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Systematic Review

Vertical stability of different orthognathic treatments for correcting skeletal anterior open bite: a systematic review and meta-analysis

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Summary

Background: Several orthognathic procedures have been applied to correct skeletal anterior open bites (SAOB). Which method is most stable has been debated and no consensus has been reached and there is no conclusive evidence for clinicians to use.
Objective: To analyse whether maxillary, mandibular, or bimaxillary surgery provides a better stability.
Materials and methods: A systematic search was conducted up to December 2020 using PubMed, EMBASE, Medline, Scopus, Web of Science, Cochrane CENTRAL, and Google Scholar. We made direct comparisons among the controlled trials and also made indirect comparisons via subgroup analysis on the aspects of occlusional, skeletal, and dento-alveolar stability to assess the overall stability of each method.
Results: Finally 16 cohort studies were identified. At the occlusional level, pooled change in overbite was 0.21 mm in maxillary surgery, 0.37 mm in bimaxillary surgery, and −0.32 mm in mandibular surgery. At the skeletal level, pooled sella–nasion–Point A angle (SNA) was −0.12 degrees in bimaxillary surgery, −0.37 degrees in maxillary surgery and −0.20 degrees in mandibular surgery. The sella–nasion to palatal plane angle (SNPP) relapsed to a statistically significant degree in all samples received single maxillary surgery. Relapse of the sella–nasion–Point B angle (SNB) was 0.47 degrees in mandibular setback, −1.8 degrees in mandibular advancement, and −0.48 degrees in maxillary surgery. The Sella–Nasion to mandibular plane angle (SNMP) relapsed more in procedures involving bilateral sagittal split osteotomy than in other procedures. As for dento-alveolar changes, intrusion of molars and extrusion of incisors took place in most patients.
Conclusions: Bimaxillary surgery produced the most beneficial post-operative increase in overbite, maxillary surgery led to a lesser but still positive overbite change, and mandibular surgery correlated with some extent of relapse. Skeletally, bimaxillary surgery was more stable than maxillary surgery at both SNA and SNPP; SNB was more stable in mandibular setback than advancement; and SNMP was unstable in both mandibular and bimaxillary surgeries versus maxillary surgery with comparable surgical changes. Dento-alveolar compensation helped maintain a positive overbite.
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Introduction

Rationale

Treatment and stability of skeletal anterior open bite (SAOB) are always challenging topics due mainly to multifactorial vertical relapse (1–5), which manifests as a decrease in overbite, eruption of molars, opening rotation of the maxilla and mandible, and an increase in facial height (6, 7). For adult SAOB patients, who experience excessive vertical growth and abnormal morphology characterized by shorter rami and greater facial height (8, 9), orthodontic–orthognathic treatment is considered to achieve optimal aesthetic and occlusal results and offer greater long-term stability than non-surgical treatments (10, 11).

Several orthognathic procedures have been proposed to correct SAOB, all of which could influence stability (2, 3, 11–16). These procedures include maxillary surgery, mandibular surgery, and a combination of the two (bimaxillary surgery). Many researchers have attempted to confirm which is the most stable surgical procedure, a very controversial topic with no consensus. Bimaxillary surgery was reported to be less stable than either maxillary or mandibular surgery alone (14, 17, 18), while Maia *et al.* demonstrated no difference in long-term overbite change between maxillary surgery and bimaxillary surgeries (1). Maxillary intervention, most commonly maxillary Le Fort I impaction, appeared to be more stable than mandibular surgery (13, 19) and, therefore, has become the most frequently used orthognathic protocol for SAOB (18); however, relapse after this intervention has also been reported (4). Meanwhile, some studies have suggested single mandibular surgery to be as least stable as maxillary impaction and bimaxillary in correcting SAOB deformities (20), and results have been very favourable and clinically stable (21).

To our knowledge, no meta-analysis or systematic review has been conducted to assure the stability of different surgical procedures for SAOB. Previous meta-analysis focussed on the differences in post-operative overbite stability between surgical and non-surgical treatments (22). Given the persistent debates on the vertical stability of orthognathic treatments, clinicians lack clear information about which orthognathic surgery—maxillary, mandibular, or bimaxillary—can provide the greatest stability when used clinically. Consequently, a systematic review and meta-analysis is needed to produce quantifiable results on the stability of orthognathic treatments and to provide evidence-based indications for clinical practice and insights for further studies by evaluating current evidence.

Objectives

The objectives of the present study were 1. to evaluate available evidence on the vertical stability of orthognathic treatments—maxillary, mandibular, and bimaxillary surgeries—for correcting SAOB with at least a 6-month follow-up period, and 2. to identify which procedure could provide the best occlusional, skeletal, or dento-alveolar stability.

Materials and methods

Protocol and registration

This systematic review was prepared in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist. We registered the protocol of this systematic review and meta-analysis in the US National Institute of Health's (NIH; Bethesda, Maryland, USA) International Prospective Register of Systematic Reviews (PROSPERO) research database (https://www.crd.york.ac.uk/prospero/; Trail Registration No. PROSPERO CRD42020198088).

Eligibility criteria

Selection criteria for this review are shown in Table 1 in reply to the question: 'What is the vertical dental and skeletal stability (outcome) of orthodontic–orthognathic treatment with different surgical procedures (interventions) for patients with skeletal anterior open bite (participants)?'

Study selection

Articles were selected in two phases. In Phase 1, two authors (WMQ and ZBW) independently screened titles and abstracts of all articles. In Phase 2, the same two reviewers independently assessed eligibility of studies enrolled in the full-text review; in the event of disagreement, the third senior author (WFL) was consulted.

Information sources and search strategy

We performed an electronic search of literature published from 1 January 2000 to 15 December 2020 in seven databases: PubMed, EMBASE, Medline, Scopus, Web of Science, Cochrane Central Register of Controlled Trials (CENTRAL), and Google Scholar to search grey literature. Medical Subject Heading (MeSH) terms combined with free-text terms were used in the literature search (Supplementary File 1). We manually searched the following journals for studies performed from January 2014 to December 2020: *American Journal of Orthodontics and Dentofacial Orthopedics* (*AJODO*), *European Journal of Orthodontics*, *Journal of Dental Research*, and *European Journal of Orthodontics, Progress in Orthodontics*, and *The Angle Orthodontist*.

Data collection and data items

Two authors (WMQ and ZBW) independently extracted data from included studies using a pre-prepared data extraction form. The following information was extracted from each study: general information (first author, year of publication, and region), methods (study design and duration), participants information (sample size, age, gender, preoperative overbite, type of malocclusion, and measurement methods), and outcome measurements. Inconsistencies were resolved in consensus meetings and confirmed with the authors of the included studies when necessary.

Quality assessment

All studies recognized eligible for systematic review were assessed for risk of bias using the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool (23). The criteria take four main categories of bias into account: selection bias, performance bias, measurement bias, and outcome reporting bias (attribution bias is not included for studies with retrospective designs). The ROBINS-I scale contains a total of seven measures: 1. inclusion and exclusion criteria; 2. random-sequence generation; 3. standard surgery in combination with rigid internal fixation (RIF); 4. blinded assessment; 5. validation of measurements; 6. statistical analysis; and 7. sufficiently long follow-up. Two reviewers (WMQ and ZBW) independently performed the assessment and attempted to resolve disagreements via discussion. If no consensus could be reached, the third senior reviewer (WFL) became involved in the final decision.

Overall risk of bias of the included articles was evaluated after the assessment. Furthermore, we determined the quality of cumulative evidence using the Grades of Recommendation, Assessment, Development and Evaluation (GRADE) system (24). Two authors (WMQ and ZBW) evaluated the quality of evidence on five aspects: risk of bias, indirectness, inconsistency, imprecision, and magnitude

Table 1. Eligibility criteria for study selection. SNMP: the angle between sella–nasion and mandibular plane; U1PP: the distance from the edge of upper incisor perpendicularly to palatal plane; U6PP: the distance from the mesial cusp tip of upper first molar perpendicularly to the palatal plane; L1MP: the distance from the edge of lower incisor to mandibular plane; L6MP: the distance from the mesial cusp tip of lower first molar perpendicularly to the mandibular line.

Category	Inclusion criteria	Exclusion criteria
Study design	Randomized controlled trials, controlled clinical trials, cohorts	Case reports with ≤5 subjects, systematic reviews, opinion, or philosophy articles without new data
Participants	Patients after the stage of rapid growth with skeletal anterior open bite and in good general health requiring surgical-orthodontic correction	Patients with systematic disease or craniofacial pathologies or anomalies potentially influencing stability or complicating treatment (periodontal disease, root resorption, oral neoplasm, cleft lip or palate, trauma, and temporomandibular disorder).
Intervention	Orthodontic–orthognathic treatment, of which surgical procedures include separated maxillary surgery, separated mandibular surgery, and bimaxillary surgery	Surgery-first approach, isolated alveolar bone corticotomy and isolated genioplasty, studies with no application of Rigid Internal Fixation was excluded
Control	Groups treated with different orthognathic treatments or subjects treated with orthognathic surgery before versus after a post-operative follow-up period >6 months	Studies with no comparison of subjects before and after a post-operative follow-up period >6 months.
Outcome measures	1.Primary outcome: numerical change of overbite (mm), frequency of relapse, or obvious overbite change (%) 2.Secondary outcome: measurements indicating vertical skeletal and dento-alveolar stability, such as change of SNA (°), SNPP (mm), SNB (°), SNMP (°), U1PP (mm), U6PP (mm), L1MP (mm), and L6MP (mm)	

of effect; and then classified it into four levels: high, moderate, low, and very low.

Summary measures and additional analysis of results

We conducted meta-analysis using Stata software version 15.1 (StataCorp., College Station, Texas, USA). The pooled post-operative change (PC) was weighted by sample size. Forest plots and quantitative τ^2, χ^2, and I^2 indices were used to indicate statistical heterogeneity. We applied the fixed-effects model if I^2 <25 per cent; otherwise, we applied the random-effects model. $P < 0.05$ was regarded to indicate a statistically significant difference. When homogeneity was insufficient in the original data ($I^2 > 50$ per cent), sensitivity analysis was applied, and subgroup analyses of different orthognathic procedures (separated maxillary surgery, separated mandibular surgery, and bimaxillary surgery) were performed to explain heterogeneity and compare stability levels among these different procedures.

Results

Study selection

The search strategy and results are detailed in Supplementary File 1. The search of major databases was performed on 15 December 2020. Figure 1 shows the study flowchart. A total of 1490 articles were retrieved by electronic search. We selected 34 recorded for full-text reading and assessment of eligibility. All publications found by manual search were also among in the electronic search results.

Ultimately, we included 16 records in the qualitative analysis and selected 12 for quantitative synthesis. The level of agreement between the two authors (WMQ and ZBW) in selecting studies for full-text review was measured by k = 98.5 per cent.

Study characteristics

All 16 studies were retrospective cohort studies. Data extraction revealed that they included a total of 506 patients who underwent orthognathic correction of SAOB. Of all patients, 180 were from Asia (China (25, 26), South Korea (12, 15)); 255 were from Europe (Sweden (4), Finland (14), UK (33), Norway (18, 30), Italy (29), Belgium (32)); and 71 were from the USA (21, 27, 28).

The sample sizes of the studies ranged from 6 (13) to 72 (25) participants, with mean age of included patients ranging from 19 (33) to 30.8 (16) years. Of all participants, 63.7 per cent were female and 36.3 per cent were male. Initial mean open bite ranged from 1.9 (30) to 6.78 mm (12). Eight studies reported the type of antero-posterior relationship. Overall, 6.0 per cent of patients had

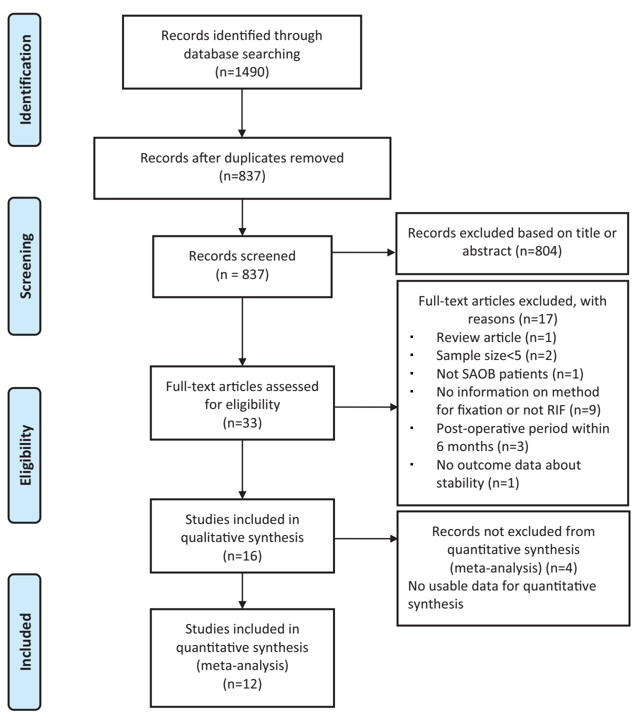

Figure 1. PRISMA diagram of the study identification process.

Class I malocclusion, 31.5 per cent had Class II malocclusion, and 62.5 per cent had Class III malocclusion.

In terms of surgical procedures, 29.7 per cent of cases received bimaxillary treatment (12–14, 25, 26, 29, 32), all of which consisted of Le Fort I in combination with bilateral sagittal split osteotomy (BSSO); 32.8 per cent of cases received a single mandibular osteotomy (15, 21, 25, 27, 30, 31) performed via BSSO or modifications thereof; and 36.3 per cent of subjects received a single maxillary surgery (4, 13, 14, 18, 26, 28–30, 32) using Le Fort I osteotomy. For six cases in one study, specific surgical procedures were not reported (1). Follow-up periods ranged from 8.3 (15) to 98 months (1); only one study had a mean follow-up period of <12 months (15). Fifteen studies measured via cephalometric radiography; only one study measured overbite clinically and on cast models (4). Detailed characteristics are presented in Supplementary Table 1.

Results of individual studies

Table 2 summarizes the outcomes reported from the included studies, classified by author (year), type of surgery, follow-up, measurements, and significance (if evaluated). As Figure 2 and Supplementary Table 2 illustrate, five studies directly compared stability among different orthognathic surgeries, setting statistical significance at $P < 0.05$ (13, 14, 25, 29, 30).

Two articles (14, 29) compared the stability of maxillary and bimaxillary surgeries. They reached no consensus on overbite relapse. Although the difference was not statistically significant, both studies observed less change in maxillary measurements [sella–nasion–Point A angle (SNA); sella–nasion to palatal plane angle (SNPP)] in bimaxillary surgery. Mean change in SNPP after maxillary surgery was significant (>2 mm). The two studies also agreed that mandibular parameters [sella–nasion–point B angle (SNB), sella–nasion to mandibular plane angle (SNMP)] relapsed less in maxillary surgery to a significant degree. Both articles observed dento-alveolar changes in incisor extrusion and molar intrusion in both surgeries, with no intergroup differences.

Two studies (13, 25) compared mandibular surgery with bimaxillary surgery. In terms of occlusion, mandibular surgery had a significantly higher frequency of significant overbite decrease and a significantly lower frequency of significant overbite increase; overbite relapsed more often in mandibular surgery, although not to a significant degree. As for SNMP, both studies observed a higher frequency of significant increase and lower frequency of significant decrease in mandibular surgery (25). Dento-alveolar changes towards compensation were also found in mandibular and bimaxillary surgeries, with no intergroup differences (13).

One article (30) compared maxillary and mandibular surgeries. Although no statistical difference was found in overbite, the frequency of no overlap significantly increased after mandibular surgery. As for skeletal changes, SNB significantly relapsed in mandibular surgery, while there was no significant change in maxillary surgery. A significantly greater SNMP relapse was observed after mandibular than after bimaxillary surgery. Remarkably, SNMP showed significantly relapse: 80 per cent of surgical correction after mandibular surgery eventually reverted to its prior form.

Synthesis of results

Primary outcome

Figure 3 presents the pooled overbite relapse rates of different surgeries. The most beneficial overbite increases were in bimaxillary surgery (n = 69; PC = 0.37 degrees; 95 per cent CI, 0.18–0.57; I^2 = 98.5 per cent, P = 0) (12–14, 29). There were fewer but still positive overbite changes in maxillary surgery (n = 114; PC = 0.21 degrees; 95 per cent CI, 0.06–0.37; I^2 = 95.0 per cent, P = 0) (4, 14, 18, 28–30), and the relapse rate for mandibular surgery had no heterogeneity (n = 79; PC = −0.32 degrees; 95 per cent CI, −0.61 to −0.02; I^2 = 0, P = 0.752) (13, 15, 21, 30, 31). One record was excluded by sensitivity analysis due to its high level of heterogeneity (27).

Secondary outcomes

Figure 4 illustrates greater and lesser rates of relapse for each skeletal measurement in all studies. Synthesized SNA had lower relapse in bimaxillary surgery (n = 61; PC = −0.12 degrees; 95 per cent CI, −0.42 to 0.17; I^2 = 0, P = 0.444) (12, 14, 29) than in maxillary surgery (n = 74; PC = −0.37 degrees; 95 per cent CI, −0.56 to −0.17; I^2 = 99.1 per cent, P = 0) (14, 28–30) and was even comparable to mandibular surgery (n = 20; PC = −0.20 degrees; 95 per cent CI, −0.73 to 0.33), which served as a non-maxillary surgical control (15). In terms of SNB, setback movement (n = 49; PC = 0.47 degrees; 95 per cent CI, 0.17–0.78; I^2 = 21.1 per cent, P = 0.281) (12, 15) was found to be as stable as non-mandibular surgery (n = 24; PC = −0.95 degrees; 95 per cent CI, −1.48 to −0.42; I^2 = 84.2 per cent, P = 0) (14, 28, 30). Obvious relapse was observed in advanced movement (n = 39; PC = −1.80 degrees; 95 per cent CI, −2.25 to −1.35) (14, 30). As for SNMP, more relapse was observed in surgeries involving BSSO, whether mandibular or bimaxillary (n = 59; PC = 3.35 degrees; 95 per cent CI, 2.71–3.99; I^2 = 0, P = 0.542) (14, 15, 30) than in maxillary surgery (n = 54; PC = 0.36 degrees; 95 per cent CI, −0.09 to 0.82; I^2 = 42.0 per cent, P = 0.178) (14, 28, 30). One study was excluded by sensitivity analysis for its significant heterogeneity (27).

Pooled results of each dento-alveolar measurement presented a tendency towards dento-alveolar compensation (Supplementary Figure 1): U1PP (n = 161; ES = 0.24 degrees; 95 per cent CI, 0.08–0.40; I^2 = 79.0 per cent, P = 0) indicated vertical eruption of upper incisors (13, 14, 21, 27, 28, 32); U6PP (n = 132; ES = −0.49 degrees; 95 per cent CI, −0.48 to −0.30; I^2 = 89.6 per cent, P = 0) showed extrusive movement of the upper first molar (14, 21, 27, 32); L1MP (n = 64; ES = 0.28 degrees; 95 per cent CI, −0.05 to 0.61; I^2 = 0, P = 0.954) showed no heterogeneity for vertical eruption of lower incisors; and L6MP (n = 95; ES = −0.06 degrees; 95 per cent CI, −0.38 to 0.25; I^2 = 83.7 per cent, P = 0) (14, 21, 27, 28) indicated high heterogeneity in the upward-movement tendency of the lower first molar. We did not perform subgroup analysis of different surgeries due to the limited number of studies.

Quality assessment

Risk of bias within studies is detailed in Supplementary Table 3. Most studies were deemed to have moderate (1, 4, 12, 15, 18, 25–27, 29, 30) or serious (4, 13, 14, 28, 31, 32) overall risk of bias. The risk of biases in performance and reporting were low. Only one study included a blinded assessment of variables, although such assessment is essential for reducing risk of bias during measurement. According to GRADE, we found the quality of evidence to be moderate to very low (Supplementary Table 4). The main factors decreasing the level of evidence were limitations of study design (observational studies), inconsistency, and low magnitude of effects.

Discussion

This study explored the post-operative stability of SAOB across three aspects: occlusional, skeletal, and dento-alveolar stability. The most beneficial overbite increase was found in bimaxillary surgery, there was less but still positive overbite change in maxillary surgery,

Table 2. Data on occlusional, skeletal, and dento-alveolar stability from the included studies. Le Fort I: Le Fort I Osteotomy; BSSO: bilateral sagittal split osteotomy; SNMP: the angle between sella–nasion to mandibular plane; L1-Me: Distance between the edge of lower incisor and menton point; FNO: Frequency of people with No vertical Overlap; FsOBd: Frequency of people with significant postsurgical overbite decrease (≥ 2mm); FsOBi: Frequency of people with significant postsurgical overbite increase (≥ 2mm); FsSNMPi: Frequency of people with significant post-surgical SNMP increase (≥ 2mm); FsSNMPd: Frequency of people with significant post-surgical SNMP decrease (≥ 2mm); T1: Measurement before follow-up; T2: Value at the end of follow-up; NR: None related Report; NR: None significance ($P \geq 0.05$).

Author (year)/surgery	Follow-up (months)	Variables	Measurements	T1 M ± (SD)	T2 M ± (SD)	Difference M ± (SD)	Significance *P*-value
Bisase *et al.* (31)/*BSSO*	12	Occlusional	OB (mm)	1.42 (0.51)	1.0 (0.6)	−0.42 (0.51)	0.045
Espeland *et al.* (18)/*Le Fort I*	36	Occlusional	OB (mm)	NR	NR	0.1 (0.4)	NS
Fontes *et al.* (21)/*BSSO*	54	Occlusional	OB (mm)	0.6 (1.0)	1.0 (1.0)	NR	NR
			FNO (%)	25.8	9.7	NR	NR
		Skeletal	SNA (°)	80.3	79.9	NR	NR
			SNB (°)	78.1	77	NR	NR
		Dento-alveolar	U1PP (mm)	32.6	32.8	NR	NR
			U6PP (mm)	26.1	25.8	NR	NR
			L1MP (mm)	44	43.8	NR	NR
			L6MP (mm)	32.5	32.2	NR	NR
Hull *et al.* (28)/*Le Fort I*	25	Occlusional	OB (mm)	1.7 (0.6)	1.5 (0.8)	−0.1 (1.1)	NR
		Skeletal	SNA (°)	81.9 (6.4)	81.2 (6.3)	−0.7 (1.1)	NR
			SNB (°)	78.1 (5.0)	77.4 (5.0)	−0.7 (1.3)	NR
			SNMP (°)	35.6 (6.2)	36.4 (6.6)	0.8 (2.1)	NR
		Dento-alveolar	U1PP (mm)	29.5 (3.2)	29.7 (2.6)	0.2 (1.0)	NR
			L1MP (mm)	30.1 (2.0)	30.4 (2.0)	0.3 (0.9)	NR
			L6MP (mm)	37.0 (2.9)	37.6 (2.9)	0.6 (0.6)	NR
Iannetti *et al.* (29) (Bi)/*Le Fort I+BSSO*	24	Occlusional	OB (mm)	NR	NR	0.875 (0.141)	NR
		Skeletal	SNA (°)	NR	NR	0.055 (0.051)	NR
			SNB (°)	NR	NR	−0.54 (0.305)	NR
Iannetti *et al.* (29) (Max)/*Le Fort I*	24	Occlusional	OB (mm)	NR	NR	0.4 (0.152)	NR
		Skeletal	SNA (°)	NR	NR	0.1 (0.117)	NR
			SNB (°)	NR	NR	0.025 (0.072)	NR
Ismail *et al.* (26) (Bi)/*Le Fort I+BSSO*	24	Occlusional	FNO (%)	20.8	12.5	−8.3	NR
Ismail *et al.* (26) (Max)/*Le Fort I*	24	Occlusional	FNO (%)	11.1	11.1	0	NR
Kwon *et al.* (15)/*BSSO*	8.3	Occlusional	OB (mm)	NR	NR	−0.2 (1.6)	0.519
		Skeletal	SNA (°)	NR	NR	−0.2 (1.2)	0.461
			SNB (°)	NR	NR	0.2 (1.3)	0.533
			SNMP (°)	NR	NR	3.6 (2.9)	<0.001
Kor *et al.* (12) (Bi1)/*Le Fort I+BSSO*	12	Occlusional	OB (mm)	NR	NR	0.75 (0.70)	NR
		Skeletal	SNA (°)	NR	NR	−0.11 (0.75)	NR
			SNB (°)	NR	NR	0.45 (0.66)	NR
Kor *et al.* (12) (Bi2)/*Le Fort I+ BSSO*	12	Occlusional	OB (mm)	NR	NR	0.06 (0.93)	NR
		Skeletal	SNA (°)	NR	NR	−0.14 (1.07)	NR
			SNB (°)	NR	NR	0.79 (1.05)	NR
Liu *et al.* (25) (Bi)/*Le Fort I+BSSO*	24	Occlusional	FsOBd (%)	10	NR		
			FsOBi (%)	8	NR		
		Skeletal	FsSNMPi (%)	19	NR		
			FsSNMPd (%)	6	NR		

Table 2. Continued

Author (year)/surgery	Follow-up (months)	Variables	Measurements	T1 M ± (SD)	T2 M ± (SD)	Difference M ± (SD)	Significance *P*-value
Liu *et al.* (25) (Mand)/*BSSO*	24	Occlusional	FsOBd (%)	18	NR		
			FsOBi (%)	4	NR		
		Skeletal	FsSNMPi (%)	25	NR		
			FsSNMPd (%)	7	NR		
Maia *et al.* (1)/*BSSO*	24	Occlusional	OB (mm)	NR	NR	−0.83 (1.42)	NR
Nina *et al.* (30) (Mande)/*BSSO*	36	Occlusional	OB (mm)	NR	−0.2	−0.3 (1.3)	NS
			FNO (%)	37	58.3	21.3	NR
		Skeletal	SNB (°)	NR	75.1	−1.2 (1.2)	<0.05
			SNMP (°)	NR	43.4	3.5 (2.1)	<0.05
			FsSNMPi (%)	80	NR		
			FsSNMPd (%)	0	NR		
Nina *et al.* (30) (Max)/*Le Fort I*	36	Occlusional	OB (mm)	NR	0.5	−0.2 (1.0)	NS
			FNO (%)	13.3	26	14	NR
		Skeletal	SNA (°)	NR	78.5	−0.5 (0.7)	NS
			SNPP (°)	NR	13.8	−0.7 (1.9)	<0.05
			SNB (°)	NR	73.6	−0.1 (0.7)	NS
			SNMP (°)	NR	41.1	0.0 (1.3)	NS
			FsSNMPi (%)	7	NR		
			FsSNMPd (%)	4	NR		
Ooi *et al.* (13) (Bi)/*Le Fort I+ BSSO*	12	Occlusional	OB (mm)	1.4	1.6	0.25 (0.80)	NR
		Dento-alveolar	U1PP (mm)	NR	NR	−0.56 (0.88)	NR
			L1–Me (mm)	NR	NR	0.03 (0.52)	NR
Ooi *et al.* (13) (Mand)/*BSSO*	12	Occlusional	OB (mm)	2.7	2.2	−0.48 (0.64)	NR
		Dento-alveolar	U1PP (mm)	NR	NR	−0.50 (0.86)	NR
			L1–Me (mm)	NR	NR	−0.19 (0.53)	NR
Silva *et al.* (4)/*Le Fort I, Segmentated*	30	Occlusional	OB (mm)	2.6 (0.15)	1.65 (0.14)	NR	<0.001
Stansbury *et al.* (27)/*BSSO*	12	Occlusional	OB (mm)	1.1 (1.1)	1.7 (0.7)	0.6 (1.2)	0.014
		Skeletal	SNMP (°)	38.5 (8.4)	38.6 (8.5)	0.1 (1.2)	NS
		Dento-alveolar	U1PP (mm)	33.1 (4.5)	33.2 (4.4)	0.8 (1.4)	0.01
			U6PP (mm)	27.3 (3.6)	27.5 (3.8)	0.2 (0.8)	0.17
			L1MP (mm)	47.0 (6.9)	47.3 (6.8)	0.3 (1.1)	0.133
			L6MP (mm)	35.9 (4.7)	35.7 (4.6)	−0.3 (0.9)	0.063
Swinnen *et al.* (32)/*Le Fort I or Le Fort I+ BSSO*	12	Occlusional	OB (mm)	NR	NR	0.5 (0.3)	NS
		Skeletal	SNA (°)	NR	NR	−0.7 (0.3)	<0.05
			SNPP (°)	NR	NR	−1.5 (0.4)	<0.0001
		Dento-alveolar	U1PP (mm)	NR	NR	0.1 (0.3)	NS
			U6PP (mm)	NR	NR	−0.7 (0.3)	<0.05
Teittinen *et al.* (14) (Bi)/*Le Fort I+ BSSO*	24	Occlusional	OB (mm)	0.98 (1.53)	0.73 (0.93)	−0.25 (1.33)	0.529
		Skeletal	SNA (°)	83.41 (5.23)	83.00 (4.67)	−0.41 (2.12)	0.515
			SNPP (°)	8.27 (3.91)	7.06 (4.14)	−1.38 (2.34)	0.066
			SNB (°)	81.39 (5.45)	78.25 (6.33)	−3.15 (1.85)	0.001
			SNMP (°)	37.48 (8.47)	41.25 (10.37)	3.60 (2.68)	0.001

Table 2. Continued

Author (year)/surgery	Follow-up (months)	Variables	Measurements	T1 M ± (SD)	T2 M ± (SD)	Difference M ± (SD)	Significance *P*-value
		Dento-alveolar	U1PP (mm)	31.97 (2.50)	32.41 (2.15)	0.44 (1.01)	0.159
			U6PP (mm)	23.37 (1.80)	23.13 (1.80)	−0.24 (0.86)	0.359
			L1MP (mm)	41.52 (3.92)	41.90 (3.99)	0.38 (0.75)	0.111
			L6MP (mm)	31.48 (2.94)	31.67 (3.69)	0.18 (1.66)	0.709
Teittinen *et al.* (14) (Max)/*Le Fort I*	42	Occlusional	OB (mm)	1.23 (1.05)	1.85 (0.93)	0.59 (1.40)	0.175
		Skeletal	SNA (°)	85.18 (2.94)	84.71 (3.67)	−0.47 (1.41)	0.276
			SNPP (°)	9.59 (3.23)	7.45 (3.08)	−2.14 (3.31)	0.046
			SNB (°)	82.26 (3.64)	81.24 (3.67)	−1.02 (1.33)	0.022
			SNMP (°)	34.17 (7.30)	35.84 (5.95)	0.84 (2.17)	0.206
		Dento-alveolar	U1PP (mm)	32.80 (4.36)	33.19 (4.44)	0.40 (1.24)	0.293
			U6PP (mm)	25.27 (4.15)	24.50 (3.93)	−0.77 (1.42)	0.088
			L1MP (mm)	43.19 (4.75)	43.31 (5.29)	0.12 (2.38)	0.864
			L6MP (mm)	32.45 (3.70)	31.84 (4.03)	−0.61 (1.54)	0.197

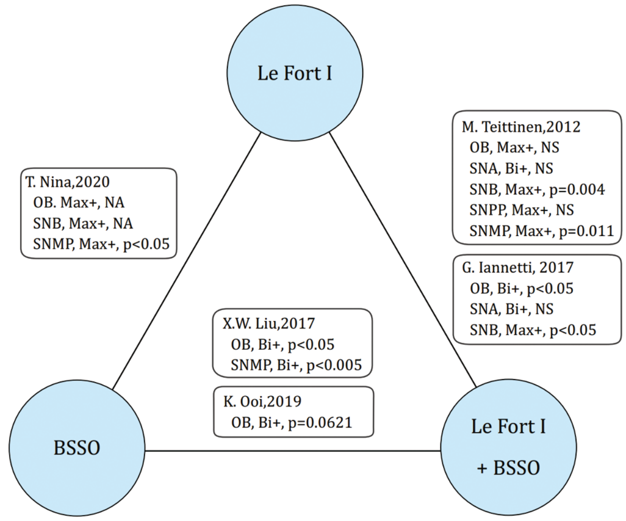

Figure 2. Direct comparison with controlled studies. Le Fort I: Le Fort I osteotomy; BSSO: bilateral sagittal split osteotomy; +: more increase in overbite or less relapse; L1–Me: distance between edge of lower incisor and menton point; FNO: Frequency of patients with No vertical Overlap; SNMP: angle between sella–nasion and mandibular plane; NS: no significance ($P \geq 0.05$).

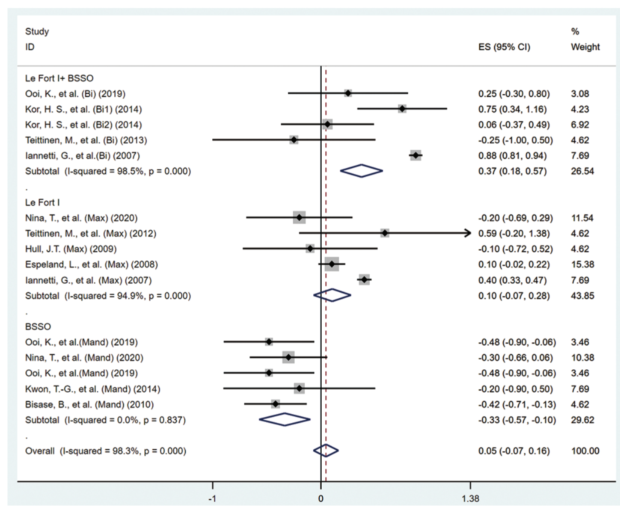

Figure 3. Pooled changes in overbite after surgery.

and some extent of relapse occurred in mandibular surgery. As for skeletal stability, bimaxillary surgery was more stable than maxillary surgery in SNA and SNPP. When it came to mandibular skeletal stability, SNB was highly stable in mandibular setback compared with mandibular advancement; as for mandibular plane, counterclockwise rotation in either mandibular or bimaxillary surgery was unstable compared with autorotation in maxillary surgery with a comparable amount of surgical correction. Furthermore, we verified that dento-alveolar compensation played an important role in maintaining positive overbite, regardless of orthognathic procedure.

To the best of authors' knowledge, few meta-analysis and systematic reviews have been conducted on the stability of orthognathic surgery in correcting SAOB (33, 34), and none of them focus on the hierarchical stability order of different orthognathic procedures. As current views are too controversial to reach a consensus, although no high-quality

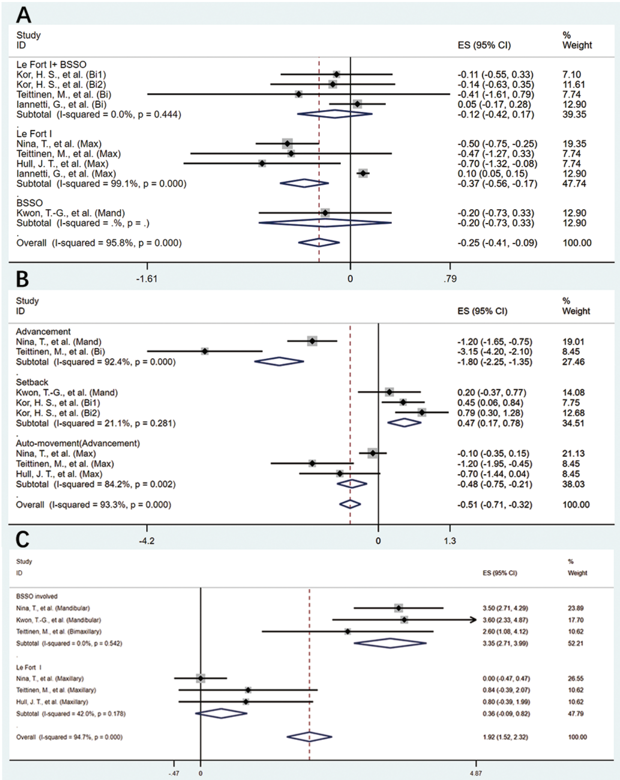

Figure 4. Postoperative skeletal stability. (A) Pooled SNA relapse. (B) Cumulative SNB relapse. (C) Pooled SNMP relapse.

clinical trials have been conducted, a quantitative summary based on currently available evidence could still provide some implications for clinical decision-making and insights for further research.

Before the advent of RIF, orthognathic surgery for SAOB was considered unstable (11, 35). As RIF ensures more stability in orthognathic surgery and has been routinely used therein (33, 36–38), we applied strict eligibility criteria to eliminate methodological heterogeneity and enrolled only studies that applied.

As for occlusional stability, both direct evidence from controlled studies (13, 25, 30) and indirect comparison by meta-analysis (2, 12–15, 18, 21, 28–30) illustrated that single mandibular surgery had some post-operative overbite relapse and was unstable compared with bimaxillary and maxillary surgeries. Despite the obvious heterogeneity within studies of bimaxillary and maxillary surgeries, it should be noted that most of them tended towards positive change compared with mandibular surgery. This could be explained by the elongation of the pterygomasseteric sling and elevator muscle after mandibular surgery (4, 12).

In terms of the skeletal stability of maxillae, it is suggested that vertical movement thereof, either superior repositioning of the posterior maxilla or downward movement of the anterior maxilla, poses the risk of undesirable reopening rotation after surgery (4, 14, 32). By contrast, Proffit *et al.* (17) classified downward movement of the maxilla as a problematic procedure, while finding maxillary upward movement to be very stable. In this study, both direct and indirect evidence proved that SNA and SNPP relapsed less in bimaxillary (12, 14, 29) than in maxillary (14, 28, 29) surgery. SNA was considered to be highly stable in bimaxillary surgery, leading to comparable or even fewer changes than non-maxillary surgical control (15). On the other hand, a statistically significant counterclockwise rotation of the PP plane was observed after surgery, especially in maxillary surgery (14, 30, 32).

In terms of mandibular stability, the studies of Gaitan-Romero *et al.* indicate more post-operative SNB relapse in individuals in skeletal Class II than in skeletal Class III (3, 19). Class II patients have also been found more likely to suffer vertical relapse than Class III patients after surgery (1, 15, 17). With the addition of different surgical directions, we evaluated SNB in three subgroups: mandibular setback (angle Class III), mandibular advancement, and auto-movement in mandibular surgery. In line with the findings given above, relapse of SNB happened the least in mandibular setback (angle Class III) (12, 15) compared with the other two subgroups (14, 28).

As for SNMP, several investigations believe that the risk of relapse increases when open bite is closed by decreasing the SNMP through BSSO procedure (39, 40) Similarly, we found maxillary surgery compared with bimaxillary surgery or single mandibular surgery based on direct and indirect evidence (13–15, 25, 28–30). Considering that previous study revealed a correlation between relapse and the amount of mandibular rotation during surgery (13, 15, 29), to avoid methodological bias, we divided studies into two groups: surgical change of SNMP above 3 degrees (14, 27) and below 3 degrees (15, 28). At a comparable level of surgical change, the application of mandibular surgery was correlated with a larger percentage of relapse (the percentage of mean relapse took in the mean magnitude of surgical movement: 124 and 66.7 per cent, separately) than separated maxillary surgery (33.3 and 21.1 per cent, separately).

In terms of dental-alveolar change, Espeland *et al.* states that post-operative incisor movements make a 50 per cent contribution towards the correction of open bite (18). In addition, compensatory post-operative eruption of anterior teeth has been observed in both arches of SAOB patients (3, 32). In the current investigation, we also found dento-alveolar changes to play an important role in preventing overbite relapse. Our data indicated that extrusion of incisors and intrusion of molars occurred after surgery, while dental changes could not be differentiated between post-operative orthodontics and self-compensation. Espeland *et al.* revealed a discrepant vertical alternation between upper incisors and anterior nasal spine point and lower incisors and Menton point (Me) in the first 6 months after surgery. Many patients wore appliances during this period, so movement of incisors seems to be more closely correlated with post-operative orthodontics (18). By contrast, Kor *et al.* reported an increase of overbite from 6 months to 1 year post-surgery (12). In addition, clinical relapse of open bite was observed both in the first 6 months post-surgery and during a 2.5-year follow-up period (4); this indicated that dental-alveolar compensation, whether originating from orthodontics or self-compensation, could only partly counteract the recurrence of open bite.

Limitations

The results and conclusions of this investigation must be adopted with caution, taking the following limitations of study design, quality problems, and statistical methods into consideration:

1. Regarding study design, there was no randomized clinical trial on the stability of orthodontic–orthognathic treatments in combination with RIF in correcting SAOB. In addition, no study used 3D techniques to assess post-operative stabilities.
2. There was heterogeneity among included subjects, especially in measurement and randomized selection. Therefore, we suggest more rigorous design in future studies.
3. The mean change could only present the overall stability. In fact, significant relapse occurred only in a small portion of patients.

Conclusions

This study compared vertical stability among maxillary, mandibular, and bimaxillary surgeries for SAOB on the aspects of occlusional, skeletal, and dento-alveolar changes. The following conclusions can be made based on current evidence:

1. At the occlusional level, the most beneficial post-operative overbite increase was observed in bimaxillary surgery. Maxillary surgery led to less but still positive overbite change. Mandibular surgery was correlated with some extent of overbite relapse.
2. In terms of skeletal stability, bimaxillary surgery was more stable than maxillary surgery in SNA and SNPP. SNB was highly stable in mandibular setback compared with mandibular advancement. As for SNMP, counterclockwise rotation in either mandibular or bimaxillary surgery was less stable than autorotation in maxillary surgery with a comparable amount of surgical correction.
3. Dento-alveolar compensation (extrusion in the anterior region and intrusion in the posterior region) contributed to counteracting skeletal relapse and maintaining positive overbite.

Supplementary material

Supplementary material is available at *European Journal of Orthodontics* online.

Supplementary File 1. Search Strategy.

Supplementary Figure 1. Dentoalveolar stability A. Postoperative change in U1PP (mm). B. Postoperative change in U6PP (mm). C. Postoperative change in L1MP (mm). D. Postoperative change in L6MP (mm).

Supplementary Table 1. Summary of descriptive characteristics of included studies.

Supplementary Table 2. Data of direct comparisons among controlled studies.

Supplementary Table 3. Assessment of risk of bias.

Supplementary Table 4. GRADE summary of findings.

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Conflict of interest

None to declare. We declare that none of us have any financial and personal relationships with other people or organizations that can inappropriately influence our work, there was no professional or other personal interest in our work.

Registration

The protocol of this systematic review and meta-analysis was registered in the US National Institute of Health's (NIH; Bethesda, Maryland, USA) International Prospective Register of Systematic Reviews (PROSPERO) research database (https://www.crd.york.ac.uk/prospero/; Trial Registration No. PROSPERO CRD42020198088)

Data availability

The data for this article are available herein and in the online supplementary material.

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