Review Article

Cranial base characteristics in anteroposterior malocclusions: *A meta-analysis*

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ABSTRACT

Objective: To investigate cranial base characteristics in malocclusions with sagittal discrepancies.

Materials and Methods: An electronic search was performed in PubMed, Embase, Web of Science, and the Cochrane Library. A fixed- or random-effect model was applied to calculate weighted mean difference with 95% confidence intervals (CIs) according to statistical heterogeneity. Outcome measures were anterior, posterior, and total cranial base length and cranial base angle. Sensitivity analysis and publication bias were conducted.

Results: Twenty studies that together included 1121 Class I, 1051 Class II, and 730 Class III cases qualified for the final analysis. Class III malocclusion demonstrated significantly reduced anterior (95% CI: −1.74, −0.53; $P < .001$ vs Class I; 95% CI: −3.30, −2.09; $P < .001$ vs Class II) and total cranial base length (95% CI: −3.33, −1.36; $P < .001$ vs Class I; 95% CI: −7.38, −4.05; $P < .001$ vs Class II). Further, Class II patients showed significantly greater anterior and total cranial base length than did Class I patients (95% CI: 0.51, 1.87; $P < .001$ for SN; 95% CI: 2.20, 3.30; $P < .001$ for NBa). Cranial base angle was significantly smaller in Class III than in Class I (95% CI: −3.14, −0.93; $P < .001$ for NSBa; 95% CI: −2.73, −0.68; $P = .001$ for NSAr) and Class II malocclusions (95% CI: −5.73, −1.06; $P = .004$ for NSBa; 95% CI: −6.11, −1.92; $P < .001$ for NSAr) and greater in Class II than in Class I malocclusions (95% CI: 1.38, 2.38; $P < .001$ for NSBa).

Conclusions: This meta-analysis showed that anterior and total cranial base length and cranial base angle were significantly smaller in Class III malocclusion than in Class I and Class II malocclusions, and that they were greater in Class II subjects compared to controls. (*Angle Orthod.* 2016;86:668–680.)

KEY WORDS: Cranial base; Malocclusion; Meta-analysis

INTRODUCTION

The cranial base, which articulates with the maxilla and mandible, might have an effect on facial morphology[1] and anteroposterior jaw relationship, thereby influencing the classification of malocclusions.[2] To date, numerous studies have investigated the relationship between cranial base morphology and malocclusions, but the results of these studies are inconsistent.

An obtuse cranial base angle was observed in patients with Class II malocclusion,[2–10] which caused the mandible to be positioned posteriorly under the cranium.[9] Some investigators[11,12] have reported that cranial base angle is negatively correlated with mandibular prognathism, but others[13] believed that the posterior cranial base leg demonstrated a statistically negative correlation with mandibular position and treatment time.

Previous studies have reported that in Class III malocclusion the cranial base has smaller linear[2,3,5,10,14–19] and angular dimensions.[2,3,12,15–17,20–26]

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Table 1. Criteria for the Assessment of Study Quality[a]

	Strong Evidence	Moderately Strong Evidence	Limited Evidence
Characteristics of study design	Prospective study; Large study samples	Prospective study; Cohort, controlled clinical trial; Well-defined retrospective study; Large study group	Cross-sectional study
Characteristics of control group	Well-defined and adequate	Clearly defined	No control group
Outcome of variables	Clearly defined and clinically appropriate	Clearly defined and clinically appropriate	Clinically inadequate
Dropout rate	Low	Low	High
Statistical analysis	Appropriate	Appropriate	Limited or no

[a] Adapted from Katyal et al.[36]

Sundareswaran and Thirumoorty[18] appreciated a significant positive association between anterior cranial base parameters and maxillary deficiency in Class III malocclusion, while Proff et al.[24] failed to show a significant reduction in anterior cranial base length in skeletal Class III malocclusion despite overall shortening of the total cranial base length.

Other studies failed to demonstrate the relationship between cranial base shape and jaw discrepancies.[27–33] Furthermore, one study[28] reported that cranial base growth pattern was similar in skeletal Class I and Class II patients, while another[33] reported that cranial base angle had a limited effect on the development of sagittal jaw discrepancies during longitudinal follow-up. The authors of yet another study[29] reported that it was jaw size, rather than cranial base flexure, that determined the type of malocclusion.

As one of the factors affecting malocclusions, cranial base is still a matter of debate. Therefore, the present meta-analysis, which integrates results from published studies, attempts to assess whether cranial base dimensions are related to malocclusion.

MATERIALS AND METHODS

Literature Search Strategy

We searched for studies on cranial base characteristics in cases of sagittal discrepancies in PubMed, Embase, Web of Science, and the Cochrane Library. Moreover, additional relevant articles were obtained through manual searches and Google Scholar searches. The last search was conducted on November 7, 2014. The main key words, modified according to the syntax rules of each database, were as follows: “Tooth Crowding,” “Crossbite*,” “Cross Bite,” “Angle’s Classification,” “Angle Classification,” “Angles Classification,” “Malocclusion*,” and “Skull Base,” “Cranial Base,” “Basis cranii,” “Base of Skull,” “Basicranium.”

According to the principles of PICO (patient, problem, or population; intervention; comparison; outcome), the criteria for inclusion were as follows: (1) recruitment of patients diagnosed with anteroposterior malocclusion based on molar relationship or ANB angle (Because cranial base angle was relatively stable from 5 to 15 years,[34] all of the subjects were above 5 years of age.); (2) availability of lateral cephalometric radiographs for each participant; (3) clearly definite classification; (4) availability of outcome measures for cranial base morphology with sufficient data for extraction; and (5) case-control trials or cohort studies.

The exclusion criteria were as follows: (1) diagnosis of incisor relationship or with congenital deformities; (2) inappropriate controls; (3) report of outcomes not pertaining to the cranial base morphology of sagittal malocclusions; and (4) reviews, editorial letters, and case reports.

Data Extraction

Data were extracted from each article into two databases independently by two authors (AX Gong and ZD Wang). Any discrepancy was resolved through discussion with other researchers. Complete articles fulfilling the inclusion criteria were retrieved for further evaluation.

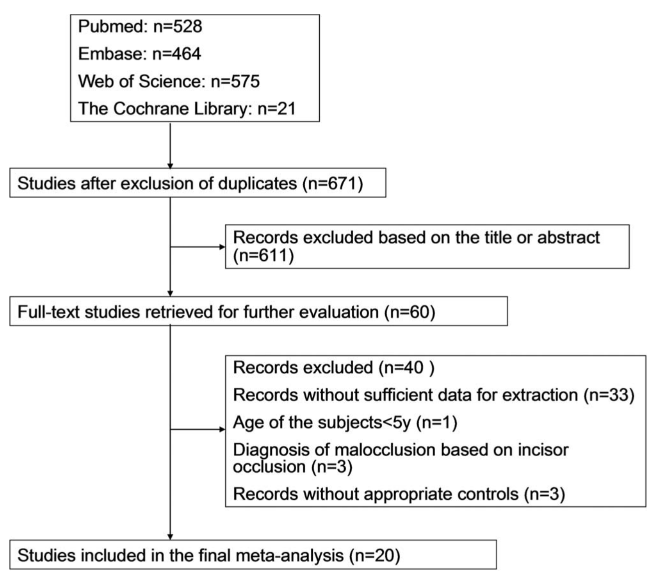


Figure 1. Flow chart of the studies included with the search strategy.

Table 2. Characteristics of the Included Studies

Study	County	Ethnicity	Diagnosis of Malocclusion
Chin et al.[10b]	China	Asian	Class II: ANB $\geq$ 5°, increased overjet Class III: ANB $\leq$ 0.6°, reduced overjet
Sanggarnjanavanich et al.[26a]	Japan	Asian	Class III: ANB < -1°, Wits appraisal < -2 mm, a negative overjet and mesial molar relationship
Agarwal et al.[32]	Rajasthan	Caucasian	Class II: ANB $\geq$ 5°, increased overjet
Thiesen et al.[19]	Brazil	Caucasian	Based on ANB angle, Wits appraisal and G′.Sn.Pg′ angle
Sundareswaran et al.[18ab]	India	Caucasian	Class III: ANB < -1°, Wits appraisal < -3 mm, and mesial molar relationship
Hassan[31]	Saudi	Caucasian	Class II[1]: distal molar relationship and overjet $>$ 5 mm
Alves et al.[12]	Brazil	Mixed	Class II: skeletal pattern Class III: skeletal pattern
Polat and Kaya[30b]	Turkey	Caucasian	Class II: ANB $\geq$ 5°, increased overjet Class III: ANB ≤ -1°, negative overjet
Sayin and Turkkahraman[9a]	Turkey	Caucasian	Class II[1]: ANB $>$ 4°, overjet $>$ 4 mm, bilateral Class II molar relationship
Chang et al.[17a]	Taiwan, China	Asian	Class III: mesial molar relationship
Wilhelm et al.[28b]	USA	Caucasian	Class II: overjet, 5–10 mm, ANB, 5–8°, Harvold unit length difference $\leq$ 20 mm
Mouakeh[16ab]	Syria	Caucasian	Class III: mesial molar relationship
Rothstein and Yoon-Tarlie[7ab]	USA	Caucasian	Class II[1]: distal molar relationship and increased overjet
Johannsdottir et al.[6ab]	Iceland	Caucasian	Class II: distal molar relationship
Rak et al.[21]	Croatia	Caucasian	Class II[1]: skeletal pattern Class III: skeletal pattern
Kasai et al.[11ab]	Japan	Asian	Class II: ANB $>$ 5°
Tollaro et al.[14b]	Italy	Caucasian	Class III: anterior crossbite, mesial step molar relationship
Bacon et al.[4b]	France	Caucasian	Class II[1]: distal molar relationship and ANB $\geq$ 6°
Kerr and Ford[3ab]	Scotland	Caucasian	Class II[1]: distal molar relationship and overjet $>$ 10 mm Class III: distal molar relationship
Hopkin et al.[2ab]	England	Caucasian	Class II[1]: distal molar relationship Class III: mesial molar relationship

[1] indicates Class II division 1 malocclusion.
[a] Matched for gender. M indicates male; F, female.
[b] Matched for age.

Analysis of Variables

The landmarks were as follows: sella (S), nasion (N), basion (Ba), and articulare (Ar). The following variables were appraised for each retrieved study: anterior cranial base length (ACBL), posterior cranial base length (PCBL), total cranial base length (TCBL), and cranial base angle (CBA). Significant differences were obtained between each of the classes of malocclusion.

The present meta-analysis was performed using the specific software RevMan (version 5.1). Heterogeneity analysis was conducted via the chi-square test and I^2 index.[35] The random effects model (D-L method) was used for the calculation of the overall combined effect if the P value was less than .05 according to the Q test. Otherwise, the fixed-effect model (M-H method) was adopted. Weighted mean difference (WMD) and 95%

Table 2. Extended

Participants				
Class I	Class II	Class III	Outcome Variables	Quality
27 subjects; mean age, 18.1 ± 3.3 y	30 subjects; mean age, 19.1 ± 5.6 y	26 subjects; mean age, 18 ± 3.2 y	SN, SBa, NBa, NSBa	Moderate
86 subjects; 86 F Mean age, 21.6 ± 3.9 y (range, 16.1–34 y)	—	86 subjects; 86 F; mean age, 22.0 ± 4.3 y (range, 16.0–35 y)	SN, SBa, NSBa	Moderate
52 subjects; 27 M, 25 F; After pubertal growth spurt	51 subjects; 25 M, 26 F; after pubertal growth spurt	—	NSAr	Moderate
20 subjects; mean age, 12.8 y (range, 8–17 y)	20 subjects; mean age, 13.1 y (range, 8–17 y)	20 subjects; mean age, 11.2 y (range, 8–17 y)	SN, SBa, NSBa	Moderate
60 subjects; 29 M, 31 F; age range, 16–29 y	—	60 subjects; 29 M 31 F; age range, 16–29 y	SN, NSBa, NSAr	Moderate
62 subjects; 29 M, 33 F; mean age, 10.4 ± 1.3 y (range, 9–12 y)	85 subjects; 44 M, 41 F; mean age, 10.8 ± 1.2 y (range, 10–13 y)	—	NSBa	Moderate
—	100 subjects Adult	100 subjects Adult	NSAr	Moderate
25 subjects; 12 M, 13 F; mean age, 15.7 ± 4.3 y	25 subjects; 11 M, 14 F; mean age, 15.6 ± 3.1 y	25 subjects; 13 M, 12 F; mean age, 14.3 ± 3.0 y	SN, SBa, NSBa, NSAr	Moderate
20 subjects; 20 F; mean age, 21.1 ± 2.2 y	40 subjects; 40 F; mean age, 17.9 ± 2.7 y	—	SN, SBa, NSBa	Moderate
100 subjects; 50 M, 50 F	—	100 subjects; 50 M, 50 F; age range, 9.4–11.5 y	SN, SBa, NBa, NSBa, NSAr	Limited
22 subjects; Mean age, 14 y	21 subjects; mean age, 14 y	—	SN, SBa, NSBa	Moderate
69 subjects; 23 M, 46 F; age range, 5–12 y	—	69 subjects; 23 M, 46 F; age range, 5–12 y	SN, NSAr	Moderate
273 subjects; 136 M, 137 F; age range, 10–14 y	325 subjects; 161 M, 164 F; age range, 10–14 y	—	SN, SBa, NBa, NSBa	Moderate
200 subjects; 100 M, 100 F; age range, 5.7–7.8 y	32 subjects; 16 M, 16 F; age range, 5.7–7.8 y	—	SN, SBa, NBa, NSBa, NSAr	Moderate
—	121 subjects; age range, 10–18 y	89 subjects; age range, 10–18 y	NSBa	Moderate
17 subjects; 17 M; mean age, 28.8 ± 10 y	29 subjects; 29 M; mean age, 28.8 ± 10 y	—	SN, SBa, NBa, NSBa	Moderate
20 subjects; 11 M, 9 F; mean age, 6 y	—	28 subjects; 15 M, 13 F; mean age, 6 y	SN, NSAr	Moderate
41 subjects; 15 M, 26 F; mean age, 10.5 y (range, 10–12 y)	45 subjects; 18 M, 27 F; mean age, 10.8 y (range, 10–12 y)	—	SN, NSBa	Moderate
31 subjects; 31 M; mean age, 10.37 ± 0.55 y	31 subjects; 31 M; mean age, 10.39 ± 0.67 y	31 subjects; 31 M; mean age, 10.15 ± 0.67 y	SN, SBa, NBa, NSBa	Moderate
96 subjects; 46 M, 50 F; mean age, 10.3 y (range, 6–14 y)	96 subjects; 46 M, 50 F; mean age, 10.5 y (range, 7–14 y)	96 subjects; 46 M, 50 F; mean age, 10.24 y (range, 7–14 y)	SN, NSAr	Moderate

confidence intervals (CIs) were calculated, and the statistical significance of pooled outcomes was determined by Z-test at $P < .05$.

Planned subgroup analyses were based on diagnosis, ethnicity, and age. The quality of the studies included was appraised according to their methodologies[36] and is presented in Table 1.

Sensitivity analysis was conducted by elimination of a single research involved in the meta-analysis each time.[37] If there were 10 or more studies, publication bias was evaluated by Begg's test and Egger's linear regression. When publication bias was found, Duval and Tweedie's[38] trim and fill procedure was performed.

RESULTS

Literature Search Outcomes

The literature search identified 671 articles: 60 relevant full articles were retrieved for further evaluation based on the title and abstract. Finally, 20

Table 3. Stratification Analysis of the Association Between Cranial Base Dimensions and Sagittal Malocclusions

	SN					SBa		
Malocclusion	n	WMD (95% CI)	P	I^2	P_h	n		P
Class II vs Class I	11	1.19 (0.51, 1.87)	<.001	76.2	<.001	9	0.50 (−0.04, 1.03)	.070
Pattern of malocclusion								
Skeletal pattern	7	−0.21 (−1.65, 1.23)	.775	77.2	<.001	6	−0.20 (−1.64, 1.25)	.791
Dental pattern	4	1.98 (1.61, 2.35)	<.001	26.1	.204	3	0.84 (0.50, 1.19)	<.001
Ethnicities								
Asian	2	−0.25 (−1.63, 1.13)	.724	0.0	.430	2	0.42 (−1.03, 1.87)	.569
Caucasian	9	1.35 (0.64, 2.06)	<.001	76.8	<.001	9	0.50 (−0.09, 1.08)	.098
Mixed	–	–	–	–	–	–	–	–
Age								
Before or during growth spurt	7	1.67 (1.13, 2.21)	<.001	57.0	.006	5	0.79 (0.46, 1.12)	<.001
After growth spurt	4	−0.30 (−2.48, 1.88)	.788	83.1	<.001	4	−0.25 (−2.35, 1.8)	.820
Class III vs Class I	10	−1.13 (−1.74, −0.53)	<.001	60.1	.004	6	−0.77 (−1.84, 0.30)	.157
Pattern of malocclusion								
Skeletal pattern	5	−0.81 (−2.27, 0.65)	.277	75.2	.001	4	−0.85 (−2.68, 0.99)	.367
Dental pattern	5	−1.32 (−1.75, −0.90)	<.001	0.3	.414	2	−0.80 (−1.64, 0.04)	.062
Ethnicities								
Asian	3	−0.69 (−1.25, −0.12)	.017	0.0	.620	3	−0.62 (−1.25, 0.01)	.053
Caucasian	7	−1.27 (−2.08, −0.45)	.002	64.5	.004	3	−0.83 (−3.61, 1.95)	.558
Mixed	–	–	–	–	–	–	–	–
Age								
Before or during growth spurt	6	−1.36 (−1.78, −0.95)	<.001	0.0	.441	3	−1.55 (−3.16, 0.07)	.061
After growth spurt	4	−0.53 (−2.17, 1.12)	.530	77.2	.001	3	−0.05 (−0.79, 0.69)	.895
Class III vs Class II	5	−2.70 (−3.30, −2.09)	<.001	50.5	.073	4	−1.78 (−3.60, 0.04)	.056
Pattern of malocclusion								
Skeletal pattern	3	−1.56 (−2.77, −0.36)	.011	41.6	.180	3	−1.94 (−4.46, 0.58)	.132
Dental pattern	2	−2.70 (−3.30, −2.10	<.001	6.1	.345	1	−1.30 (−3.17, 0.57)	.172
Ethnicities								
Asian	1	−1.70 (−3.32, −0.08)	.039	–	–	1	−1.70 (−3.46, 0.06)	.058
Caucasian	4	−2.86 (−3.51, −2.21)	<.001	52.3	.078	3	−1.80 (4.41, 0.80)	.175
Mixed	–	–	–	–	–	–	–	–
Age								
Before or during growth spurt	2	−3.09 (−3.77, −2.42)	<.001	0.0	.541	2	−2.81 (−5.75, 0.13)	.061
After growth spurt	3	−1.14 (−2.49, 0.21)	.097	33.2	.221	2	−0.80 (−2.08, 0.48)	.218

[a] n indicates number of studies; WMD, weighted mean difference; CI, confidence interval; P, P value for Z test; P_h, P value of Q-test for heterogeneity.

studies were selected based on the inclusion criteria. The searching process is presented in Figure 1.

Table 2 shows the main characteristics of the included studies. A total of 1121 Class I, 1051 Class II, and 730 Class III subjects were included in the meta-analysis.

Meta-analysis of the Malocclusions

Association between ACBL and anteroposterior malocclusions. Sixteen articles evaluated this outcome using the variable SN (Table 3; Figure 2).

Class II patients had a significantly higher ACBL than did Class I patients (WMD: 1.19, $P < .001$). In the stratified analysis, the difference was more pronounced among dental pattern, Caucasians, and before or during growth spurt cases.

Class III patients had a significantly lower ACBL than did Class I (WMD: −1.13, $P < .001$) and Class II patients (WMD: −2.70, $P < .001$). In the subgroup analysis, differences were observed among dental pattern, Asians and Whites, and before or during growth spurt cases compared with Class I controls, while skeletal and dental pattern, Asians and Whites, and before or during growth spurt cases compared with the Class II group.

Association between PCBL and anteroposterior malocclusions. Eleven articles assessed this outcome using the variable SBa (Table 3; Figure 3).

PCBL was not significantly higher in Class II than in Class I patients, but there were differences in the subgroups of dental pattern and before or during growth spurt cases.

Class III patients did not have a significantly lower PCBL value than Class I (WMD: −0.77, $P = .157$) or Class II patients (WMD: −1.78, $P = .056$). No differences were detected in the stratified analysis.

Table 3. Extended

SBa		NBa					NSBa	
I^2	P_h	n	WMD (95% CI)	P	I^2	P_h	n	WMD (95% CI)
63.4	.001	5	2.75 (2.20, 3.30)	<.001	10.3	.348	10	1.88 (1.38, 2.38)
75.7	.001	2	0.69 (−1.30, 2.68)	.499	0.0	.478	6	1.21 (−0.24, 2.67)
7.0	.376	3	2.97 (2.34, 3.49)	<.001	0.0	.650	4	2.06 (1.48, 2.64)
0.0	.978	2	0.69 (−1.30, 2.68)	.499	0.0	.478	2	1.45 (−0.53, 3.43)
69.0	.001	3	2.97 (2.34, 3.49)	<.001	0.0	.650	8	1.91 (1.39, 2.43)
–	–	–	–	–	–	–	–	–
15.8	.298	2	0.69 (−1.30, 2.68)	.499	0.0	.478	4	1.99 (1.45, 2.53)
83.8	<.001	3	2.97 (2.34, 3.49)	<.001	0.0	.650	6	1.17 (−0.19, 2.54)
71.6	.004	3	−2.34 (−3.33 ± −1.36)	<.001	34.5	.217	7	−2.03 (−3.14, −0.93)
82.6	.001	1	−3.40 (−6.42, −0.38)	.027	–	–	5	−2.23 (−3.12, −1.35)
0.0	.683	2	−2.22 (−3.26, −1.17)	<.001	60.4	.112	2	−2.09 (−5.31, 1.13)
0.0	.509	2	−1.94 (−3.07, −0.81)	.001	4.7	.306	3	−2.08 (−3.80, −0.35)
87.7	<.001	1	−3.60 (−5.60, −1.60)	<.001	–	–	4	−1.98 (−3.11, −0.85)
–	–	–	–	–	–	–	–	–
73.3	.024	2	−2.22 (−3.26, −1.17)	<.001	60.4	.112	3	−1.19 (−3.52, 1.15)
58.1	.092	1	−3.40 (−6.42, −0.38)	.027	–	–	4	−2.70 (−3.65, −1.75)
74.9	.008	2	−5.71 (−7.38, −4.05)	<.001	9.4	.294	5	−3.40 (−5.73, −1.06)
82.7	.003	1	−4.70 (−7.22, −2.18)	<.001	–	–	4	−2.62 (−3.78, −1.45)
–	–	1	−6.50 (−8.72, −4.28)	<.001	–	–	1	−7.10 (−9.31, −4.89)
					–	–		
–	–	1	−4.70 (−7.22, −2.18)	<.001	–	–	1	−4.90 (−7.24, −2.56)
83.2	.003	1	−6.50 (−8.72, −4.28)	<.001	–	–	4	−3.01 (−5.90, −0.11)
–	–	–	–	–	–	–	–	–
					–	–		
80.2	.024	1	−6.50 (−8.72, −4.28)	<.001	–	–	3	−3.73 (−10.40, 2.93)
52.9	.145	1	−4.70 (−7.22, −2.18)	<.001	–	–	2	−3.22 (−4.52, −1.91)

Association between TCBL and anteroposterior malocclusions. Six articles recorded this outcome using the variable NBa (Table 3; Figure 4).

Class II malocclusion had a significantly longer TCBL than did Class I controls (WMD: 2.75, $P < .001$), and the differences were greater when the patients were among dental pattern, Whites, and before or during growth spurt patients.

Class III patients had a shorter TCBL than did Class I (WMD: −2.34, $P < .001$) and Class II patients (WMD: −5.71, $P < .001$), and the differences were also found in stratified analysis.

Association between CBA and sagittal malocclusions. Twenty articles assessed this outcome using the variable NSBa or NSAr (Table 3; Figures 5 and 6).

The Class II group had a significantly larger WMD of 1.88° ($P < .001$) with regard to NSBa angle with low heterogeneity, but NSAr angle was not significantly larger than in Class I patients (WMD: 1.81, $P = .089$). The difference was statistically significant among dental pattern, Whites, and after growth spurt cases for NSBa, while it was significant for dental pattern and before or during growth spurt cases for NSAr.

CBA was significantly lower in Class III than in Class I (WMD: −2.03, $P < .001$ for NSBa; WMD: −1.71, $P = .001$ for NSAr) or Class II patients (WMD: −3.40, $P = .004$ for NSBa; WMD: −4.01, $P < .001$ for NSAr). Significant differences were observed in subgroups of skeletal pattern, Asians and Whites, and after growth spurt cases.

Sensitivity Analysis and Risk of Publication Bias

After the study of Sayin and Turkkahraman[9] was eliminated from the analysis, the difference in PCBL between Class II and Class I patients was altered (WMD: 0.08, 95% CI: 0.48, 1.11). Furthermore, Class II patients were found to have a significantly larger NSAr

Table 3. Extended

	NSBa			NSAr				
Malocclusion	*P*	I^2	P_h	n	WMD (95% CI)	*P*	I^2	P_h
Class II vs Class I	<.001	27.1	.151	4	1.81 (−0.28, 3.90)	.089	83.0	<.001
Pattern of malocclusion								
Skeletal pattern	.102	53.5	.045	2	−0.40 (−1.84, 1.04)	.589	58.5	.121
Dental pattern	<.001	0.0	.616	2	3.48 (2.44, 4.52)	<.001	27.2	.253
Ethnicities								
Asian	.151	0.0	.560	–	–	–	–	–
Caucasian	<.001	35.1	.094	4	1.81 (−0.28, 3.91)	.089	83.0	<.001
Mixed	–	–	–	–	–	–	–	–
Age								
Before or during growth spurt	.091	56.7	.330	2	3.48 (2.44, 4.52)	<.001	27.2	.253
After growth spurt	<.001	11.7	.074	2	−0.40 (−1.84, 1.04)	.589	58.5	.121
Class III vs Class I	<.001	55.2	.029	6	−1.71 (−2.73, −0.68)	.001	50.8	.047
Pattern of malocclusion								
Skeletal pattern	<.001	39.4	.143	2	−3.03 (−4.62, −1.44)	<.001	0.0	.453
Dental pattern	.203	82.8	.016	4	−1.31 (−2.06, −0.55)	.001	55.4	.062
Ethnicities								
Asian	.018	71.4	.030	1	−1.50 (−2.76, −0.24)	.020	–	–
Caucasian	.001	53.3	.073	5	−1.79 (−3.08, −0.50)	.007	57.7	.028
Mixed	–	–	–	–	–	–	–	–
Age								
Before or during growth spurt	.320	75.8	.016	4	−1.31 (−2.06, −0.55)	.001	55.4	.062
After growth spurt	<.001	0.0	.864	2	−3.03 (−4.62, −1.44)	<.001	0.0	.453
Class III vs Class II	.004	80.1	<.001	3	−4.01 (−6.11, −1.92)	<.001	77.6	.004
Pattern of malocclusion								
Skeletal pattern	<.001	61.2	.052	2	−2.69 (−3.96, −1.42)	<.001	0.0	.412
Dental pattern	<.001	–	–	1	−5.65 (−7.00, −4.30)	<.001	65.1	.090
Ethnicities								
Asian	<.001	–	–	–	–	–	–	–
Caucasian	.042	83.8	<.001	2	−4.43 (−7.13, −1.73)	.001	76.0	.015
Mixed	–	–	–	1	−2.91 (−4.29, −1.53)	<.001	–	–
Age								
Before or during growth spurt	.272	93.5	<.001	1	−5.65 (−7.00, −4.30)	<.001	65.1	.090
After growth spurt	<.001	47.3	.150	2	−2.69 (−3.96, −1.42)	<.001	0.0	.412

after elimination of the study by Polat and Kaya[30] (WMD: 2.64, 95% CI: 0.78, 4.51). The other outcomes were roughly similar before and after removal of each article.

With regard to publication bias, the funnel plot was found to be asymmetrical by the Egger and Begg test only for SN length in the comparison between Class II and Class I cases. However, similar findings were observed after applying the fill and trim procedure (data not shown).

DISCUSSION

The meta-analysis demonstrated that ACBL and TCBL were significantly higher in Class II than in Class III malocclusions. As the nasomaxillary complex is connected to the anterior cranial base region, growth of the spheno-occipital synchondrosis might influence the depth of the upper face.[39] Thus, shorter ACBL and TCBL could partially explain the retrusive maxilla and concave profile that is typical of a Class III malocclusion.[13,16,40] Conversely, greater anterior cranial base might be responsible for the prognathic maxilla and convex profile observed in a Class II division 1 malocclusion.[7,31]

We found no evidence for the relationship between PCBL and sagittal discrepancies. As identification of the Ba point is associated with greater errors, both statistically and clinically, compared with other landmarks on conventional cephalograms and relies more on cone beam computed tomography–derived cephalograms,[41] further studies should be conducted using three dimensions.

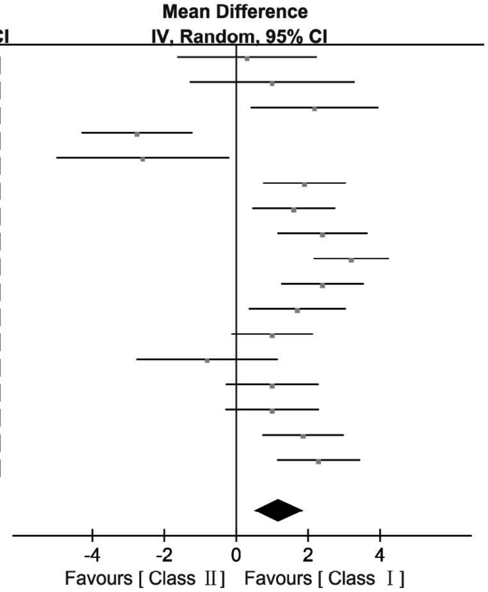
In this meta-analysis, Class II patients showed a significantly larger NSBa angle with low heterogeneity, but the same was not observed for the NSAr angle. Some researchers[9,12] believe that the mandible has a more posterior position under the cranium and that there is more open flexure of the cranial base in Class II cases. However, Rothstein and Yoon-Tarlie[7] stated that the increase in CBA did not contribute to the retruded mandibular positon. Furthermore, it has been reported[27]

SN length

A

Study or Subgroup	Class II Mean	Class II SD	Class II Total	Class I Mean	Class I SD	Class I Total	Weight	Mean Difference IV, Random, 95% CI
Chin et al. 2014	70.4	2.8	30	70.1	4.4	27	4.9%	0.30 [-1.64, 2.24]
Thiesen et al. 2013	70.4	4.7	20	69.4	2.3	20	4.2%	1.00 [-1.29, 3.29]
Polat et al. 2007	67.8	3.03	25	65.62	3.37	25	5.2%	2.18 [0.40, 3.96]
Sayin et al. 2005	69.32	3.45	40	72.08	2.53	20	5.7%	-2.76 [-4.30, -1.22]
Wilhelm et al. 2001	69.9	4.59	21	72.5	3.32	22	4.0%	-2.60 [-5.00, -0.20]
Rothstein et al. 2000 (A)	69.1	3	55	67.2	2.9	47	6.6%	1.90 [0.75, 3.05]
Rothstein et al. 2000 (B)	70.1	2.9	58	68.5	2.9	42	6.5%	1.60 [0.45, 2.75]
Rothstein et al. 2000 (C)	71.2	2.8	51	68.8	3.5	48	6.3%	2.40 [1.15, 3.65]
Rothstein et al. 2000 (D)	71.9	2.8	51	68.7	2.5	48	6.8%	3.20 [2.16, 4.24]
Rothstein et al. 2000 (E)	72.5	2.7	70	70.1	3.2	43	6.6%	2.40 [1.25, 3.55]
Rothstein et al. 2000 (F)	73.4	3.4	50	71.7	3.3	45	6.1%	1.70 [0.35, 3.05]
Johannsdottir et al. 1999	63.1	3.1	32	62.1	2.6	200	6.6%	1.00 [-0.13, 2.13]
Kasai et al. 1995	62.22	4.26	29	63.03	2.53	17	4.8%	-0.81 [-2.77, 1.15]
Bacon et al. 1992	64.3	3.2	45	63.3	2.9	41	6.3%	1.00 [-0.29, 2.29]
Kerr et al. 1991	72	2.8	31	71	2.4	31	6.2%	1.00 [-0.30, 2.30]
Hopkin et al. 1968 (A)	73.34	2.45	46	71.48	3.05	46	6.6%	1.86 [0.73, 2.99]
Hopkin et al. 1968 (B)	71.48	3.01	50	69.19	2.87	50	6.5%	2.29 [1.14, 3.44]
Total (95% CI)			**704**			**772**	**100.0%**	**1.19 [0.51, 1.87]**

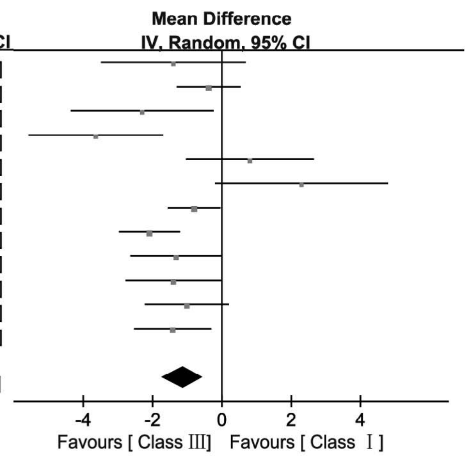
Heterogeneity: Tau² = 1.51; Chi² = 67.29, df = 16 (P < 0.00001); I² = 76%
Test for overall effect: Z = 3.42 (P = 0.0006)



B

Study or Subgroup	Class III Mean	Class III SD	Class III Total	Class I Mean	Class I SD	Class I Total	Weight	Mean Difference IV, Random, 95% CI
Sanggarnjanavanich et al. 2014	68.7	3.3	26	70.1	4.4	27	5.4%	-1.40 [-3.49, 0.69]
Chin et al. 2014	68.26	3.11	86	68.64	3.07	86	11.3%	-0.38 [-1.30, 0.54]
Thiesen et al. 2013	67.1	4.1	20	69.4	2.3	20	5.5%	-2.30 [-4.36, -0.24]
Sundareswaran et al. 2012 (A)	69.07	4.51	30	72.71	4.27	60	6.0%	-3.64 [-5.58, -1.70]
Sundareswaran et al. 2012 (B)	73.52	4.19	30	72.71	4.27	60	6.3%	0.81 [-1.04, 2.66]
Polat et al.2007	67.92	5.4	25	65.62	3.37	25	4.3%	2.30 [-0.20, 4.80]
Chang et al. 2005	66.9	2.8	100	67.7	2.7	100	12.4%	-0.80 [-1.56, -0.04]
Mouakeh et al. 2001	65.88	2.81	69	67.97	2.46	69	11.6%	-2.09 [-2.97, -1.21]
Tollaro et al. 1994	64.6	2.7	28	65.92	1.97	20	8.9%	-1.32 [-2.64, 0.00]
Kerr et al. 1991	69.6	3.1	31	71	2.4	31	8.6%	-1.40 [-2.78, -0.02]
Hopkin et al. 1968 (A)	70.47	2.89	46	71.48	3.05	46	9.5%	-1.01 [-2.22, 0.20]
Hopkin et al. 1968 (B)	67.77	2.82	50	69.19	2.87	50	10.1%	-1.42 [-2.54, -0.30]
Total (95% CI)			**541**			**594**	**100.0%**	**-1.13 [-1.74, -0.53]**

Heterogeneity: Tau² = 0.62; Chi² = 27.54, df = 11 (P = 0.004); I² = 60%
Test for overall effect: Z = 3.67 (P = 0.0002)



C

Study or Subgroup	Class III Mean	Class III SD	Class III Total	Class II Mean	Class II SD	Class II Total	Weight	Mean Difference IV, Fixed, 95% CI
Chin et al. 2014	68.7	3.3	26	70.4	2.8	30	13.9%	-1.70 [-3.32, -0.08]
Thiesen et al. 2013	67.1	4.1	20	70.4	4.7	20	4.9%	-3.30 [-6.03, -0.57]
Polat et al. 2007	67.92	5.4	25	67.8	3.03	25	6.2%	0.12 [-2.31, 2.55]
Kerr et al. 1991	69.6	3.1	31	72	2.8	31	16.8%	-2.40 [-3.87, -0.93]
Hopkin et al. 1968 (A)	70.47	2.89	46	73.34	2.45	46	30.4%	-2.87 [-3.96, -1.78]
Hopkin et al. 1968 (B)	67.77	2.82	50	71.48	3.01	50	27.8%	-3.71 [-4.85, -2.57]
Total (95% CI)			**198**			**202**	**100.0%**	**-2.70 [-3.30, -2.09]**

Heterogeneity: Chi² = 10.09, df = 5 (P = 0.07); I² = 50%
Test for overall effect: Z = 8.77 (P < 0.00001)

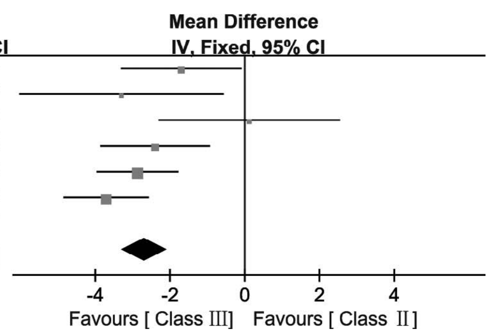


Figure 2. Forest plot depicting the association between ACBL and anteroposterior malocclusions. Rothstein (A): 10-year-old female; Rothstein (B): 12-year-old female; Rothstein (C): 14-year-old female; Rothstein (D): 10-year-old male; Rothstein (E): 12-year-old male; Rothstein (F): 14-year-old male; Hopkin (A): male; Hopkin (B): female; Sundareswaran (A): Class III with a maxillary retrusion; Sundareswaran (B): Class III with a nonmaxillary retrusion.

that the skeletal position of the mandible is normal except for the chin in children with Class II malocclusion. These disparities depict the complexity of the etiology of Class II malocclusion. Therefore, more studies need to be performed on the association between cranial base dimensions and maxillary and mandibular cephalometric parameters in order to understand the etiology and expression of Class II malocclusion.

Closed CBA was found in Class III malocclusion, as depicted by the decrease in NSBa and NSAr angles.

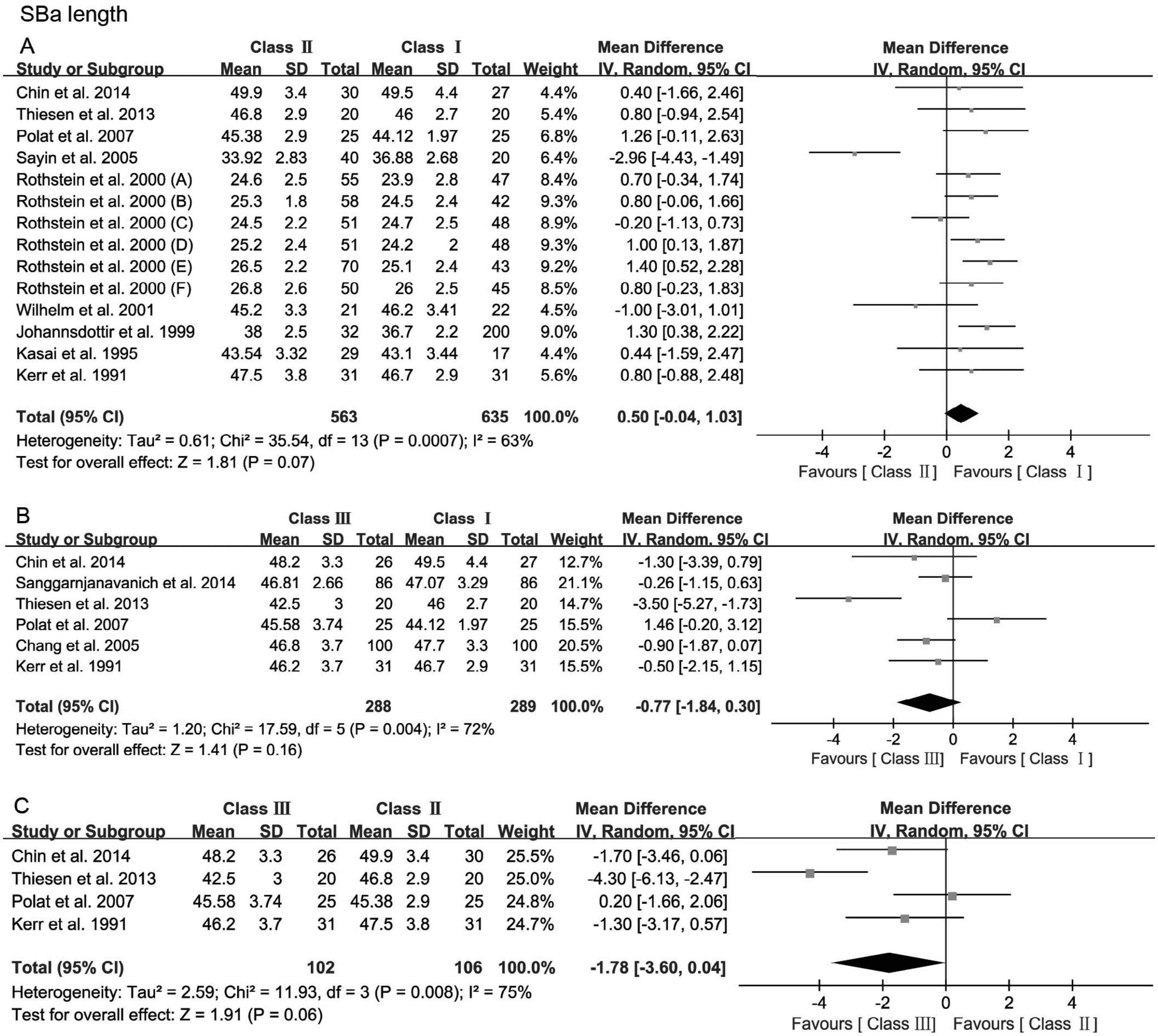


Figure 3. Forest plot depicting the association between PCBL and anteroposterior malocclusions. Rothstein (A): 10-year-old female; Rothstein (B): 12-year-old female; Rothstein (C): 14-year-old female; Rothstein (D): 10-year-old male; Rothstein (E): 12-year-old male; Rothstein (F): 14-year-old male.

Mesial positioning of the glenoid fossa[42] and a relatively protrusive condyle[43] have been reported in Class III patients, which suggests that the Ar point, located at the junction of the dorsal outline of condyles and temporal bone, is positioned forward. Thus, the anterior displacement of the Ar point might contribute to the decrease in the NSAr angle, which is related to the prognathism of the mandible.[12,17,21,24]

In the stratified meta-analysis, CBA was smaller in Class III than in Class I patients based on the skeletal but not on the dental pattern. Cranial base dimensions are more important in the establishment of malocclusion when there are significant discrepancies in the skeletal pattern.[29] Furthermore, we found evidence of the association between CBA and Class III malocclusion after but not before and during growth spurt. The variations observed might result from cranial base elongation during pubescence.[44] Moreover, in Class II malocclusion, the cranial base angle and length were significantly greater among Whites but not among Asians. Therefore, ethnic differences in genetic background and environmental context may play a role in cranial base morphology. Differences in natural head posture, evolutionary history, and genetic origin might contribute to the difference in cranial base orientation and flexure.[45]

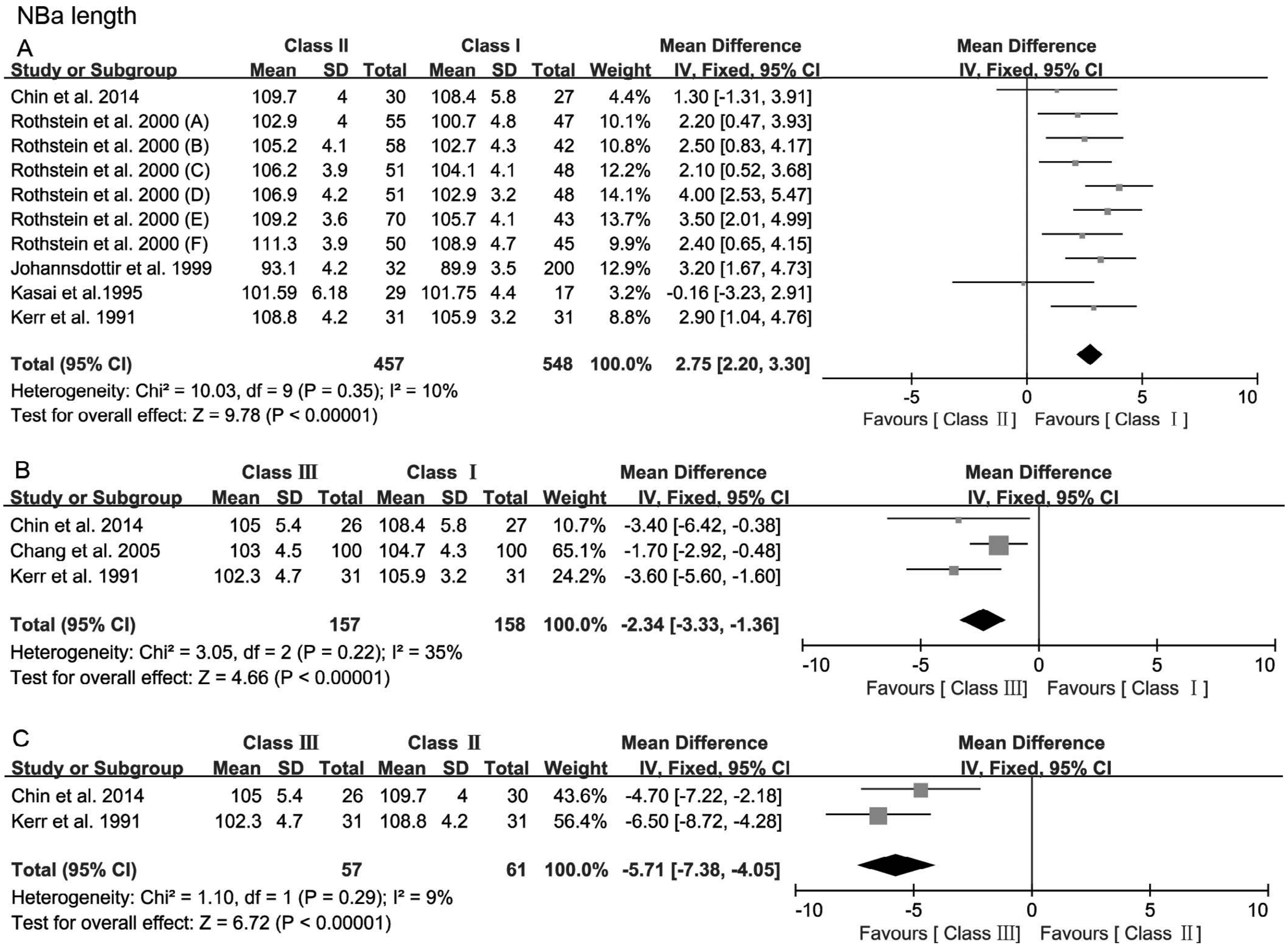


Figure 4. Forest plot depicting the association between TCBL and anteroposterior malocclusions. Rothstein (A): 10-year-old female; Rothstein (B): 12-year-old female; Rothstein (C): 14-year-old female; Rothstein (D): 10-year-old male; Rothstein (E): 12-year-old male; Rothstein (F): 14-year-old male.

There are a few limitations to this meta-analysis. First, we failed to stratify the data by gender because very few studies have recorded the data according to gender. Second, we included studies[6,11,12] on both Class II division 1 and division 2 cases, which have different craniofacial characteristics.[4] However, one of the strengths is that we performed stratification analysis according to certain influential factors in order to assess the heterogeneity among studies. Furthermore, sensitivity analysis was conducted to test the stability of the results. Therefore, despite the said limitations, our findings are rather useful for orthodontic diagnostic assessment and treatment.

CONCLUSIONS

- The meta-analysis demonstrated that CBA, ACBL, and TCBL are greater in Class II than in Class III subjects.
- There is not enough evidence for a significant relationship between PCBL and anteroposterior malocclusions.

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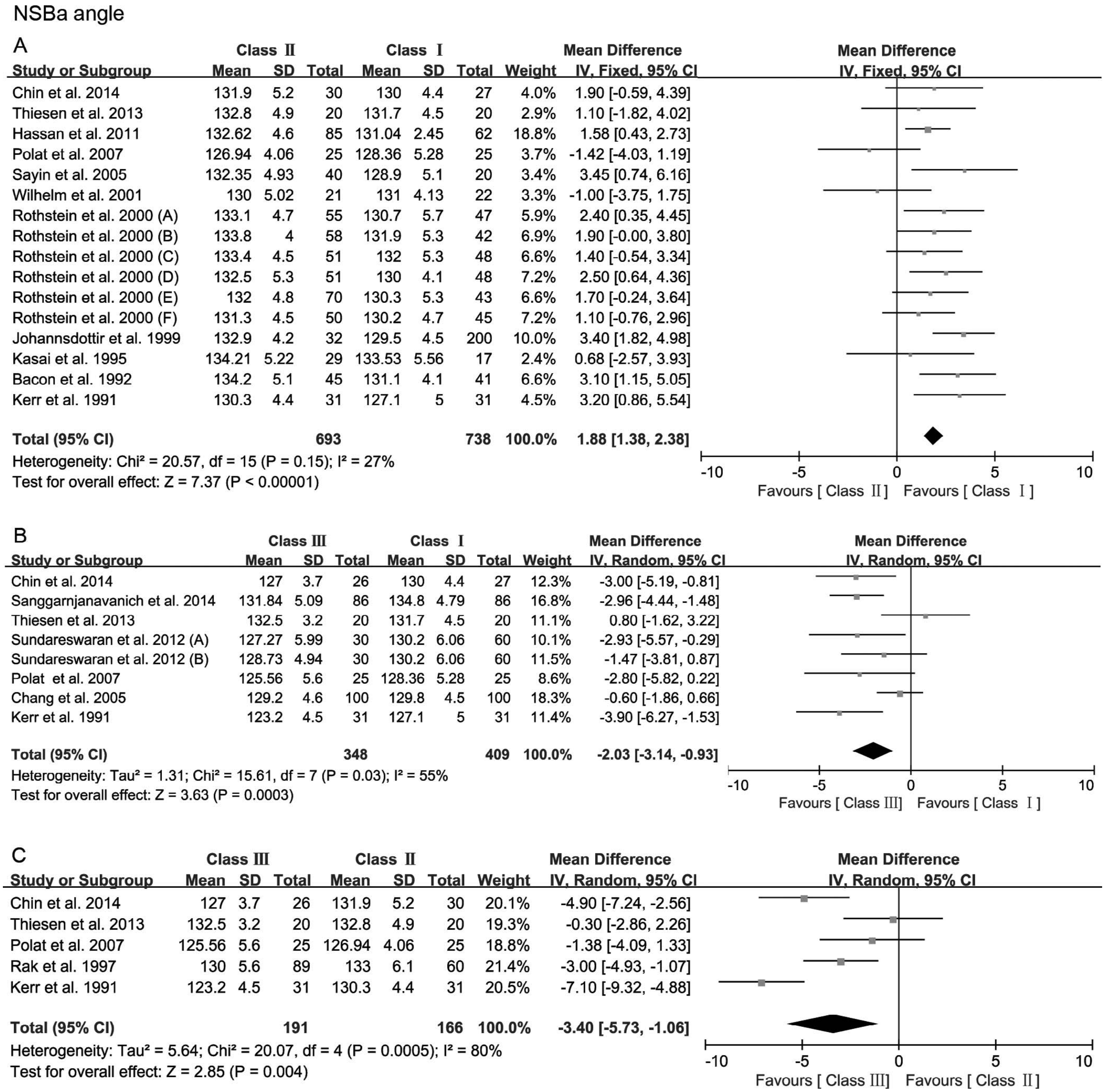

Figure 5. Forest plot depicting the association between NSBa angle and anteroposterior malocclusions. Rothstein (A): 10-year-old female; Rothstein (B): 12-year-old female; Rothstein (C): 14-year-old female; Rothstein (D): 10-year-old male; Rothstein (E): 12-year-old male; Rothstein (F): 14-year-old male; Sundareswaran (A): Class III with a maxillary retrusion; Sundareswaran (B): Class III with a nonmaxillary retrusion.

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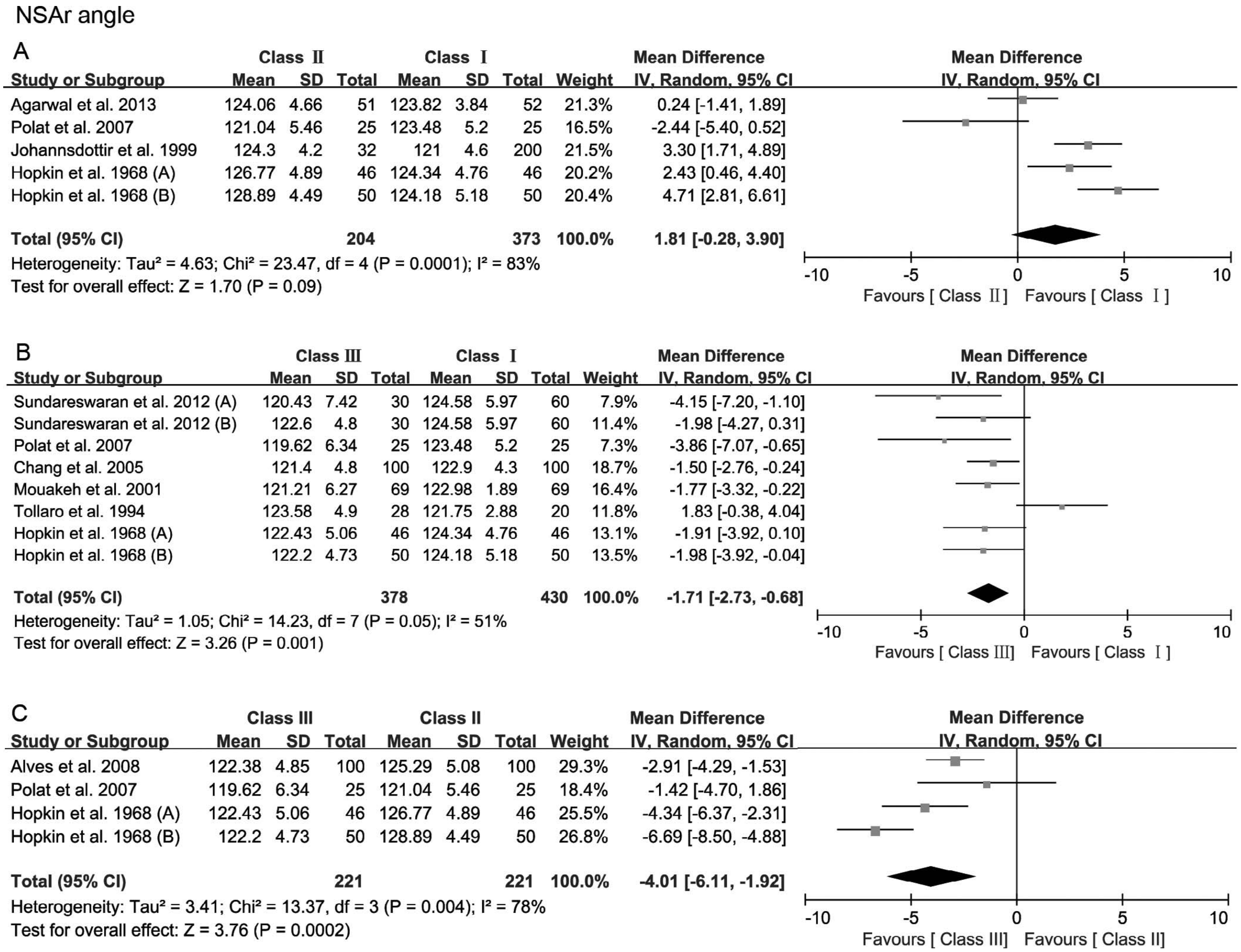

Figure 6. Forest plot depicting the association between NSAr angle and anteroposterior malocclusions. Hopkin (A): male; Hopkin (B): female; Sundareswaran (A): Class III with a maxillary retrusion; Sundareswaran (B): Class III with a nonmaxillary retrusion.

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