Original Article

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Comparing maxillary surgical accuracy in mandible-first and maxilla-first sequencing for bimaxillary orthognathic surgery: a retrospective study in facial asymmetry patients

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Objective: This study aimed to compare the surgical accuracy of the maxilla between the maxilla- and mandible-first sequence bimaxillary orthognathic surgery for facial asymmetry patients

Materials and Methods: A retrospective cohort study was conducted on forty patients with skeletal asymmetry of the jaw(s) who underwent bimaxillary orthognathic surgery. The patients were evenly divided into the maxilla-first and mandible-first sequence groups. Surgical accuracy of the maxilla was determined by comparing the maxillary position in immediate postoperative cone beam computed tomography images to the simulated surgical plans. Three linear measurements using seven reference points and three angular measurements (roll, pitch, and yaw) were performed. Statistical analysis, including the independent samples t-test and the Mann-Whitney U test, was used to compare the means and medians between the two groups. The level of significance was set at $p < 0.05$.

Results: The accuracy of the maxilla, as measured by linear measurements, showed no significant differences between the two groups (p = 0.05–0.92). On the other hand, significant differences were observed in the roll and yaw rotations, with p-values of 0.03 and 0.04, respectively. In the anteroposterior direction, the greatest inaccuracy was found at the MB cusp of tooth 26 in the maxilla-first group (mean deviation 1.42 ± 0.86 mm) and at the MB cusp of tooth 16 in the mandible-first group (mean deviation 1.47 ± 0.79 mm).

Conclusions: The accuracy of the maxilla after bimaxillary orthognathic surgery in patients with skeletal asymmetry was comparable between the maxilla-first and mandible-first sequencing techniques. The statistically significant differences found in the roll and yaw axes were not clinically relevant. Similar postoperative accuracy and intraoperative benefits suggest that the mandible-first sequence may be the preferred technique in patients with skeletal asymmetry.

Keywords: dentofacial deformities, Lefort osteotomy, orthognathic surgical procedure, prognathism, sagittal ramus osteotomy,

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Introduction

Facial asymmetry, defined as an imbalance or disproportion between the right and left sides of the face, is one of the most common concerns among patients undergoing orthognathic surgery [1]. In bimaxillary orthognathic surgery, Le Fort I osteotomy and BSSO (bilateral sagittal split osteotomy) are the most widely used techniques for correcting dentofacial deformities. The conventional (maxilla-first) surgical sequencing begins with maxillary surgery using Le Fort I osteotomy, followed by the BSSO in the mandible. In 1978, the mandible-first approach was introduced,

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starting the operation on the mandible while using the intact maxilla as a stable reference [2]. This approach gained traction after the widespread adoption of internal rigid fixation in orthognathic surgery, a necessary component for successful mandible-first procedures. Consequently, the debate regarding the optimal jaw sequencing order has gained interest.

Comparisons between maxilla-first and mandible-first sequencing techniques have primarily focused on accuracy and indications [2-13]. While many studies have reported no significant differences [3, 4, 6, 9-11], the mandible-first approach has been suggested to improve surgical accuracy, particularly in patients exhibiting conditions such as down grafting of the posterior maxilla, unclear interocclusal registration, difficulties with intraoperative maxillomandibular fixation in the interim position, non-rigid maxillary fixation, or concomitant TMJ (temporomandibular joint) surgery [8, 14].

Mandible-first sequencing can be particularly beneficial in specific situations, such as multisegmental Le Fort I osteotomy, large maxillomandibular advancements, and cleft lip repairs [13]. Additionally, Cottrell and Walford (1994) highlighted its advantages in addressing complex facial asymmetry and reporting satisfactory outcomes [4].

However, the use of this approach in cases of asymmetric skeletal deformities remains underreported, and concerns about the maxillary accuracy of mandible-first sequencing persist. Furthermore, potential disadvantages of this method include an increased risk of operational failure in the event of a bad split and the possibility of secondary posterior open bite following counterclockwise rotational advancements [15].

This study aimed to compare the surgical accuracy of the maxilla between the mandible-first and maxilla-first approaches in patients with facial asymmetry. The null hypothesis was that there is no statistically significant difference in the accuracy of the maxilla between these two sequencing methods.

Materials and Methods

This study was approved by the Institutional Review Board of the Faculty of Dentistry/Faculty of Pharmacy, Mahidol University (Approval number: COA.NO.MU-DT/PY-IRB 2022/017.0604). This retrospective cohort study included patients who underwent bimaxillary osteotomy surgery performed by the same surgical team at the Oral and Maxillofacial Surgery department, Faculty of Dentistry, Mahidol University, between January 2018 and July 2022.

The inclusion criteria were patients with facial asymmetry exhibiting ≥ 2 mm of upper and/or lower midline deviation, ≥ 2 mm menton deviation from the facial midline, or ≥ 2 mm of maxillary canting. Exclusion criteria included patients who: (1) underwent mandibular jaw surgery other than BSSO; (2) lacked postoperative CT scans; (3) had concomitant TMJ surgery; (4) underwent maxillary or mandibular segmentation; (5) experienced unfavorable fractures during mandibular osteotomy; or (6) had syndromic craniofacial deformities.

After applying the inclusion and exclusion criteria, a total of 40 cases were included; 20 cases of mandible-first sequencing were identified within the study period, all of which were included in this study as Group 2. For the maxilla-first sequencing group, 20 eligible patients were randomly selected to form Group 1. Patient data, including age, sex, deformity diagnosis, midline discrepancy, menton deviation, maxillary canting, and surgical techniques, were collected from patient records.

For patients undergoing the maxilla-first sequence, Le Fort I osteotomy was performed following the surgical simulation plan. An intermediate splint was utilized along with intermaxillary vertical elastics to establish the maxillomandibular complex. Premature bony interferences were removed to eliminate interference between segments. Once the maxilla was positioned as planned, osteosynthesis was completed using 4 mini plates and 16 screws. After completing osteosynthesis of the maxilla, BSSO was then performed as guided by the final splint. The proximal mandibular segments were carefully repositioned posteriorly and superiorly to ensure proper seating of the condyles within the glenoid fossa. Any premature contact between the proximal and distal segments of the mandible was meticulously trimmed to achieve a precise fit. Mini plates and screws were applied to stabilize the mandibular body and secure osteosynthesis. On the other hand, in the mandible-first sequence, BSSO was performed first, using the intermediate splint to guide the planned mandibular movement, followed by Lefort I osteotomy of the maxilla, utilizing the final splint to ensure alignment.

Surgical accuracy was evaluated by superimposing the immediate postoperative CBCT (cone beam computed tomography) image acquired within 1 month after the operation onto the virtual surgical planning image and measuring deviations.

First, the immediate postoperative CBCT (Digital Imaging and Communications in Medicine, DICOM) file was obtained using a KODAK 9500 cone-beam 3D system [parameters: 90 kVp, 5 mA; field of view: 18 cm (height) × 20.6 cm (diameter); scanning time: 10.8 seconds; voxel size: 0.3 × 0.3 × 0.3 mm^3]. This file was then imported into ProPlan software version 3.0 (Leuven, Belgium) and converted into an STL (stereolithography) file.

Next, the virtual surgical planning STL file, generated from the preoperative CBCT DICOM file by Dolphin Imaging software version 11.95.08.58 (California, USA), was imported into ProPlan. The postoperative CBCT image was superimposed onto the virtual surgical planning STL file using a surface-based method, with the FH (Frankfort horizontal) plane as the reference (Figure 1). A region of interest on the skull base, outside the surgically treated region, was selected for the matching.

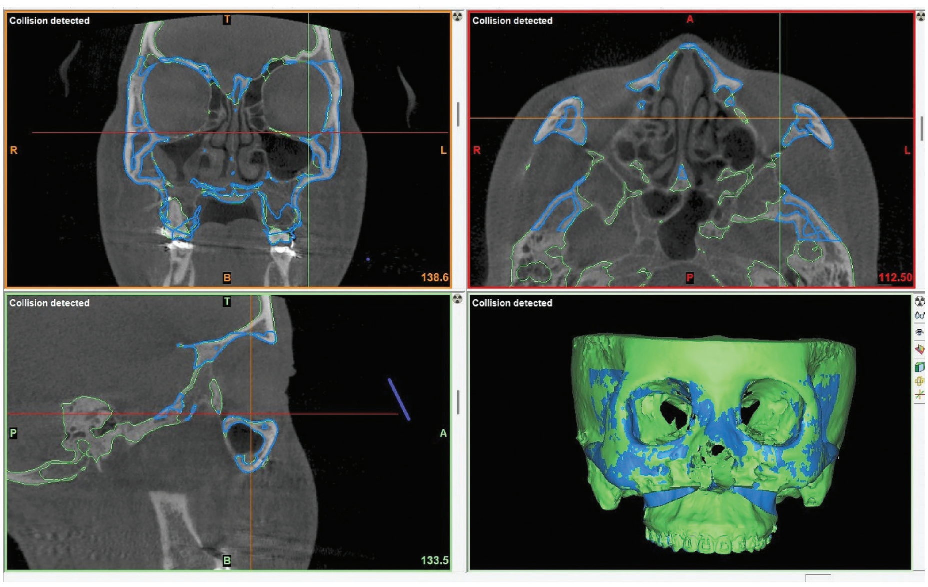

Figure 1 Superimposition of postoperative CBCT (Converted to STL file) and surgical virtual planning (STL file)

Finally, linear and angular deviations between the actual postoperative outcomes and the virtual planning were measured using ProPlan software. The methods were similar to those used in studies by Bozok et al. and Borikanphanitphaisan *et al.* [3, 16].

Linear deviation was evaluated in three directions—vertical, anteroposterior, and transverse (Figure 2) according to the axis —at seven reference points: the MB (mesiobuccal) cusp of tooth 16 (maxillary right first molar), cusp tip of tooth 13 (maxillary right canine), mid-incisal edge of tooth 11 (maxillary right central incisor), cusp tip of tooth 23 (maxillary left canine), MB cusp of tooth 26 (maxillary left first molar), ANS (anterior nasal spine), and A-point (Figure 3).

Angular deviation was assessed in three rotational directions: roll, pitch, and yaw (Figure 4). Roll rotational deviation was evaluated by measuring the angle between the virtual plan and postoperative intercanine lines in the coronal view. Pitch rotation was determined by calculating the difference between the virtual plan and postoperative FH plane-occlusal plane angle in the sagittal view. Yaw rotation was evaluated by measuring the angle between the virtual plan and postoperative intermolar lines in the axial view (Figure 4).

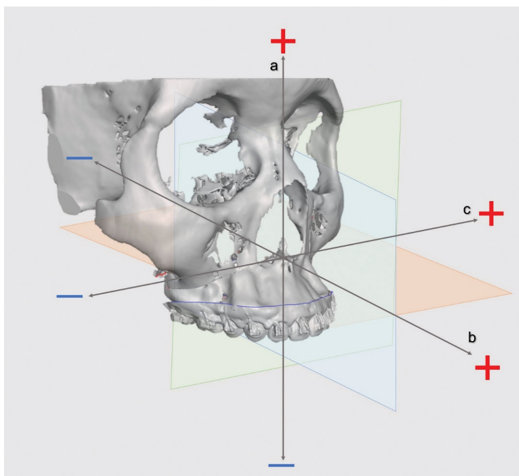

Figure 2 Linear measurement. (a) Vertical (b) Anteroposterior (c) Transverse

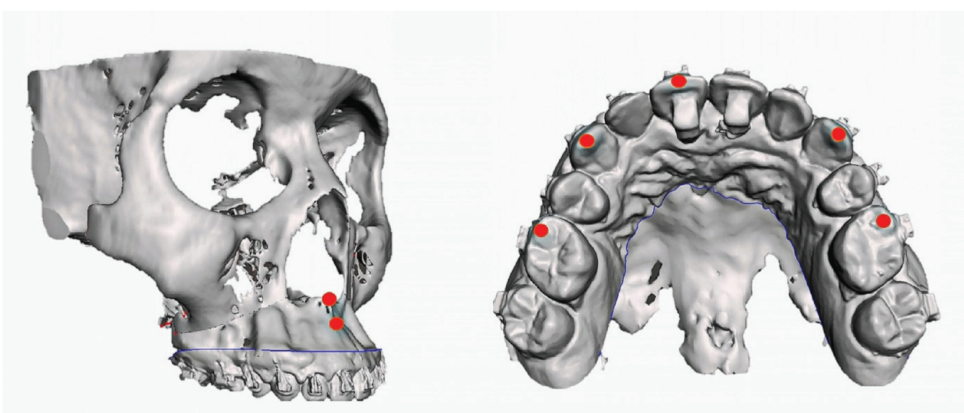

Figure 3 Seven reference points (Red dot): ANS; A point; MB cusp of Tooth 16; Cusp tip of tooth 13; Mid-incisal edge of tooth 11; Cusp tip of tooth 23; MB cusp of Tooth 26

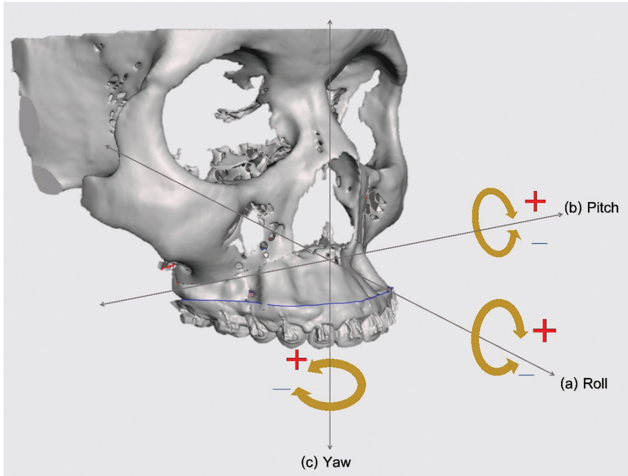

Figure 4 Angular measurement. (a) Roll (b) Pitch (c) Yaw

Before evaluation, intra- and inter-examiner reliability was assessed in ten randomly selected cases. For statistical analysis, normality was tested using the Shapiro-Wilk test and histogram analysis. When the data distribution was normal, independent samples t-tests were employed to analyze mean differences between groups; otherwise, Mann-Whitney U tests were applied. The significance level was set at $p < 0.05$. Statistical analysis was conducted using SPSS software (IBM SPSS Statistics 19.0, SPSS Inc., Chicago, USA).

Results

A total of 40 patients were enrolled, with 20 assigned to each group based on surgical sequencing. The average age in both groups was approximately 25 years. The male-to-female ratio was 9:11 in the maxilla-first group and 7:13 in the mandible-first group; differences in age and sex were not statistically significant ($p = 0.89$ and $p = 0.52$, respectively). Most patients exhibited skeletal class III deformities, with maximum asymmetry reaching up to 8 mm. Regarding lower dental midline deviation exceeding 4 mm, 2 cases were observed in the maxilla-first group and 5 in the mandible-first group (Table 1). Good to excellent inter- and intra-rater reliability was demonstrated, with ICC (intraclass correlation coefficient) values ranging from 0.75 to 0.99 for inter-rater reliability and 0.87 to 0.99 for intra-rater reliability.

Linear Deviation

In the anteroposterior direction, there were no significant differences in linear measurements at seven reference points between the groups (p = 0.05–0.87). The largest mean deviation was observed at the MB cusp of tooth 26 in the maxilla-first group (1.42 ± 0.86 mm) and at the MB cusp of tooth 16 in the mandible-first group (1.47 ± 0.79 mm).

Table 1 Patient demographics

Characteristic	Maxilla-First n (%)	Mandible-First n (%)	*p-Value*
N	20	20	
Sex			
Male	9(45)	7(35)	0.52[†]
Female	11(55)	13(65)	
Age; years (Mean ± SD)	25.4 ± 4.36	25.2 ± 4.54	0.89[‡]
Diagnosis of deformity			
Skeletal class I	2(10)	1(5)	
Skeletal class II	1(5)	-	
Skeletal class III	17(85)	19(95)	
Lower dental midline deviation (mm.)			
0-2	11(55)	9(45)	
>2-4	7(35)	6(30)	
>4	2(10)	5(25)	

[†] χ^2 test

[‡] Independent T-test

Vertical deviation measured at teeth 13, 16, and 26 cusp tips showed non-normal distribution; thus, Mann-Whitney U tests were used for group comparisons. The *p*-values indicated no statistically significant differences at any reference points, whether analyzed with the independent t-test (p = 0.2–0.25) or the Mann-Whitney U test (p = 0.57–0.92). Normally distributed means of deviations ranged between 0.72-0.92 mm for the maxilla-first and 0.98-1.19 mm for the mandible-first groups. The medians of the non-normally distributed data ranged between 0.63-0.67 mm and 0.63-1.15 mm for the maxilla-first and mandible-first groups, respectively.

In the transverse direction, no significant differences were noted between groups (p = 0.18-0.68). The means of deviations varied between 0.88 and 1.37 mm, with the largest deviation at the mid-incisal edge of tooth 11 (1.37±0.61 mm) in the maxilla-first group. In the mandible-first group, the means of deviations ranged between 1.11 and 1.21 mm, with the greatest at A point (1.21±0.74 mm) (Table 2).

Angular Deviation

For roll rotation, the respective medians of deviations of the maxilla-first and mandible-first sequencing were 0.3° and 0.95°, showing a statistically significant difference (p = 0.03). Similarly, the Mann-Whitney U test revealed a statistically significant difference in medians between the two groups for yaw rotation (p = 0.04). The medians of deviations in yaw rotation for the maxilla-first and mandible-first sequencing were 1.25° and 2.80° respectively. However, no significant difference was observed in pitch rotation (p = 0.77) (Table 2).

Table 2 Absolute Mean or Median Differences for Between-Group Comparison of skeletal and dental landmarks between maxilla-first and mandible-first sequencing

			Mean (Mean (SD) / Median (P25,P75)) of deviations†		*p - value*
			Maxilla-First (n=20)	Mandible-First (n=20)	
Linear measurement (mm)	Anteroposterior	A point	1.20 (0.82)	1.28 (0.74)	0.76
		ANS	1.26 (0.84)	1.22 (0.73)	0.87
		11	1.14 (0.94)	0.94 (0.63)	0.44
		13	1.12 (0.80)	1.31 (0.68)	0.43
		16	1.21 (0.72)	1.47 (0.79)	0.29
		23	1.28 (0.83)	0.88 (0.50)	0.08
		26	1.42 (0.86)	0.96 (0.52)	0.05
	Vertical	A point	0.72 (0.59)	0.99 (0.71)	0.2
		ANS	0.73 (0.6)	0.98 (0.73)	0.25
		11	0.89 (0.63)	1.17 (0.87)	0.25
		13	0.63 (0.31,0.96)	0.99 (0.21,1.58)	0.57
		16	0.67 (0.26,1.03)	0.63 (0.22,1.72)	0.92
		23	0.92 (0.69)	1.19 (0.63)	0.21
		26	0.66 (0.38,1.70)	1.15 (0.43,1.51)	0.75
	Transverse	A point	0.93 (0.62)	1.21 (0.74)	0.2
		ANS	0.88 (0.65)	1.20 (0.80)	0.18
		11	1.37 (0.61)	1.11 (0.77)	0.25
		13	1.22 (0.50)	1.13 (0.84)	0.68
		16	1.03 (0.50)	1.20 (0.72)	0.39
		23	1.22 (0.52)	1.13 (0.83)	0.68
		26	1.02 (0.52)	1.14 (0.76)	0.58
Angular measurement (degree)		Roll	0.3 (0.03,0.83)	0.95 (0.50,2.00)	**0.03***
		yaw	1.25 (0.43,2.10)	2.80 (0.68,3.88)	**0.04***
		Pitch	0.90 (0.13,2.33)	0.65 (0.10,2.60)	0.77

† The difference between the treatment plan simulation and the actual surgical outcome was converted to a positive value before calculating the average

* Statistically significant ($p < 0.05$)

A comparison of the linear and angular measurement medians between the two groups of patients with mandibular asymmetry and a lower midline deviation ≥ 2 mm is presented in Table 3. There were no statistically significant differences in the linear measurements found at each reference point in all directions (p = 0.11-0.98) and all angular measurements (p = 0.05, 0.63), except for roll rotation (p = 0.04)

Table 3 Absolute Median Differences for Between-Group Comparison of skeletal and dental landmarks between maxilla-first and mandible-first sequencing in patients with lower dental midline deviation ≥ 2 mm

			Median (P25,P75) †		*p-value*
			Maxilla-First (n=13)	Mandible-First (n=15)	
Linear measurement (mm)	Anteroposterior	A point	1.26 (0.60,2.15)	1.16 (0.61,1.91)	0.85
		ANS	1.60 (0.58,2.20)	1.06 (0.66,1.79)	0.87
		11	1.21 (0.41,2.08)	0.79 (0.30,1.34)	0.33
		13	1.41 (0.33,1.98)	1.13 (0.61,1.79)	0.98
		16	1.58 (0.47,2.11)	1.67 (0.64,2.03)	0.98
		23	1.15 (0.62,2.29)	0.73 (0.40,1.23)	0.14
		26	1.04 (0.64,2.41)	0.74 (0.50,1.34)	0.23
	Vertical	A point	0.56 (0.22,1.24)	0.94 (0.42,1.70)	0.17
		ANS	0.55 (0.22,1.16)	0.93 (0.56,1.62)	0.17
		11	0.55 (0.22,1.48)	1.11 (0.43,2.00)	0.15
		13	0.49 (0.22,0.90)	0.96 (0.19,2.10)	0.45
		16	0.50 (0.20,1.03)	0.62 (0.21,1.61)	0.91
		23	0.68 (0.19,1.51)	1.20 (0.79,1.72)	0.21
		26	0.71 (0.40,1.75)	1.21 (0.51,1.53)	0.60
	Transverse	A point	0.79 (0.40,1.54)	1.12 (0.34,1.79)	0.61
		ANS	0.79 (0.34,1.40)	1.21 (0.36,2.01)	0.37
		11	1.21 (1.02,1.77)	0.73 (0.59,1.22)	0.11
		13	1.00 (0.91,1.48)	0.77 (0.36,1.58)	0.17
		16	0.78 (0.60,1.35)	1.11 (0.64,1.49)	0.32
		23	0.98 (0.88,1.51)	0.74 (0.51,1.41)	0.15
		26	0.80 (0.57,1.28)	1.09 (0.60,1.50)	0.49
Angular measurement (degree)		Roll	0.30 (0.05,0.50)	0.80 (0.10,1.30)	**0.04***
		yaw	0.90 (0.45,2.00)	2.80 (0.90,3.80)	0.05
		Pitch	1.00 (0.20,3.05)	0.80 (0.10,2.70)	0.63

† The difference between the treatment plan simulation and the actual surgical outcome was converted to a positive value before calculating the average

* Statistically significant ($p < 0.05$)

Discussion

Achieving satisfactory outcomes in orthognathic surgery for facial asymmetry correction requires accurate diagnosis, meticulous surgical planning, and appropriate techniques, often aided by advanced technologies such as 3D (three-dimensional) virtual planning. This technology has become essential, especially for complex skeletal deformities, and is also valuable for evaluating surgical accuracy with high precision.

Several studies have compared the accuracy of different surgical sequencing techniques, discussing the topic from various perspectives such as indications, surgical techniques, and outcomes [2, 3, 5, 6, 8-11, 14, 16] The mandible-first sequence is frequently used when the surgical plan involves counterclockwise rotation of the maxillomandibular unit [6, 8, 11, 14]. However, the choice of sequencing largely depends on surgeon preference. While concerns have been raised regarding the accuracy of maxillary repositioning using the operated mandible as a reference in the mandible-first method, prior research has shown comparable accuracy between both techniques when appropriate case selection is applied. Bozok *et al.* reported that VSP (virtual surgical planning) achieves high accuracy in both the sagittal and coronal planes, regardless of whether maxilla-first or mandible-first sequencing is performed [16]. Ritto *et al.* favored the mandible-first technique, citing its ability to minimize bite registration errors, ensure accurate TMJ positioning, and reduce joint edema [9].

Conversely, other authors have reported greater accuracy with the maxilla-first sequence [6, 10, 11]. Liebregts *et al.* noted that the mandible-first method required double TMJ seating, which may compromise surgical precision. They concluded that the mandible-first technique is more predictable in specific scenarios, such as counterclockwise rotation of the maxillomandibular complex [6].

This study compared the surgical accuracy of the maxilla between the maxilla-first and mandible-first groups using CBCT, focusing on linear and angular measurements. No significant differences were found in linear measurements across all directions. The maximum mean deviation in both groups was 1.47 mm, consistent with findings from a recent study [3] . However, significant differences were observed in the medians of angular deviations for roll and yaw measurements, with a maximum median angular deviation of 2.80°. Despite these differences, the linear and angular inaccuracies in both groups were within clinically acceptable thresholds of ≤2 mm and ≤4°, respectively [3]. Notably, no reoperations for maxillary position correction were required in this study.

Anterior and transverse maxillary positions were guided using a surgical splint, while the vertical position was controlled through clinical measurement. Previous reports have investigated vertical accuracy using external and internal references for intraoperative maxillary positioning [17-21]. In this study, four internal reference points (at the canines and first molars) were used for evaluation by the same surgical team. The largest mean vertical deviation, observed at the cusp tip of tooth 23 in the mandible-first group, was 1.19 ± 0.63 mm, which is considered clinically insignificant.

Focusing on facial asymmetry patients with a lower dental midline deviation of ≥ 2 mm, no statistically significant differences were found in linear measurements. Angular measurements differed significantly only in the roll axis. The minor inaccuracies observed in both groups support the mandible-first technique as an accurate and favorable alternative to the conventional sequence for skeletal asymmetry cases.

The stability of the mandible is critical for the mandible-first sequence. Accurate repositioning of the maxilla using the operated mandible as a reference requires consistent mandibular movement without condylar torque. Eliminating bony interferences between proximal and distal segments before passively seating the condyles in the articular fossa—prior to fixation with miniplates and screws—is essential. Another potential concern is mandibular stability as a reference for maxillary repositioning if unexpected mandibular fractures occur, which could disrupt the operation. However, the reported incidence of unfavorable splits is low (1.81–5%) [22, 23]. According to our practice, no unexpected fractures prevented the completion of any operations.

In patients with mandibular asymmetry, any part of the mandible—chin, body, or ramus, along with the overlying soft tissue—may be affected. The surgical plan should prioritize establishing a symmetric skeletal framework. In the mandible-first method, BSSO with complete removal of bony interferences and proper vertical and parallel positioning of the rami, provided improved symmetry and minimized soft tissue distortion. This sequence facilitated the correction of asymmetric cheeks, chin prominence, and lip asymmetry (including differing mouth corner levels, vermilion border distortion, and lip midline deviation) before Le Fort I osteotomy, making intraoperative assessment of maxillary position, particularly midline alignment and canting, easier than with the conventional sequence [24].

Although mandible-first sequencing has been increasingly performed in skeletal asymmetry cases, the number of studies remains limited [4, 25]. Although patients in this study showed lower dental midline deviations of up to 8 mm, few had severe asymmetry. Further research involving larger sample sizes and cases of more pronounced asymmetry is needed to better understand the implications of surgical sequencing in this population.

Conclusion

The accuracy of the maxilla between both sequencing methods in patients with skeletal asymmetry was comparable from a clinical perspective. Although the result showed a statistically significant difference in angular movements, the magnitude of inaccuracy was too small to be clinically significant. The mandible-first sequencing method offers certain advantages when appropriate case selection, surgical planning, and intraoperative techniques are applied. Future studies with larger sample sizes and a broader range of asymmetry severity are warranted to further explore the impact of surgical sequencing on outcomes.

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