fig. 5B).

According to ethnicity, the highest number of studies were reported from Brazil (n = 5) resulting in an average BF of 278.81 (174.10; 446.50) N, followed by Denmark (n = 3) and Japan (n = 2)—which reported average BF values of 345.49 (296.61; 402.42) N and 341.46 (258.71; 450.69) N respectively. (Fig. 5E).

3.3.3 Permanent dentition (ages 12 to 19 years)

From ten included studies and 2673 participants, the average BF of children with only permanent teeth was estimated as 489.35 (399.86; 598.87) N. Studies revealed that males (n = 792) had a greater masticatory force of 547.57 (537.11; 558.24) N than females (n = 898) with 424.71 (416.48; 433.10) N. Molar BF of the right side computed to 441.59 (315.77; 617.53) N and that on the left to 411.15 (281.54; 600.44) N. Similar observations were made while comparing bite forces of males (n = 305) 40.12 (29.62; 54.36) and females (n = 327) 31.96 (20.06; 50.90) in kg, and of males (n = 60) 40.51 (35.29; 46.51) and females (n = 80) 36.13 (28.55; 45.74) in kgf.

A total of six out of the 18 included studies contributed to the analyses of parameters, specific to the site (permanent 1st molar), device, and ethnicity. The values for device and ethnicity reported similar BF estimates as given in (Fig. 5C and Fig. 5F).

3.3.4 Overlapping dentition (combination of ages from 3 through 19)

A few authors reported studies in which participants (n = 1102) had overlapping dentitions (*i.e.*, primary and mixed together or mixed and permanent together) with various units for analysis. Meta-analysis could not be performed since the collected data from the above studies were diverse due to the lack of a clear distinction of the recorded dentition. However, one study [32] showed that BF measured in kgf differed based on gender when subjected to meta-analysis. The males (n = 356) and females (n = 322) of the study had BF values of 40.51 (35.29; 46.51) kgf and 36.13 (28.55; 45.74) kgf, respectively.

3.4 Review of clinical trials

Subsequent to the consideration of heterogeneity in the included clinical trials, we qualitatively summarized the pre and post-intervention results.

Observations from the qualitative description of the ten included clinical trials revealed various treatment modalities, such as orthodontic management of malocclusion (n = 5), while two studies demonstrated an increase in the BF values post-treatment with orthodontic appliances [33, 34]. Two studies [35, 36] reported a decrease in the BF estimation, post-treatment. The results reported an immediate decrease post-treatment with an expansion plate and quad helix while data showed an increased BF value at a 4–6-month follow-up using the same appliance [37].

Restorative management for caries-affected teeth (n = 2) included stainless steel crowns [38] and conventional glass-ionomer restorations [18]. Both studies showed a clinically significant increase in MVBF results post-treatment.

Prosthetic replacement of missing teeth with a removable partial denture (n = 1) showed an increase in the masticatory force at 6–12 month follow-up [39]. A steady increase in MVBF was observed in a report by Alkan *et al*. [40] (2006) post-surgical osteotomy in children with mandibular deficiency, at five intervals. Also, a trial by Martini *et al*. [13] which included healthy controls and a study group with craniosynostosis, showed that the MVBF values of the healthy controls were greater than that of the study group.

4. Discussion

This meta-analysis aimed to quantify the MVBF of children based on age, gender, site, ethnicity, measuring device and side for this systematic review. While several studies have successfully calibrated BF among various types of dentitions, to the best of our knowledge, this is the first systematic review on pooled MVBF values in children and adolescents based on age and dentition. The principal findings of this study showed the magnitude of BF to be comparatively greater in the permanent dentition than in the mixed and primary dentition. Also, results observed in the 'gender' group concerning age were correlative. Males and females with permanent dentition had greater BF than those with mixed and primary dentitions. A study by Usui *et al*. [32] (2007) reported that BF tended to increase with age, up to 20 years in males and 17 years in females. Kamegai *et al*. [41] (2005) found that mean BF increased in females until age 14. A gradual increase was noted thereafter until age 17; however, the mean value did not exceed the mean recorded at age 14.

The secondary findings showed a significant association between gender and MVBF. Males had greater BF than females in all types of dentitions, an observation consistent with the interpretations of Abu-Alhaija *et al*. [30] (2018), Palinkas *et al*. [42] (2010), Ingervall and Minder [43] (1997), and Shiau and Wang [44] (1993). This could be because males had more confidence [15] when recording BF and their anatomic [36] and hormonal variations could have contributed to this increase [45]. Also, a greater dental size concomitant with a larger periodontal ligament area [10] results in males developing a more pronounced masticatory ability. In contrast, several authors have reported no gender influence on occlusal forces other than elements such as age, body weight, and height [46–50]. The right side showed greater masticatory forces than the left in all three dentitions. Though multiple studies [15, 28–31, 38, 65, 84] have reported the MVBF values estimated bilaterally in their respective subjects, the rationale for the same is unclear. 'Side dominance' (right and left-handedness) could be one possible reason for the increase in right-side BF value and further studies are required to understand the factors influencing the changes in the measured values. The results of this study based on side, showed a decline in the MVBF values of the mixed dentition while comparing the primary dentition. A possible explanation for this underestimation could be due to included studies recruiting children with mixed dentition but conducted the analysis on either permanent first molars or primary molars. This combination of sites for analysis could have altered the magnitude of the biting force. Further, the inclusion of children in various stages of dental development, such as eruption and incipient exfoliation, might have led to the improper recording of occlusal pressure. Nevertheless, a comparison between primary and permanent dentitions showed approximately a two-fold increase in the permanent dentition values for side.

The present systematic review reports 11 different types of devices for recording BF and the data analysis is presented in **Supplementary Table 1**. Among these, the portable occlusal bite force gauge/meter (OBF/OBG) is the most commonly used due to its portability, comfortable biting element, and instant digital display of BF. Exclusive to the primary dentition, the pressurized transducer and dental pre-scale systems are preferred devices because the vinyl rubber tube is confined to the occlusal pattern, facilitating accurate reflection of BF.

Most of the studies included were cross-sectional, which affected the generalizability of the results. Harmonization of study designs can compensate for any dissimilarity caused by including observational studies and trials. Second, it would be helpful for future research if inter- and intra-comparison of the most influential variables, such as age, dentition, gender, side, and site, could be assessed since a selective omission in a few of the included studies can influence the outcome. For variables such as height [31, 51], weight [16, 31], and BMI [9, 15–17, 52, 53] a clear correlation among included studies could not be established since a few authors reported a direct association while a few contradicted the same. This conflict could be due to recruitment bias. Therefore, study participants should be equally identified across the spectrum of obese, overweight, healthy, underweight, and malnourished individuals. Also, recording the status of the dentition is essential, since the presence of caries [54] and restorations [14, 55] alters the structural integrity and pain threshold of the tooth, thereby reducing the masticatory function. Moreover, the absence of teeth [31] leads to reduced BF due to loss of antagonistic contacts. Malocclusions such as aberrant overjet [30] overbite [31], and cross-bite [56–58] can affect the child's ability to bite since fewer occlusal contact points result in weaker occlusal support and musculature [8]. Therefore, further studies are required to understand the relation between occlusion, tooth size, and BF. The current findings call attention to the fact that, among the world regions included, there is a lack of significant data on MVBF from certain areas of the globe, such as the continents of Australia and Africa. The occlusal table for the Australian population is more pronounced mesiodistally [59], which may contribute to a higher value of MVBF. Thus, consideration of body and dental health variables is required for comprehensible data and improved study quality.

Third, few authors have reported findings as mean average values only and lack of standard deviation resulted in the exclusion of studies from the meta-analysis. An understanding of these drawbacks in published studies and the design of future clinical trials aimed at recording MVBF in healthy versus affected individuals with a uniform reporting protocol is required to better understand the developmental and environmental influences over time. Few authors assessed BF using a custom-made device. However, the reliability and reproducibility of such self-made equipment are questionable. Therefore, standardized devices with established sensitivity and specificity should be considered. Apart from longitudinal studies targeted at specific dentitions to assess the role of factors influencing BF, studies to enable standardization of BF recording devices are required to rule out methodological biases.

This systematic review had both strengths and limitations. Our current findings will likely provide dental professionals with the highest possible available evidence on MVBF including various devices and sites to assess the same. Therefore, the concept of BF, if applied to regular clinical practice with the results of this study, can prove to be a useful adjunct investigative tool for the diagnosis of any deviation from normal function and development. This review provides the first comprehensive analysis of mean BF values in all types of dentitions-primary, early to late mixed, permanent dentition and, combination dentition among children and adolescents. Our findings revealed average BF values range from 246.22–489.35 N and 5.69–16.1 kg in children and adolescents. In addition, the average BF values for devices ranged from 226.52 to 428.08 N. The results of this review provide clinicians with an insight on the amount of biting force that can exist in each dentition and may serve as a baseline value for future studies and clinical assessment. The absence of time limits for the inclusion of studies available in the literature renders the evidence presented robust. Multiple factors influencing BF have been addressed in this review, age being the most vital variable [60], along with a direct method of BF assessment. Subgroup analysis included other variables such as gender and side. Other factors influencing BF and the accuracy of the apparatus used for recording BF were not considered in this review. Also, we deviated from the registered protocol because we were unable to assess the pre and post-MVBF values of the various clinical trials. The lack of information (raw data) from 81 studies, despite multiple reminders, could also have affected the results.

5. Conclusion

1. Systematic analysis of the data showed that BF ranged from 246.22–489.35 N and 5.69–16.1 kg in children and adolescents and the average BF values for devices ranged from 226.52 to 428.08 N.

2. The portable occlusal bite force gauge/meter (OBF/OBG) was the most commonly used device to record BF in all dentitions.

3. The transition from primary to early-mixed to late-mixed and permanent dentitions is a dynamic process. Hence, the BF taken at a given period may differ from one type of dentition to another.

4. Not only physiologic changes but also pathologic conditions like caries, malocclusion, and the early shedding of primary teeth can affect BF values.

5. Thus, BF is an entity that needs close and continuous monitoring for clinical relevance.

AVAILABILITY OF DATA AND MATERIALS

The data are contained within this article and supplementary material.

AUTHOR CONTRIBUTIONS

PJ, GFP and MSM—Contributed to conception, design, data acquisition, analysis and interpretation, drafted and critically revised the manuscript. RK—Contributed to analysis and interpretation and critically revised the manuscript. NP and SSA—Contributed to data acquisition and critically revised the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jocpd.com/files/article/1651170756277485568/attachment/Supplementary%20material.docx.

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