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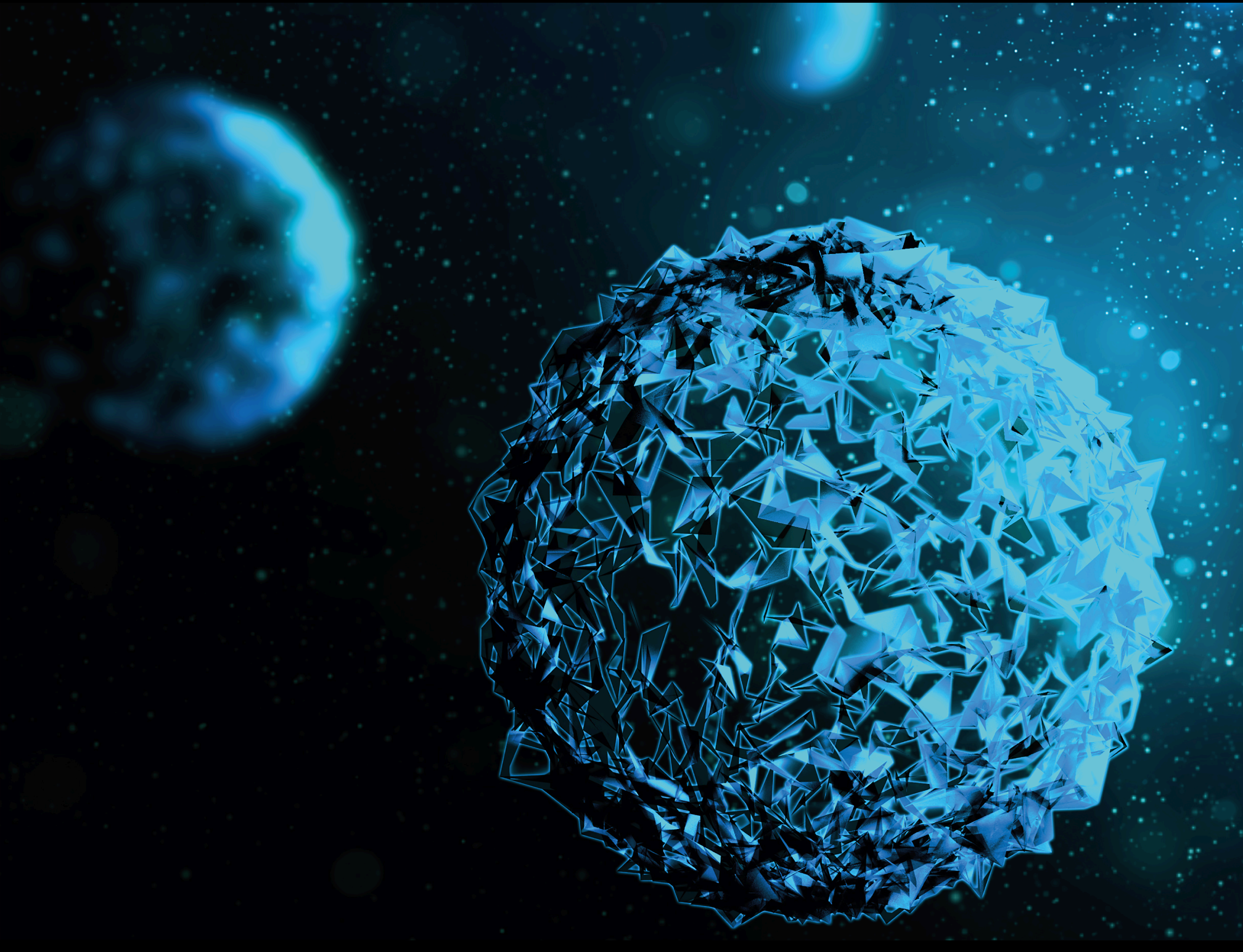

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Contents

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Research Article

Three-Dimensional Outcome Assessments of Surgical Correction in Cleft and Noncleft Patients with Class III Skeletal Relation: A Case-Control Study

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Background. The orthognathic strategies to treat patients with a concave profile but different tissue conditions remain controversial. The aim of this case-control study was to investigate the outcome predictability of orthognathic surgery in cleft lip and palate (CLP) patients and matched controls. *Methods*. Fifty consecutive CLP and 45 matched non-CLP patients who received whole-piece Le Fort I and bilateral sagittal split osteotomy to correct class III skeletal relations were enrolled. The outcome discrepancies (ODs) from simulations among all groups were evaluated with consideration of the possible influences from planned surgical movements (PSM). Receiver operating characteristic curves were used to determine threshold values of PSMs that yielded clinically relevant OD. *Results*. Unilateral CLP (UCLP) patients had comparable postsurgical OD to non-CLP patients in both jaws, whereas bilateral CLP (BCLP) patients had greater deviations from predicted results. Vertical movement of the A − point > 1.33 mm and yaw correction > 1.65° in the BCLP patients was associated with clinically relevant maxillary OD. *Conclusions*. The OGS outcomes of BCLP patients were less predictable than those of the UCLP and noncleft patients. Vertical movements of the A − point > 1.33 mm and yaw correction > 1.65° in BCLP patients increased OD to a clinically relevant extent.

1. Introduction

Orthognathic surgery (OGS) is the treatment of choice for patients with excessive skeletal discrepancies [1, 2]. Extraordinary midface retrusion is a well-recognized phenomenon in cleft lip and palate (CLP) patients. Given the desire to recover or enhance facial aesthetics, the predictability of surgical results is a strong concern for surgeons, orthodontists, and patients. However, OGS is usually more challenging in CLP patients than in non-CLP patients because of the remarkable postsurgical relapse [3, 4]. Although two-jaw surgery can provide functional harmony with correction of the maxillomandibular complex (MMC) [5], soft tissue tension and bony segment instability inherently influence the postsurgical stability of CLP patients [6].

Conventionally, it is assumed that the postsurgical changes would differ between CLP and non-CLP patients. Nevertheless, existing evidence did not fully support such an assumption [6, 7]. For instance, maxillary advancement, the major component in treatments of patients with class III jaw relation, is ranked as "stable" in bimaxillary procedures of non-CLP patients. However, the so-called "stable" procedure is associated with a diverse relapse rate ranging from 25% to 49% [8]. On the other hand, in CLP patients, a 37% rate of horizontal relapse was reported in an earlier review [9]. Such controversial results [8, 9] implied that the actual impacts from inherent tissue defects and strain of CLP patients were not clearly revealed.

There have been only a few case-control studies to investigate how tissue disharmony affects the orthognathic

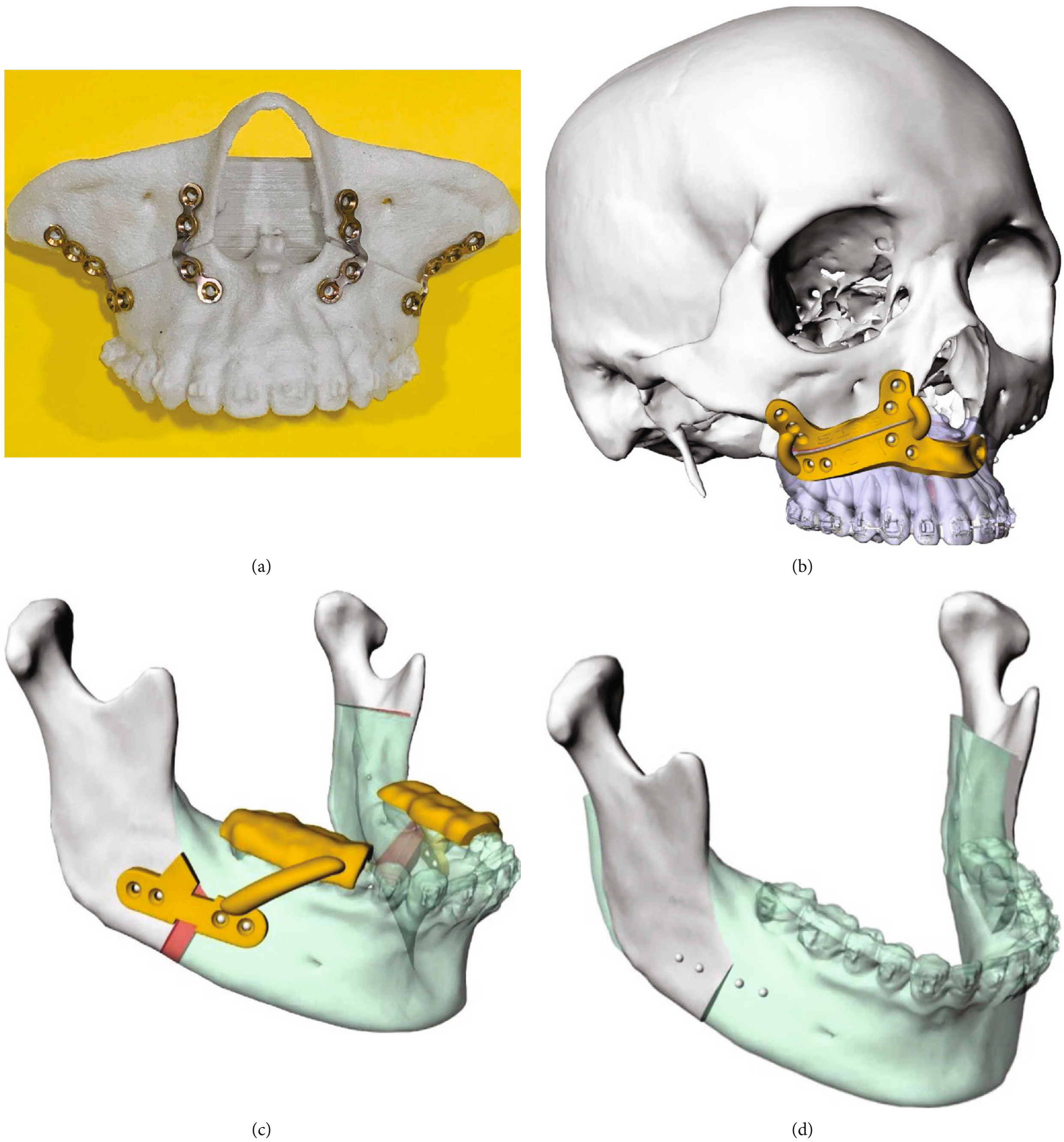

Figure 1: (a) Reverse engineering was applied to fabricate the surgical guide. A stereolithographic model demonstrating the planned maxillary reposition was produced. The fixation miniplates serving as the guiding plate (the 2nd guiding plate) were prebent according to the plate holes marked on the model. (b) Anterior nasal spine (ANS) and infrazygomatic crest (IZC) were used as reference structures for designing the guiding plate on the presurgical virtual maxilla. (c, d) The mandibular guiding plates were also fabricated according to the final position of MMC to provide predicted amounts of the movements of the mandibular segments intraoperatively.

outcomes in CLP patients [6, 10]. Based on the postsurgical results of patients receiving only maxillary advancement, comparable relapse tendency was reported between unilateral CLP (UCLP) patients and noncleft patients [6]. On the other hand, with concomitant porous-block hydroxyapatite grafting, Mehra et al. also reported similar outcome predictability in two-jaw surgeries among CLP and non-CLP patients [10].

The controversial results against the common acknowledgements might result from the limitation of traditional cephalometric assessments. The surgical plans of CLP patients have been reported to be unable to completely fulfill the simulated goals intraoperatively by conventional two-dimensional evaluation [11]. Not until development of three-dimensional surgical simulation (3DSS) has the actual difference from the planned jawbone position been able to be determined [12, 13, 14].

Therefore, the aim of this study was to assess the OGS outcomes of CLP patients by using a case-control design.

Figure 2: The virtual triangles representing orientation of the maxilla in different stages (yellow: simulation, blue: 6-month outcome) were used for the outcome assessments. All the three-dimensional images were registered on the same coordination system.

Table 1: The angular and translational outcome differences from simulation models of all samples (one-sample t-test).

Groups	Non-CLP (45)		BCLP (17)		UCLP (33)	
Outcome discrepancy	Mean	P value	Mean	P value	Mean	P value
Translational (mm)						
A-X	0.66 ± 0.53	0.000*	0.69 ± 0.53	0.000*	0.61 ± 0.48	0.000*
A-Y	0.69 ± 0.73	0.000*	1.15 ± 0.83	0.000*	0.96 ± 0.89	0.000*
A-Z	0.73 ± 0.66	0.000*	1.38 ± 1.39	0.000*	0.83 ± 0.68	0.000*
MxR-X	0.61 ± 0.44	0.000*	0.80 ± 0.66	0.000*	0.71 ± 0.52	0.000*
MxR-Y	1.08 ± 0.95	0.000*	1.72 ± 1.14	0.000*	1.06 ± 0.93	0.000*
MxR-Z	0.99 ± 0.71	0.000*	0.93 ± 0.70	0.000*	1.08 ± 0.91	0.000*
MxL-X	0.63 ± 0.48	0.000*	0.84 ± 0.76	0.000*	0.69 ± 0.49	0.000*
MxL-Y	0.75 ± 0.75	0.000*	1.31 ± 1.11	0.000*	1.20 ± 1.14	0.000*
MxL-Z	1.12 ± 0.74	0.000*	1.62 ± 1.02	0.000*	1.23 ± 0.80	0.000*
Angular (°)						
Roll	0.94 ± 0.81	0.000*	1.34 ± 0.88	0.000*	1.16 ± 0.77	0.000*
Pitch	1.97 ± 1.62	0.000*	2.64 ± 2.86	0.000*	2.34 ± 1.71	0.000*
Yaw	1.07 ± 0.86	0.000*	1.72 ± 1.13	0.000*	1.13 ± 0.87	0.000*

*The mean difference is significant at the 0.05 level.

The central hypothesis was that there is no difference in the outcome predictability between CLP and non-CLP patients.

2. Materials and Methods

In this study, the medical records of 200 consecutive patients who underwent OGS from January 2013 to September 2017 at the Craniofacial Center of Kaohsiung Chang Gung Memorial Hospital (Kaohsiung, Taiwan) were retrospectively reviewed. A total of 45 healthy non-CLP adult patients with mandibular prognathism and 50 nonsyndromic CLP adult patients met the inclusion criteria for analysis. All patients underwent whole-piece Le Fort I osteotomy and bilateral segmental sagittal osteotomy (BSSO) to correct jawbone discrepancies with the use of 3DSS. Patients with syndromic craniofacial disorders and those who underwent multipieced maxillary osteotomy, posttraumatic reconstruction, facial reconstruction, or modified surgical planning intraoperatively were excluded. The study protocol was approved by the Institutional Review Board of Kaohsiung Chang Gung Memorial Hospital (approval no. 201701645B0).

2.1. Data Retrieval and Processing. All the images were retrieved from medical CT (Aquilion, Toshiba Corp., Tokyo, Japan) (120 kVp; 350 mA; rotation time, 0.5 s; slices thickness, 0.5 mm) three weeks before the OGS. The Rhinoceros 5.0 (Robert McNeel & Associates, Seattle, Wash.) and Geomagic Studio (12th edition; Geomagic, Inc., Cary, N.C.) were used for image processing and virtual planning. The tentative plans were validated by setting the final occlusion of MMC checked by senior orthodontists. The final orientation and

Table 2: Comparison of the PSMs of all samples (ANOVA).

Outcome discrepancy	Groups Non-CLP (45)	BCLP (17)	UCLP (33)	P value	Scheffe N[@]-B[#]	N-U[%]	B-U
Translational (mm)							
A-X	1.05 ± 0.91	1.56 ± 1.38	1.74 ± 1.37	0.032*	-0.51	-0.69*	-0.19
A-Y	3.22 ± 1.39	4.91 ± 1.91	4.26 ± 2.02	0.001*	-1.69*	-1.05*	0.64
A-Z	1.43 ± 1.01	1.54 ± 1.95	1.13 ± 1.02	0.436	-0.11	0.30	0.41
MxR-X	0.73 ± 0.84	1.29 ± 1.55	1.28 ± 0.92	0.037*	-0.55	0.55	0.006
MxR-Y	3.55 ± 1.69	4.84 ± 2.44	5.26 ± 3.25	0.009*	-1.29	-1.71*	-0.42
MxR-Z	2.82 ± 1.75	1.99 ± 2.66	2.14 ± 1.42	0.156	0.83	0.68	-0.15
MxL-X	0.72 ± 0.77	1.21 ± 1.61	1.20 ± 0.81	0.061	-0.49	-0.48	0.00
MxL-Y	2.82 ± 1.76	4.84 ± 2.09	3.94 ± 2.29	0.001*	-2.02*	-1.12	0.90
MxL-Z	2.88 ± 1.72	1.27 ± 0.69	2.05 ± 2.17	0.005*	1.61*	0.83	-0.77
Angular (°)							
Roll	1.30 ± 1.08	2.67 ± 4.93	2.10 ± 1.75	0.106	-1.37	-0.80	0.57
Pitch	4.25 ± 2.65	4.33 ± 3.69	2.29 ± 2.40	0.006*	-0.09	1.96*	2.04
Yaw	1.63 ± 1.74	2.09 ± 1.53	3.47 ± 2.98	0.002*	-0.46	-1.84*	-1.38

*The mean difference is significant at the 0.05 level; @Non-CLP patients; #patients with bilateral cleft lip and palate; %patients with unilateral cleft lip and palate.

feasibility of the whole planning were confirmed by the same surgeon (J.P. Lai).

2.2. Fabrication of the Surgical Guide (the Detailed Procedures Were Described in Reference [13]). The reverse engineering was applied to the fabrication of the surgical guide (Figure 1). A stereolithographic model demonstrating the planned maxillary reposition was produced (Figure 1(a)). The fixation miniplates serving as the guiding plate (2nd guiding plate) were prebent according to the plate holes marked on the model (Figure 1(a)). Meanwhile, another guiding plate (1st guiding plate) registering the orientation and thickness of the cutting lines was also 3D printed with clear biocompatible resin (MED610) (Figure 1(b)). On the other hand, the mandibular guide was also fabricated according to the final position of the MMC (Figures 1(c) and 1(d)).

2.3. The Surgical Procedures and Post-OGS Caring Protocol. All the patients received the "maxilla-first" concept for the surgical procedures. The first guiding plate was adapted to the maxillary surface to locate the screw holes and the cutting lines before the Le Fort I osteotomies (Figure 1(b)). After releasing the maxilla, the single stent technique was applied to guide the distal mandibular segments. At last, the prebent mandibular miniplates were used to verify the position of the proximal mandibular segments. All the surgical procedures have been performed by the same surgeon (JPL).

All the patients received the same postsurgical caring protocol including the intermaxillary fixation for 2–4 weeks and bilateral anterior vertical elastics for another 2-4 weeks. The postsurgical orthodontic treatments were initiated once primary wound healing was achieved.

2.4. Using Representative Triangles to Verify the Jawbone Changes. All the virtual planning was carried out on the world coordinate system. The virtual skulls were oriented by the reference plane passing through the bilateral orbitales and porions. The images of different stages were registered by the voxel-based method to determine the surgical movements. To verify the jawbone movements of each stage, a virtual triangle was plotted along with three bony anatomic end points including A-point and the most lateral points bilaterally, the MxR and the MxL (Figure 2). Once the A-point was

Table 3: ANCOVA on outcome discrepancies and characteristics of the samples.

Outcome discrepancy	Regression coefficients (n = 95) PSM	N[@]-B[#]	N-U[%]	B-U
Translational (mm)				
A-X	0.018	0.021	-0.066	0.087
A-Y	0.089	0.312	0.184	0.128
A-Z	0.017	0.642*	0.097	0.545*
MxR-X	0.079	0.146	0.060	0.086
MxR-Y	0.023	0.609*	-0.062	0.671*
MxR-Z	0.007	-0.053	-0.088	-0.142
MxL-X	0.170*	0.128	-0.027	0.155
MxL-Y	0.144*	0.271	0.290	-0.019
MxL-Z	0.082	0.627*	0.181	0.445
Angular (°)				
Roll	0.107*	0.259	0.138	0.121
Pitch	0.176*	0.646	0.119	-0.062
Yaw	0.136*	0.592*	-0.193	0.785*

*The mean difference is significant at the 0.05 level; @non-CLP patients; #patients with bilateral cleft lip and palate; %patients with unilateral cleft lip and palate.

Table 4: ROC curves were plotted to identify the cutoff value leading to ODs of clinical significance.

	AUROC	Best cutoff point	Sensitivity	Specificity	Accuracy
Abi_AZ					
Control/unilateral	0.684	1.37	100	47.9	52.6
Bilateral	0.810	1.33	100	71.4	76.4
Abi_LZ					
Control/unilateral	0.680	2.78	81.8	59.7	62.8
Bilateral	0.558	0.60	100	33.3	54.9
RY					
Control/unilateral	0.542	1.05	30.8%	95.4%	84.6%
Bilateral	0.667	7.31	60.0%	100%	88.2%
Abi_yaw					
Control/unilateral	0.678	2.0	76.9	60.0	62.8
Bilateral	0.857	1.65	100	70.0	82.4

registered by orthodontists, the tangent lines passing through the A-point were generated automatically to identify the MxR and the MxL at the same transverse plane. Such a representative triangle was then transferred to different stages by the voxel-based registration of the posterior nasal spine (PNS) to superimpose the virtual maxilla without deformation. More details have been described in our earlier study [12]. The jawbone orientations between different stages were then assessed by measuring the linear movements of each landmark and angular differences among the representative triangles.

2.5. The Cephalometric Assessments of Mandibular Position. The mandibular position was surveyed by lateral cephalometric films by the AudaxCeph Empower software (Version 5.2, Ljubljana, Slovenia). The distance from the pogonion to the nasion perpendicular line (A-Nv) was measured to assess the mandibular OD in the vertical direction. Meanwhile, the menton projection to the Nv was used to verify the mandibular position in the sagittal axis.

2.6. Reliability Test and Statistical Analysis. After collecting the primary data, 25 patients were randomly chosen for assessment of the interobserver and intraobserver reliabilities of the proposed method at a minimum interval of 2 weeks. The intraclass correlation coefficients were used to test the interobserver and intraobserver reliabilities of this method. The one-sample t-test was used to examine the positional differences of the virtual maxilla between the actual outcome and the simulation model (Table 1).

2.7. Identification of the Cutoff Values Leading to Outcome Discrepancies (OD) of Clinical Significance. Because the planned surgical movements (PSMs) of non-CLP and CLP patients might not be equivalent (Table 2), ANCOVA was chosen to adjust the mean value in each group before describing intergroup differences. Post hoc analysis (Scheffe method) was adopted to further identify intergroup differences (Table 3). For those measurements showing intergroup differences, receiver operating characteristic curves (ROC curves) were plotted to identify the cutoff values leading to OD of clinical significance (Table 4). At last, the one-way ANOVA was used to evaluate the mandibular OD among all groups.

3. Results

The one-sample t-test showed significant OD from simulation in all of the examined measurements in each group (Table 1). According to the results, the CLP usually required larger PSM than the non-CLP patients. However, there was no difference in PSM between the unilateral CLP (UCLP) and BCLP patients (Table 2).

The ANCOVA was then performed to adjust possible effects of PSM on OD. The results showed no significant difference in OD between the non-CLP and UCLP groups. On the other hand, three translational measurements (A-Z, MxR-Y, and MxL-Z) and one angular measurement (yaw) revealed significant intergroup differences. In these four measurements, the BCLP group showed increased maxillary OD than the UCLP and non-CLP groups (Table 3). The similar pattern was also revealed in the mandibular assessment (Table 5).

The ROC curves were then plotted to determine the cutoff values leading to 2 mm/2° OD. Because of the homogeneous characteristics, the non-CLP and UCLP groups were regarded as having the same characteristics. According to the results, the >1.33 mm anterior vertical movements (A-Z) and/or >1.65° yaw correction in BCLP are more vulnerable to OD of clinical significance (Table 4).

The intraexaminer and interexaminer reliabilities were in agreement (0.972 and 0.988, respectively).

4. Discussion

OGS is the treatment of choice for patients with excessive skeletal discrepancies [1, 2]. However, the surgical treatments of patients with craniofacial deformities are especially challenging [4]. Therefore, in the present study, we compared the outcome predictability between CLP and non-CLP patients in a case-control manner.

Table 5: The cephalometric assessments of mandibular position.

Outcome discrepancy	Groups Non-CLP (45)	BCLP (17)	UCLP (33)	LSD N[@]-B[#]	N-U[%]	B-U
Pog-Nv (sagittal OD)	0.54 ± 2.65	4.30 ± 4.47	0.98 ± 3.83	-3.76*	-0.44	3.32*
Me on Nv (vertical OD)	−0.36 ± 1.74	−3.60 ± 2.53	−0.96 ± 2.20	-3.23*	0.59	2.64*

*The mean difference is significant at the 0.05 level; [@]non-CLP patients; [#]patients with bilateral cleft lip and palate; [%]patients with unilateral cleft lip and palate.

According to the results, the postsurgical outcomes were not identical to the presurgical simulation. All groups presented significant OD in all translational and angular measurements (Table 1). Such differences could be attributed to repositioning errors during operation and postsurgical relapse. In the present study, all patients received the same 3DSS protocol, surgical procedures, and guiding modalities, such that repositioning errors should have equally affected all groups. Therefore, postsurgical relapse may have been the major contributor to OD differences between the groups.

In addition to surgical procedures, which were controlled by enrolled criteria, PSMs are the other well-known factors of postsurgical relapse [12, 15]. In the present study, larger PSMs were prescribed to correct bony discrepancies in the CLP patients (Table 2). Under this circumstance, the actual effects of CLP-related deformities were masked. Therefore, the surgical predictabilities between the CLP and non-CLP patients were compared after statistically adjusting for PSM factors (Table 3). The results indicated that UCLP had a level of postsurgical OD comparable to that of non-CLP patients in all translational and angular measurements. However, the BCLP group is inherently more vulnerable to reduced surgical predictability in both jaws. Thus, the central hypothesis of this study was partially rejected. The results showed that UCLP patients had potentially equivalent OGS predictabilities to non-CLP patients, whereas BCLP tended to have larger discrepancies from the presurgical simulation estimates. This finding agreed with earlier cephalometric reports [6, 7]. Compared with UCLP patients, the unique characteristics, such as isolated premaxilla and bilateral alveolar clefts of BCLP patients, were believed to contribute to the instability [6, 7].

For decades, CLP patients were regarded as a special group because of their congenital deformities. However, according to recent reviews, non-CLP patients [8] did not obtain overwhelming advantages in postsurgical stability versus CLP patients [9]. The present study results support such an idea.

Generally, 2 mm differences have been commonly regarded as clinically relevant changes [11]. According to the results, vertical repositioning of the anterior maxilla > 1.33 mm in BCLP would result in a clinically relevant vertical OD. Additionally, for a 2° difference, the yaw corrections more than 1.65° would possibly face dominant OD after surgery (Table 4).

These results could be useful in guidelines for clinical practice. For CLP-related OGS, maxillary advancement with vertical downward movement has previously been reported to be unstable after surgery [16, 17]. The ROC results in the present study support such a concept, especially in BCLP patients. To improve vertical stability, the intraoperative grafting [18] and sufficient incisor display set up would be helpful in the BCLP patients. For yaw correction, small changes can noticeably affect postsurgical predictability in BCLP patients. To limit yaw correction when adjusting the MMC, orthodontists should try to achieve optimal coordination of dental and skeletal discrepancies before surgery.

There are some limitations in this study. First, although non-CLP patients experienced major relapse within the first 6 months after surgery [19, 20], the 6-month observation might not be long enough to reveal the progressed changes in CLP patients. Second, our study included only the CLP patients receiving whole-piece Le Fort I osteotomy, so we cannot provide insights regarding patients who received multipieced Le Fort I procedures. Finally, due to the lack of a reliable mandibular registration method, which is the common limitation of similar studies, only the cephalometric assessments could be provided for the mandibular assessments.

5. Conclusions

The OGS outcomes of BCLP patients are less predictable than those of UCLP and noncleft patients. Vertical movements of the A – point > 1.33 mm and yaw correction > 1.65° in BCLP patients increased OD to a clinically relevant extent.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

All the authors in this study claimed no interests and conflicts related to this research.

Acknowledgments

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Research Article

Changes in Pharyngeal Airway Space and Craniocervical Angle after Anterior Bimaxillary Subapical Osteotomy

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Purpose. This study explored the effects of genioplasty (Gep) and anterior subapical osteotomy of the maxilla and mandible (ASOMx+ASOMd) on the pharyngeal airway dimensions of patients with bimaxillary protrusion (BiP). *Method*. Thirty-two patients were divided into 2 groups. Group 1 received ASOMx+ASOMd, and group 2 received ASOMx+ASOMd+Gep. The cephalograms of the patients were collected before surgery and 2 months after surgery. Changes in the landmarks, related cephalometric angles (gonial, SN-GoGn, *Y*-axis, and SN-C2C4 angles), and 2 pharyngeal airway dimensions (uvulo-pharyngeal airway [UOP] and tongue–pharyngeal airway [TOP]) were analyzed. *Results*. Before surgery, the parameters (incisor superius, incisor inferius, menton, most superior and anterior point of the hyoid bone, tip of the uvula, inferoanterior point on the second cervical vertebra, and inferoanterior point on the fourth cervical vertebra) and measured angles (SNA, SNB, ANB, gonial, SN-GoGn, *Y*-axis, and C4C2-SN) of both groups showed no significant differences. Following ASOMx, the patients in groups 1 and 2 exhibited a setback by 7.0 and 6.6 mm, respectively. After ASOMd, groups 1 and 2 exhibited 4.9 and 5.3 mm setbacks, respectively. No significant difference in the amount of setback was observed between groups 1 and 2. The postoperative horizontal and vertical positions of Me in group 2 were significantly forward by 6.1 mm and upward by 1.5 mm, respectively. Regarding pharyngeal airway dimensions, TOP was decreased in group 1 (1.7 mm) and group 2 (1.3 mm). In the postoperative Pearson correlation coefficient test, the horizontal and vertical positions of Me showed no significant correlation with TOP in both groups. Therefore, Gep did not prevent the reduction of TOP in group 2. *Conclusion*. After bimaxillary anterior subapical osteotomy, the TOP of patients with BiP was decreased, and this situation was unavoidable, regardless of whether Gep was performed.

1. Introduction

Bimaxillary protrusion (BiP) is a facial deformity associated with the anterior segments of the maxilla and mandible. This condition is characterized by severe protrusion of the maxillary and mandibular dental arches and is frequently accompanied by underdevelopment of the chin. Patients with BiP exhibit a convex facial profile and experience difficulty closing their lips; consequently, they must flex their facial muscles to close their lips, causing mentalis muscle strain [1–3]. A gummy smile or toothy face is a common clinical characteristic and the most frequent chief complaint of such patients. Patients with BiP typically exhibit properly aligned teeth, with normal posterior occlusion, although some patients might exhibit slightly crowded teeth. The deformity in the facial profiles of such patients affects them psychologically and causes them to develop an introverted personality or to feel inferior or angry, which in turn affects their work and social interactions.

Depending on symptom severity, the clinical treatment for BiP involves orthodontic correction alone or in combination with orthognathic surgery. Bimaxillary anterior subapical osteotomy (ASO) is an established surgical technique for the treatment of BiP. Although orthognathic surgery can improve the facial profile of patients with BiP, several studies [4–6] have demonstrated that the surgery causes mandibular setback and affects the organization of tissues. In addition, the bimaxillary setback procedure considerably reduces the pharyngeal airway space and lowers the position of the tongue and hyoid, thereby changing the position of the head. Therefore, this study investigated the effects of maxillary ASO (ASOMx) and mandibular ASO (ASOMd) with or without genioplasty (Gep) on dental position, pharyngeal airway space, and head position in patients with BiP. The null hypothesis was that the postoperative tongue–pharyngeal airway dimension would not differ significantly between group 1 (without Gep) and group 2 (with Gep).

2. Material and Method

This study included 32 patients with BiP who received treatment at the Department of Oral and Maxillofacial Surgery, Kaohsiung Medical University. The inclusion criteria of this study were as follows: (1) BiP without deformed lips prior to surgery and (2) no other facial injuries or etiology. The patients were divided into 2 groups. Group 1 underwent ASOMx+ASOMd, and group 2 underwent ASOMx +ASOMd+Gep (Figures 1 and 2). Group 1 (mean age: 28.9, ranged from 19 to 43) comprised 14 female and 2 male patients, and group 2 (mean age: 24.8, ranged from 16 to 33) included 13 female and 3 male patients. Groups 1 and 2 did not differ significantly ($p = 0.061$) in terms of age by the Student t-test. According to the classification of skeletal patterns (class I, $0^\circ < \text{ANB} < 4^\circ$; class II, $\text{ANB} \geq 4^\circ$; class III, $\text{ANB} \leq 0^\circ$), group 1 had 11 class II patients and 5 class I patients, and group 2 had 14 class II patients and 2 class I patients.

All patients received the traditional fixed orthodontic appliance (OPAK system bracket with a 0.022 in × 0.028 in slot [Tomy Co., L, Tokyo, Japan]). In group 1, the mean durations of pre- and postsurgical orthodontic treatment were 5.8 and 13.5 months, respectively. In group 2, the mean durations of pre- and postsurgical orthodontic treatment were 5.3 and 14.2 months, respectively. The mean total orthodontic treatment time of group 1 and group 2 were 19.3 and 19.5 months, respectively. The 4 first premolars were extracted during the surgical procedure, and then, ASOMx+ASOMd was performed through the extraction spaces.

The cephalograms of each patient were collected preoperatively and 2 months postoperatively. The following landmarks were recorded: sella (S), nasion (N), posterior nasal spine (PNS), incisor superius (Is), incisor inferius (Ii), gnathion (Gn), menton (Me), gonion (Go), tip of the uvula (U), inferoanterior point on the second cervical vertebra (C2), inferoanterior point on the fourth cervical vertebra (C4), and most superior and anterior point of the hyoid bone (H). The following distances were measured: length of the soft palate (i.e., the distance between U and PNS [SPL]), the widest distance of the soft palate (SPW), and the Wits appraisal (mm). The following angles were measured: lines tangent to the posterior border of the ramus and Go-Me plane (gonial angle), angle formed by lines S-N and Go-Gn (SN-GoGn angle), angle between S-Gn and the Frankfort horizontal plane (Y-axis angle), and craniocervical angle (i.e., angle between C2C4 line and SN line [SN-C2C4 angle]). The pharyngeal airways were also measured as follows: (1) uvula pharyngeal airway (i.e., distance between the horizontal plane through U intersecting posterior pharyngeal wall [UOP]) and (2) shortest distance from the posterior tongue to the pharyngeal wall (TOP).

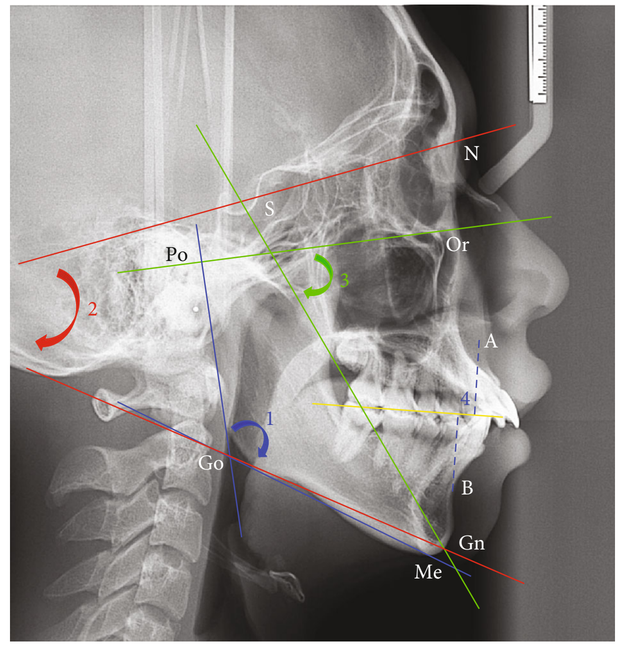

Figure 1: Cephalometric landmarks: S: sella; N: nasion; Or: orbitale; Po: porion; A point; B point; Gn: gnathion; Me: menton; Go: gonion. The following measurements: (1) blue color: gonial angle (lines tangent to the posterior border of the ramus and Go-Me plane), (2) red color: SN-GoGn angle (angle formed by lines S-N and Go-Gn), (3) green color: Y-axis angle (angle between S-Gn and Or-Po plane), and (4) Wits appraisal (mm).

The process of cephalometric landmark identification was performed twice by the author. Subsequently, the calculated intraobserver reliability (correlation coefficient > 0.900, $p < 0.001$) was determined to be acceptable. The changes in surgical landmarks were collected for statistical analyses (SPSS version 20, IBM Corporation, Armonk, NY, USA), including the calculation of mean and standard deviation values. Student's t-test was used with a 95% confidence level to test the statistical significance. The Pearson correlation coefficient test was performed to compare the correlations between the variables and pharyngeal airway dimensions.

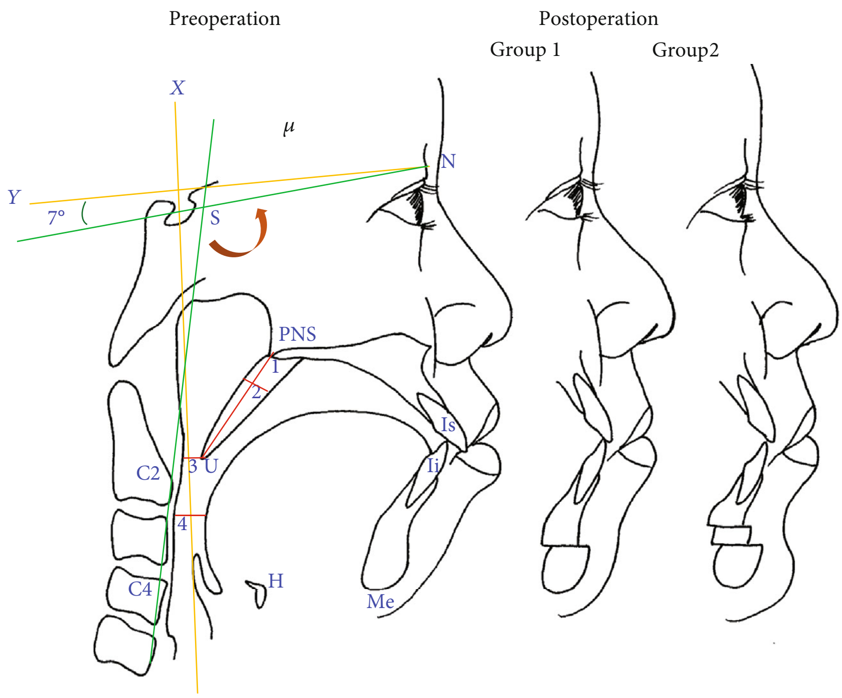

FIGURE 2: Preoperation and postoperation (group 1 and group 2) in patient with bimaxillary protrusion. X-axis (horizontal axis): a line through nasion 7° up from SN line. Y-axis (vertical axis): a line through sella (S) perpendicular to the X-axis. The measurements: (1) length of the soft palate and (2) width of the soft palate. Pharyngeal airway space: (3) UOP and (4) TOP craniocervical angle: C2C4-SN angle. Group 1 received ASOMx+ASOMd, and group 2 received ASOMx+ASOMd+GeP.

The correlation strength was derived as the absolute value of the ratio of the compared variables: very weak (0-0.19), weak (0.20-0.39), moderate (0.40-0.59), strong (0.60-0.79), and very strong (0.80-1.0).

3. Results

The preoperative characteristics of group 1 and group 2 are presented in Table 1. Regarding the horizontal and vertical position of several landmarks (Is, Ii, Me, H, U, C2, and C4), no significant difference was noted between group 1 and group 2. All measured angles (SNA, SNB, ANB, gonial, SN-GoGn, Y-axis, and C4C2-SN) exhibited no significant difference between groups 1 and 2 (Table 2). Therefore, the baseline vertical and horizontal patterns did not differ significantly between groups 1 and 2. Furthermore, the SPL and pharyngeal airway space (UOP and TOP) did not differ significantly between groups 1 and 2. The postoperative results obtained for groups 1and 2 are presented in Tables 3 and 4. Is and Ii were significantly set back by 7.0 and 4.9 mm, respectively, in group 1 and by 6.6 and 5.3 mm, respectively, in group 2 (Table 3). Me was significantly advanced forward by 6.1 mm in group 2. However, the postoperative position of the landmarks (Is, Ii, H, U, C2, and C4) did not differ significantly between groups 1 and 2. Postoperative changes in H revealed no significant difference between groups 1 and 2, indicating that the advancement of Gep exerted no significant effect on the H position.

As presented in Table 4, SNA and SNB were significantly decreased in group 1 after surgery. The measured angles (SNA, SNB, ANB, gonial, and SN-GoGn) were significantly decreased in group 2 (Table 4). In the intergroup comparison, the gonial angle in group 2 was significantly decreased relative to that in group 1. The increase in SPL was nonsignificant between groups 1 and 2. Concerning changes in the pharyngeal airway space, UOP and TOP were significantly reduced by 2.2 and 1.7 mm, respectively, in group 1. Changes in UOP and TOP in group 2 were nonsignificant. The SN-C2C4 angle of the 2 groups exhibited no significant differences after surgery.

Table 5 lists postoperative changes in landmarks and pharyngeal airways derived in the Pearson correlation test. In group 1, UOP and TOP exhibited no significant correlation with the landmarks (Is, Ii, Me, H, U, C2, and C4). In group 2, horizontal U exhibited a significant strong positive correlation with UOP ($r = 0.770$) and significant moderate correlation with TOP ($r = 0.593$). Vertical U exhibited a significant strong negative correlation with TOP ($r = -0.726$) in group 2. Table 6 lists the results of the Pearson correlation coefficient test between pharyngeal airways and related measured angles. In group 1, the gonial angle exhibited a significant moderate positive correlation ($r = 0.533$) with TOP. In group 2, UOP had a moderate positive correlation ($r = 0.504$) with the ANB angle and a significant strong negative correlation ($r = -0.634$) with SPL. TOP showed a significant moderate negative correlation ($r = -0.560$) with SPL. Furthermore, significant positive correlations were observed between UOP and TOP in both groups (group 1: $r = 0.559$ and group 2: $r = 0.622$). The horizontal and vertical positions of Me were not significantly correlated with TOP in both

Table 1: Preoperative characteristics in both groups.

Variables	Group 1 Mean	Group 1 SD	Group 2 Mean	Group 2 SD	Intergroup comparison p value
Horizontal					
Is	80.6	8.45	79.0	4.11	0.517
Ii	75.9	7.53	74.9	4.35	0.661
Me	55.5	10.13	50.6	6.07	0.139
H	14.0	8.47	11.8	9.64	0.551
U	0.3	6.61	-0.7	4.96	0.612
C2	-20.1	7.30	-20.6	7.45	0.833
C4	-25.7	11.09	-26.1	10.22	0.919
Vertical					
Is	91.6	4.13	92.0	4.30	0.774
Ii	88.1	4.44	88.4	3.65	0.857
Me	131.3	5.17	132.4	4.26	0.579
H	116.9	6.95	118.9	11.32	0.631
U	82.9	3.49	82.9	6.34	1.000
C2	95.4	5.35	95.1	7.05	0.876
C4	130.8	6.04	131.1	9.73	0.939

Group 1: ASO; group 2: ASO+Gep. *Intergroup comparison: statistically significant, $p < 0.05$.

Table 2: Preoperative pharyngeal airway-related value in both groups.

Variables	Group 1 Mean	Group 1 SD	Group 2 Mean	Group 2 SD	Intergroup comparison p value
SNA	85.1	2.76	86.1	2.41	0.210
SNB	80.4	3.58	80.2	3.27	0.821
ANB	4.6	2.58	6.0	1.73	0.068
Gonial	120.6	5.08	123.3	5.43	0.200
SN-GoGn	33.0	6.49	35.8	3.90	0.120
Y-axis	62.2	3.86	64.5	2.49	0.055
Wits appraisal	2.7	3.40	3.4	2.21	0.410
SN-C2C4	105.4	6.44	106.1	7.67	0.815
SPL	36.3	3.32	34.2	5.32	0.238
SPW	8.3	1.00	9.0	0.98	0.013*
Pharyngeal airway					
UOP	12.4	2.19	10.9	3.34	0.123
TOP	11.9	3.27	12.1	2.96	0.811

Group 1: ASO; group 2: ASO+Gep. *Intergroup comparison: statistically significant, $p < 0.05$.

groups. Accordingly, the null hypothesis was accepted, demonstrating that Gep advancement is not significantly correlated with changes in TOP.

4. Discussion

The prevalence of facial deformity and malocclusion varies considerably within different races. Farrow et al. [7] observed that black Americans differ significantly from white Americans in terms of dental, skeletal, and soft tissue parameters. Drummond [8] compared white Americans with black Americans and discovered that black patients exhibited bimaxillary dental protrusion, a steep mandibular plane, and anterior placement of the maxilla. Boeck et al. [9] surveyed the occurrence of skeletal malocclusions in Brazilian patients with dentofacial deformities and observed a low incidence (7%) of BiP in the Caucasians. Isiekwe [10] reported a 20% prevalence of BiP in Nigeria, with 75% having a skeletal class I jaw relationship. Sundareswaran and Kizhakool [11] examined malocclusion in 13–15-year-old adolescents in southern India and reported a 21.3% prevalence of BiP.

Table 3: Postoperative changes of characteristics in both groups.

Variables	Group 1 Mean	Group 1 SD	Group 1 p value	Group 2 Mean	Group 2 SD	Group 2 p value	Intergroup comparison p value
Horizontal							
Is	-7.0	3.19	<0.001*	-6.6	2.0	<0.001*	0.684
Ii	-4.9	2.78	<0.001*	-5.3	2.0	<0.001*	0.674
Me	0.4	2.83	0.603	6.1	2.3	<0.001*	<0.001**
H	-0.4	4.24	0.728	1.5	6.4	0.355	0.253
U	-3.2	4.45	0.01*	-0.6	4.6	0.609	0.091
C2	0.0	3.10	0.968	2.0	6.1	0.209	0.189
C4	-0.6	4.65	0.636	1.9	7.6	0.338	0.209
Vertical							
Is	-1.3	3.82	0.190	-1.9	5.5	0.180	0.743
Ii	0.1	4.54	0.957	-0.4	4.3	0.691	0.764
Me	0.7	4.11	0.495	-1.5	2.6	0.035*	0.134
H	1.7	5.19	0.205	-1.6	5.4	0.251	0.130
U	-0.9	3.96	0.358	1.2	2.5	0.081	0.100
C2	1.2	4.53	0.299	0.9	4.8	0.446	0.879
C4	1.4	6.32	0.387	-0.5	3.8	0.615	0.394

Group 1: ASO; group 2: ASO+Gep. *Intragroup comparison: statistically significant, $p < 0.05$. **Intergroup comparison: statistically significant, $p < 0.05$.

The pharynx is a muscular channel with a wide top and a narrow bottom. The top of the pharynx is connected with the cranial basis, and the bottom is located near the sixth cervical vertebra. The front wall of the pharynx is not completely sealed and is connected to the nasopharynx, oropharynx, and laryngopharynx. The posterior wall of the pharynx is composed of loose connective tissues that are attached to the prevertebral fascia. From top to bottom, the pharynx is divided into 3 parts: the nasopharynx, oropharynx, and laryngopharynx (or hypopharynx). The nasopharynx and oropharynx are separated by the palate, and the oropharynx and laryngopharynx are separated by the epiglottis [12, 13]. Both food and air pass through the pharyngeal airway, where the digestive tract and respiratory tract intersect. Therefore, the pharynx is crucial to swallowing and respiratory functions and affects respiratory defense mechanisms, middle ear pressure regulation, and auditory functioning. The pharynx also serves as a resonance cavity that can adjust its size when required through the raising and lowering of the dorsum and soft palate.

Table 4: Postoperative changes of pharyngeal airway in both groups.

Variables	Group 1			Group 2			Intergroup comparison
	Mean	SD	p value	Mean	SD	p value	p value
SNA	-2.7	2.44	0.001*	-3.5	2.07	<0.001*	0.387
SNB	-2.0	1.88	0.001*	-2.0	1.88	0.001*	0.966
ANB	-0.6	1.88	0.226	-1.5	1.55	0.001*	0.206
Gonial	1.4	3.08	0.088	-3.8	3.61	0.001*	<0.001**
SN-GoGn	-1.2	3.29	0.180	-2.2	2.28	0.002*	0.341
Y-axis	0.5	3.08	0.526	-1.0	2.38	0.103	0.050
Wits appraisal	-1.0	3.47	0.248	-1.4	1.84	0.010*	0.764
SN-C2C4	1.4	3.52	0.131	0.3	5.99	0.838	0.556
SPL	1.4	3.35	0.106	1.2	3.09	0.131	0.840
SPW	0.8	1.38	0.032*	-1.0	1.13	0.002*	<0.001**
Pharyngeal airway							
UOP	-2.2	2.42	0.003*	0.2	3.08	0.794	0.028**
TOP	-1.7	2.56	0.017*	-1.3	2.99	0.116	0.600

Group 1: ASO; group 2: ASO+Gep. *Intragroup comparison: statistically significant, $p < 0.05$. **Intergroup comparison: statistically significant, $p < 0.05$.

Table 5: Pearson's correlation coefficient test between pharyngeal airways and landmarks.

Variables	Group 1		Group 2	
	UOP	TOP	UOP	TOP
Horizontal				
Is	0.304	0.237	0.020	-0.328
Ii	0.214	0.344	0.021	0.131
Me	0.323	0.188	0.022	0.112
H	0.222	-0.100	0.344	0.245
U	0.434	0.034	0.770*	0.593*
C2	0.221	-0.146	0.178	0.181
C4	0.008	-0.143	0.036	-0.049
Vertical				
Is	-0.064	-0.222	-0.057	-0.468
Ii	-0.108	-0.197	-0.072	-0.330
Me	-0.039	-0.284	0.231	-0.275
H	-0.047	-0.416	-0.181	-0.495
U	0.085	-0.025	-0.289	-0.726*
C2	0.311	-0.055	0.217	0.157
C4	0.156	-0.105	0.020	-0.081

*Statistically significant, $p < 0.05$.

BiP presents a convex facial profile and can be corrected by orthodontic treatment alone or in combination with orthognathic surgery. By contrast, maxillary deficiency can be treated using various nonsurgical approaches in growing patients. Jamilian et al. [14] used a tongue appliance to push the maxilla into a forward position in growing patients with maxillary deficiency. Jamilian et al. [14] evaluated the effects of treatment with a maxillary protraction appliance (tongue appliance) on upper airway dimensions and demonstrated that a tongue appliance does not affect sagittal airway dimensions but increases vertical airway dimensions within a short time. Pamporakis et al. [15] investigated the effects of rapid maxillary expansion (RME) and facemask (FM) use on pharyngeal airway space in growing patients with class III maxillary deficiency. After RME/FM treatment, a significant increase was observed in the maxillary sinus volume, whereas the increases in the volumes of the upper and lower pharyngeal airway space were nonsignificant. Tahmasbi et al. [16] compared the effects of 2 surgical methods, anterior maxillary segmental distraction (AMSD) versus conventional Le Fort I osteotomy, on cephalometric changes in the velopharyngeal area of patients with cleft lip and palate. They observed that AMSD could improve the facial profile to a level almost similar to that achieved by conventional Le Fort I advancement; although a significant decrease was observed in the nasopharyngeal area, no increase was noted in the velopharyngeal sphincter. However, conventional Le Fort I maxillary advancement could be effective in increasing the pharyngeal airway space.

Recently, the development of theories related to surgical techniques and the advances in hypotensive anesthesia technology have increased the frequency of orthognathic surgery for the treatment of facial deformities. Orthognathic surgery is no longer limited to patients with severe conditions; those who seek efficient treatment outcome or who hope to reduce treatment time also receive orthognathic surgery-assisted treatment. However, such surgery displaces both jaws, thereby altering the airway space. Scholars [17–19] have suggested that mandibular advancement surgery causes the forward movement of the hyoid bone, whereas mandibular setback surgery results in the backward movement of the hyoid bone. Studies [18, 19] have also reported that mandibular setback surgery causes the backward movement of the tongue, leading to the narrowing of the airway space.

The ANB angle and Wits appraisal are common cephalometric parameters used in the interpretation of the anteroposterior jaw relationship. The Wits appraisal is a valuable linear cephalometric measurement used in evaluating the

Table 6: Pearson's correlation coefficient test between pharyngeal airways and related measured angles.

Variables	Group 1		Group 2	
	UOP	TOP	UOP	TOP
SNA	0.005	-0.135	0.444	0.468
SNB	-0.027	0.092	-0.028	0.311
ANB	0.051	-0.258	0.504*	0.352
Gonial	0.161	0.533*	0.357	0.115
SN-GoGn	0.050	0.023	0.236	0.107
Y-axis	0.027	-0.055	0.219	0.190
Wits appraisal	0.347	0.356	-0.009	0.167
SN-C2C4	0.178	0.150	0.203	0.260
SPL	-0.158	-0.191	-0.634*	-0.560*
SPW	0.239	-0.211	-0.085	0.026
UOP	1	0.559*	1	0.622*
TOP	0.559*	1	0.622*	1

*Statistically significant, $p < 0.05$.

anteroposterior relationship of the anterior bimaxillary apical bases. The Wits appraisal is also commonly applied in the diagnosis of the severity or degree of anteroposterior jaw disharmony. Before and after surgery, no significant difference in the ANB angle and Wits appraisal was observed in both group 1 and group 2. Gonial angle is a cephalometric analysis used to both predict the growth pattern and infer the rotation of the mandible. SN-GoGn angle is used to assess the mandibular vertical growth and determine the direction of mandibular growth rotation. Y-axis angle is also an indicator of mandibular growth direction. In the present study, we used gonial angle, SN-GoGn angle, and Y-axis angle to evaluate the growth pattern and the rotation of the mandible. Both groups showed similar facial patterns.

In the ASOMx procedure, the 4 first premolars are removed to achieve setback of the anterior maxillary segment. In this study, ASOMx resulted in the setback and upward displacement of the Is position. Anatomically, ASOMx causes changes to soft tissues mainly in the upper lips and nose and exerts a minimal effect on the pharyngeal airway, especially in the UOP. Before surgery, the Is positions of group 1 were more anterior than those of group 2. The amount of setback in group 1 (7.0 mm) was larger than that in group 2 (6.6 mm). Moreover, preoperative UOP did not differ significantly between groups 1 and 2. The postoperative intragroup comparison revealed that UOP was significantly reduced by 2.2 mm in group 1 and was nonsignificantly increased by 0.2 mm in group 2. This finding can be because group 1 had a larger setback in Is without Gep for chin advancement.

Before surgery, the Ii positions of groups 1 and 2 did not differ significantly. However, group 2 exhibited more chin deficiency than group 1 did. Preoperatively, the Me position of group 2 was 4.9 mm behind that of group 1. After surgery, the Ii setback distance of group 1 was 4.9 mm, which was smaller than that of group 2 (5.3 mm). Consequently, group 2 required Gep to advance Me by 6.1 mm. After surgery, the horizontal Me positions of groups 1 and 2 were 55.9 and 56.7 mm, respectively, and the vertical Me distances were 133.0 and 130.9 mm, respectively. Therefore, the Me positions of the 2 groups differed nonsignificantly after surgery. The postoperative H position of group 2 was forward by 1.5 mm, indicating that Gep affected the H position. However, this finding did not reach statistical significance. After surgery, the SPL of the 2 groups increased. This might be attributable to the setback of the tongue following ASOMd, which stretched the palatal arch muscle and thereby increased the soft palate length. Because the middle pharyngeal constrictor muscle is proximally attached to the hyoid bone, the geniohyoid muscle passes from the chin to the hyoid bone. Therefore, the postoperative H of group 2 was moved forward by 1.5 mm and upward by 1.6 mm through Gep advancement. A significant postoperative reduction in UOP was found in group 1 (without Gep). Chin advancement (Gep) affected the attached muscles, including the hyoglossus, genioglossus, geniohyoid, and mylohoid. Thus, TOP could be changed after Gep. The extent of TOP reduction in group 1 (1.7 mm) was larger than that in group 2 (1.3 mm). However, the postoperative TOP of group 2 decreased by only 0.4 mm through Gep. Although Gep prevented the reduction of UOP and TOP, the corresponding result did not reach statistical significance.

This study also examined whether the relative positions of the head and cervical vertebrae are changed following surgery. Clinical observation showed that prior to surgery, the head positions of the patients tilted slightly downward compared with the healthy patients. This posture enables such patients to conceal the protruded facial profile caused by BiP. After surgery, setback and lowering of the C2 landmark were observed in both groups. This might have been caused by the narrowing of the airway space, which would prompt patients to naturally adjust their head positions to improve respiratory function [20]. Accordingly, the patients' head positions moved slightly backward and tilted upward. Nevertheless, the position of C2 and C4 changed nonsignificantly. Another notable physiological change among the patients was the increase in SN-C2C4 angle, which was due to reductions in the UOP and TOP. This was evident after surgery, as patients naturally tilted their heads upward to breathe more easily and to accommodate the reductions in the UOP and TOP.

Pearson correlation analysis was performed to determine the correlation of postoperative changes in UOP and TOP with landmarks. No significant correlations were observed in group 1. However, changes in the horizontal and vertical positions of U showed moderate positive and strong negative correlations with TOP, respectively. This finding demonstrates that Gep moved hyoid bone anterosuperiorly and resulted in a lower reduction in postoperative TOP. However, the advancement of Me by Gep in group 2 presented no significant correlation with UOP or TOP. Gep did not prevent the reduction of TOP.

5. Conclusion

Regardless of whether they receive Gep, patients with BiP experience a reduction of the pharyngeal airway space following ASOMx+ASOMd. We observed that the reduction of the pharyngeal airway space is caused primarily by the setback of the mandible. After surgery, such patients must adjust their head position as required by natural physiological function. This increases the SN-C2C4 angle, allowing patients to breathe more easily. This indicates that mandibular setback surgery affects the pharyngeal airway space and head position of patients with BiP.

Data Availability

The data used to support the findings of this study are included within the article and are also available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Han-Sheng Chen and Chun-Ming Chen contributed equally to this work.

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Research Article

Postsurgical Stability of Temporomandibular Joint of Skeletal Class III Patients Treated with 2-Jaw Orthognathic Surgery via Computer-Aided Three-Dimensional Simulation and Navigation in Orthognathic Surgery (CASNOS)

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Objective. The aim of this study is to clarify the postsurgical stability of temporomandibular joints in skeletal class III patients treated with 2-jaw orthognathic surgery which was performed utilizing computer-aided three-dimensional simulation and navigation in orthognathic surgery (CASNOS) protocol. *Materials and Methods*. 23 consecutive nongrowing skeletal class III patients with mandibular prognathism associated with maxillary retrognathism treated with 2-jaw orthognathic surgery between 2018 and 2019 were enrolled in this study. The surgery was planned according to the standardized protocol of CASNOS (computer-aided three-dimensional simulation and navigation in orthognathic surgery). Computed tomography (CT) scans were performed in all patients 3 weeks presurgically and 6 months postsurgically. ITKSNAP and 3D Slicer software were used to reconstruct three-dimensional facial skeletal images, to carry out image segmentation, and to superimpose and quantify the TMJ position changes before and after surgery. Amount of displacement of the most medial and lateral points of the condyles and the change of intercondylar angles were measured to evaluate the postsurgical stability of TMJ. *Results*. A total amount of 23 skeletal class III patients (female : male = 12 : 11) with age ranged from 20.3 to 33.5 years (mean: 24.39 ± 4.8 years old) underwent Le Fort I maxillary advancement and BSSO setback of the mandible. The surgical outcome revealed the satisfactory correction of their skeletal deformities. The mean displacement of the right most lateral condylar point (RL-RL′) was 1.04 ± 0.42 mm and the mean displacement of the left most lateral condylar point (LL-LL′) was 1.19 ± 0.41 mm. The mean displacement of the right most medial condylar point (RM-RM′) was 1.03 ± 0.39 mm and the left most medial condylar point (LM-LM′) was 0.96 ± 0.39 mm. The mean intercondylar angle was $161.61 \pm 5.08^\circ$ presurgically and $159.28 \pm 4.92^\circ$ postsurgically. *Conclusion*. The postsurgical position of TM joint condyles in our study only presented a mild change with all the landmark displacement within a range of 1.2 mm. This indicates the bimaxillary orthognathic surgery via 3D CASNOS protocol can achieve a desired and stable result of TMJ position in treating skeletal class III adult patients with retrognathic maxilla and prognathic mandible.

1. Introduction

Structural changes of the condyles may occur after orthognathic surgeries due to the adaptation mechanism after mandibular osteotomies which lead to the changes of loading distribution [1]. It can be classified into two categories of condylar structural changes as condylar remodeling and condylar resorption [2, 3]. The former is a physiological process, and the latter is a pathological change. Clinical symptoms of temporomandibular joint (TMJ) and relapse of surgical outcome may follow after condylar resorption.

Another issue associated with the postsurgical stability of the TMJ condyles is the alteration of their position after orthognathic surgery which often occurs after mandibular osteotomies [1]. Some studies believed that several complications after orthognathic surgery such as condylar resorption, disc displacement, and other symptoms of temporomandibular joint disorders (TMD) may be associated with the significant position change of the condyles [4, 5]. The relationship between orthognathic surgery and TMD is still poorly understood, and the acceptable and harmless amount of condylar position change remains unclear. Previous studies regarding the alteration of condylar position were frequently analyzed with 2D radiographs or the slicing images in 3D radiographs [6–10]. Furthermore, the condyle-fossa relationship was often assessed with 2D measurement. The analysis utilizing three-dimensional imaging system and the actual amount of the condylar position changes were rarely shown.

In our study, we applied 3D imaging software to reconstruct the craniofacial area from the preoperative and postoperative data of computer tomography. The superimposition of two-stage 3D image and quantitative measurement was carried out. It was aimed at investigation of postsurgical stability of TMJ position in skeletal class III patients treated with 2-jaw surgery using the standard protocol of CASNOS (computer-aided three-dimensional simulation and navigation in orthognathic surgery).

2. Materials and Methods

The retrospective study was carried out on computed tomography (CT) scans of nongrowing class III skeletal patients with mandibular prognathism and maxillary retrognathism, who received nonextraction orthodontic and orthognathic treatment including Le Fort I osteotomy combined bilateral sagittal split osteotomy (BSSO). The enrolled patients were treated between July 2018 and December 2019 at the Craniofacial Center, Kaohsiung Chang Gung Memorial Hospital. The selected criteria for the skeletal class III patients were corresponded: overjet ≤ -5 mm; ANB ≤ 0 degree [11]. The exclusion criteria were those patients who presented with degenerative TMJ disease, severe facial asymmetry, deformity secondary to trauma, cleft lip and palate, or systemic disease. Treatment with extraction pattern was also excluded. All operations were arranged only when no further growth of patients was demonstrated, and it was assessed by superimposition of lateral cephalograms between initial and at least 6 months after presurgical orthodontic treatment.

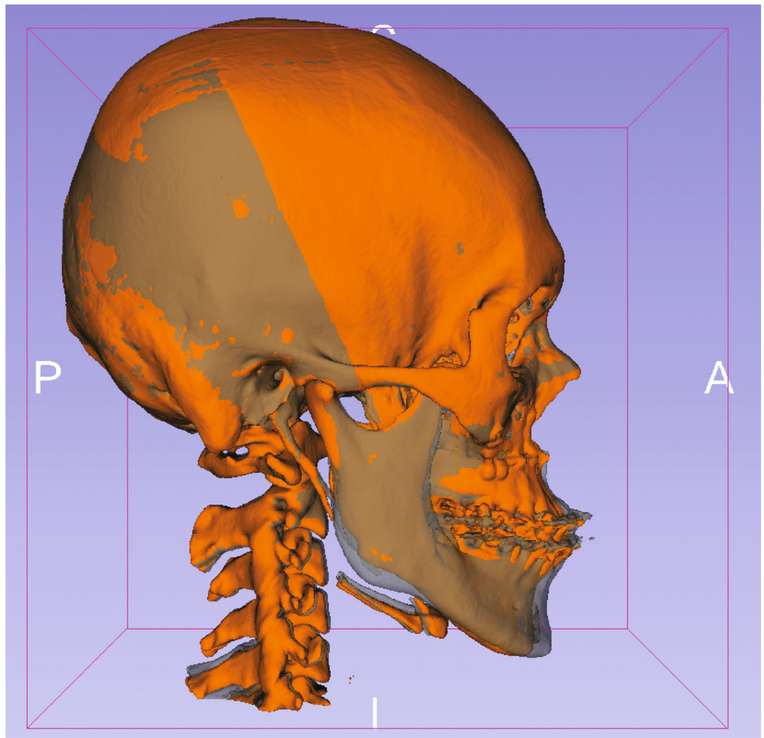
All operations were conducted by an experienced surgeon after completion of presurgical orthodontic preparation. Before the operation, three-dimensional surgical simulation and navigation were executed according to CASNOS protocol proposed by Chang [12]. Under 3D simulation of volumetric data combining with physical manipulation of stereolithographic models and the following lab work, including the fixation miniplate, mandibular positioning splint and the occlusal splint were fabricated. During the operation, the relative positioning of the maxilla and mandible was achieved and maintained with the occlusion stent. The maxillomandibular complex was repositioned according to the planned navigation and fixed to the basal bone with the prefabricated miniplates. The fixation methods for all our orthognathic surgical patients were (1) internal fixation miniature titanium bone plates and cortical screws and (2) the intermaxillary fixation (IMF) with concomitant fixed orthodontic appliances and supplementary elastics for stabilization at least 2 weeks after the surgery.

CT images (Toshiba Aquilion 64: 120 kVp, 350 mA, rotation time: 0.5 sec, 64×0.5 mm slices) over the craniofacial area were obtained 3 weeks before surgery (T1) when all the required orthodontic preoperative movements had been completed. The second CT scan was obtained at 6 months postoperatively (T2) to assess the treatment outcome with orthodontic fixed appliance still in place. Two open-source software programs, ITKSNAP (available at: http://www.itksnap.org/pmwiki/pmwiki.php) and 3D Slicer (available at: http://www. http://slicer.org/), were used to precisely segment, superimpose, and quantify the TMJ position changes after surgery. Open-source software tools were applied to calculate the dental and skeletal changes. Intrarater reliability was also validated.

2.1. 3D Analysis of TMJ Stability. The selected landmarks were identified using the CT images. The head orientation relative to the Frankfort horizontal (FH) plane was considered the horizontal reference. The porion (Po) and orbitale (Or) were utilized to set up the horizontal reference line. And this reference line was applied to form the horizontal reference plane with orbitale of the left side. The FH plane was formed by three points: orbitale left, orbitale right, and a landmark in the middle of the two porions (mid-Po). Landmark identification was conducted by one trained and calibrated operator, and measurements were taken by the same examiner (Ling-Chun Wang). These landmarks were identified on both the T1 (3 weeks before surgery) and the T2 (6 months after surgery) scans. All T1 and T2 scans were registered to the cranial base using a voxel-based registration algorithm (Figure 1) [13, 14].

Identification of landmarks of the TMJ (Figure 2) were defined as anatomical landmarks as (1) preoperative (T1): RL (right), LL (left)—the most lateral point of the condyle, RM (right), LM (left)—the most medial point of the condyle and (2) postoperative (T2): RL′ (right), LL′ (left)—the most lateral point of the condyle, RM′ (right), LM′ (left)—the most medial point of the condyle.

All these corresponding 3D points were visualized using 3D Slicer's quantitative 3D cephalometric (quantification of



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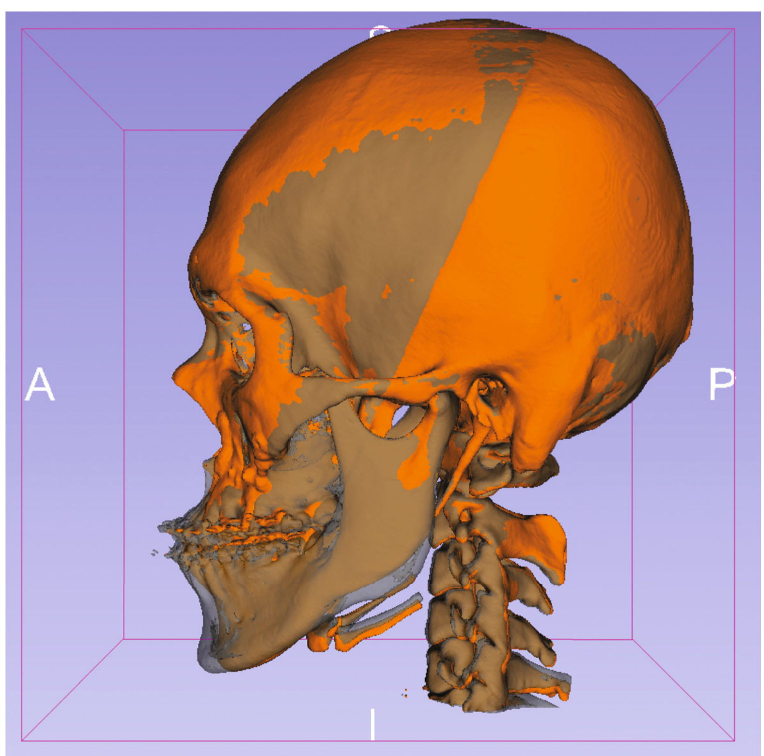
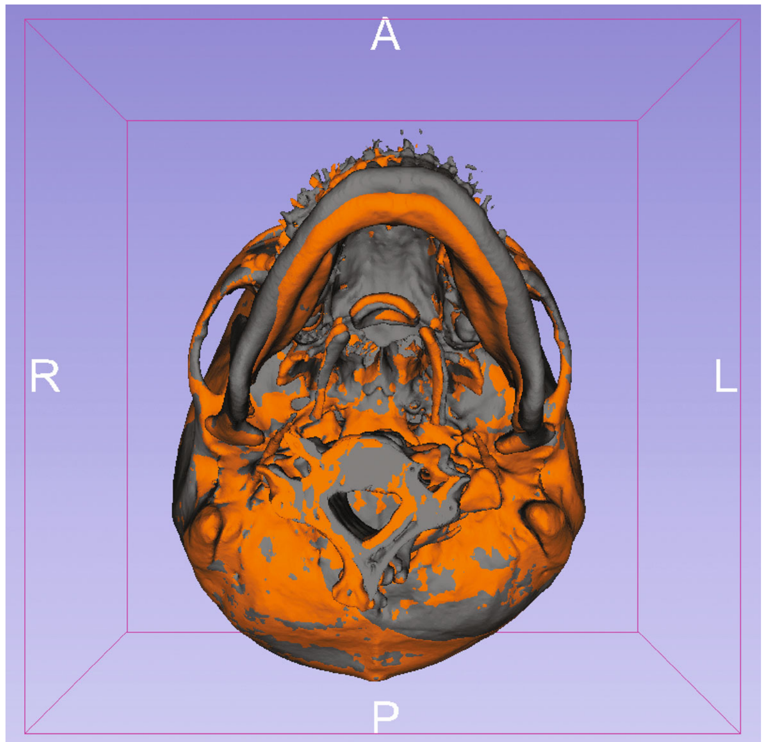


(b)

Figure 1: Continued.



(c)

Figure 1: The superimposition of presurgical (T1, gray area) and postsurgical craniofacial area (T2, orange area). The head was orientated relatively to the Frankfort horizontal (FH) plane which was established by bilateral orbitale and the landmark in the middle of the two porions (mid-Po). The superimpositions of T1 and T2 scans were registered to the cranial base using a voxel-based registration algorithm ((a) the right side; (b) the left side; (c) the bottom view side).

3D components [Q3DC]) tool (Figure 1). By placement of fiducial markers, this tool allows users to compute (1) the 3D distance between the T1 and registered T2 TMJ points and (2) the differences of the angle along each of the axes. Then, distances were measured between the most medial point of the condyles (RM-RM$'$ and LM-LM$'$) and between the most lateral point of the condyles (RL-RL$'$ and LL-LL$'$) in preoperative and postoperative imaging. In addition, the cutting angle between the axes (intercondylar angle) was also calculated (Figure 3). Paired t-test was applied to detect the differences between presurgical and 6-month postsurgical variables. The level of significance was set as the level of $p = 0.05$. The overall position discrepancy of TM joint condyles between T1 and T2 was assessed by superimposition of the frontal head surface, and the surface difference of the TMJ condyles was indicated by the color mapping that extends the discrepancies over the surface area. It was defined as the geographical summation error [12].

2.2. Intrarater Reliability. Intrarater reliability was measured using intraclass correlations for 3 variables (two 3D distances and intercondylar angle) in 5 subjects, with measurements taken on each subject 2 weeks apart. There was no statistical difference in defining the points and angle among the 3D quantitative points.

3. Results

A total of 23 patients with malocclusion who underwent bimaxillary orthognathic surgery met the eligible criteria for this study. The age of patients was ranged from 19 to 36 years (mean: 24.39 ± 4.8 years). The ratio of gender was 12 : 11 (female: male) (Table 1). The gender groups did not show any statistical difference in age. All these patients were diagnosed with midface deficiency and mandibular prognathism (Table 2), and their mean value of presurgical ANB was $-6.23 \pm 1.91°$. The mean distances of point A and pogonion to N-perpendicular line were 0.47 ± 1.59 mm and 10.65 ± 3.73 mm, respectively. The average presurgical Wits appraisal was -11.81 ± 3.34 mm. All the patients underwent bimaxillary surgical treatment with Le Fort I maxillary advancement and BSSO setback of the mandible. The surgical outcome revealed ANB was significantly improved into $2.33 \pm 1.54°$; the mean distances of point A and pogonion to N-perpendicular line were 2.5 ± 1.2 mm and 1.25 ± 0.58 mm, respectively. The mean postsurgical Wits appraisal was improved into 1.32 ± 3.22 mm (Table 2). The amount of Le Fort I maxillary advancement was 3.67 ± 1.68 mm in the right side (range: 1~4.5 mm) and 3.39 ± 1.47 mm in the left side (range: 1 to 5 mm). The amount of BSSO setback of the mandible was 9.87 ± 2.51 in the right side (range: 5 to 14 mm) and 9.04 ± 2.36 mm in the left side (range: 6 to

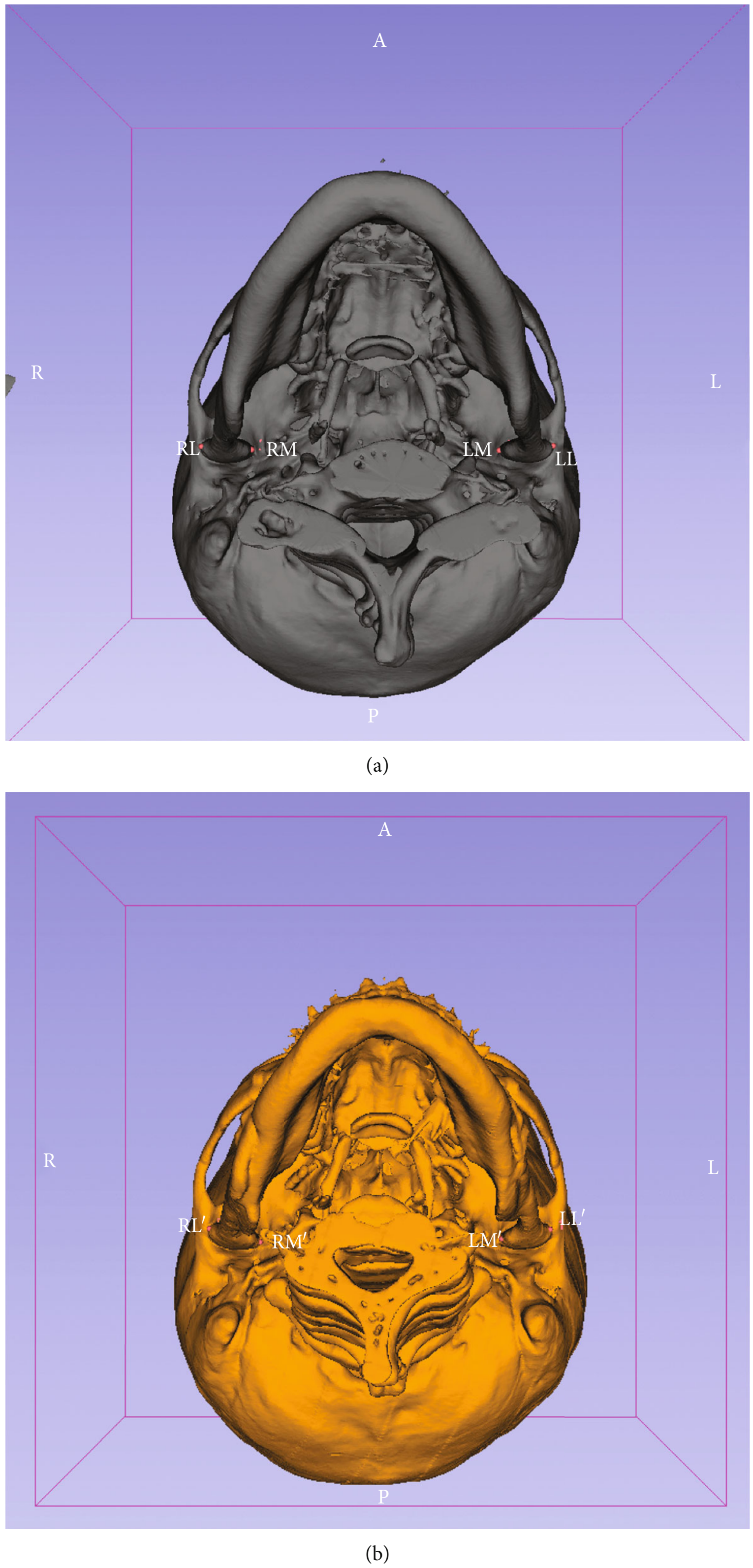
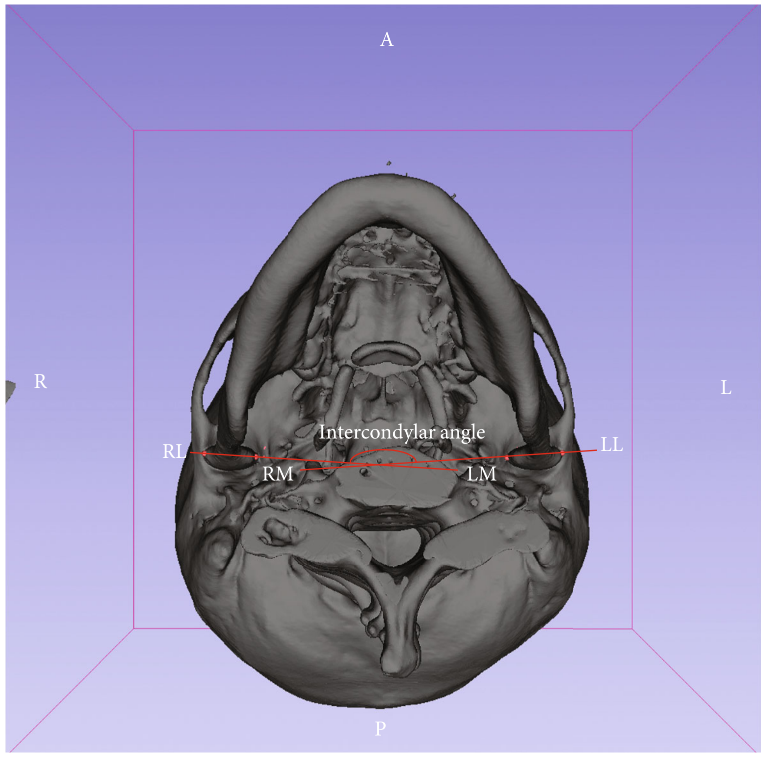


Figure 2: The 3D imaging of the craniofacial area reconstructed with the open-source software. RL (right), LL (left): the most lateral points of the condyles; RM (right), LM (left): the most medial points of the condyles are identified ((a) the presurgical view: T1; (b) the postsurgical view: T2).



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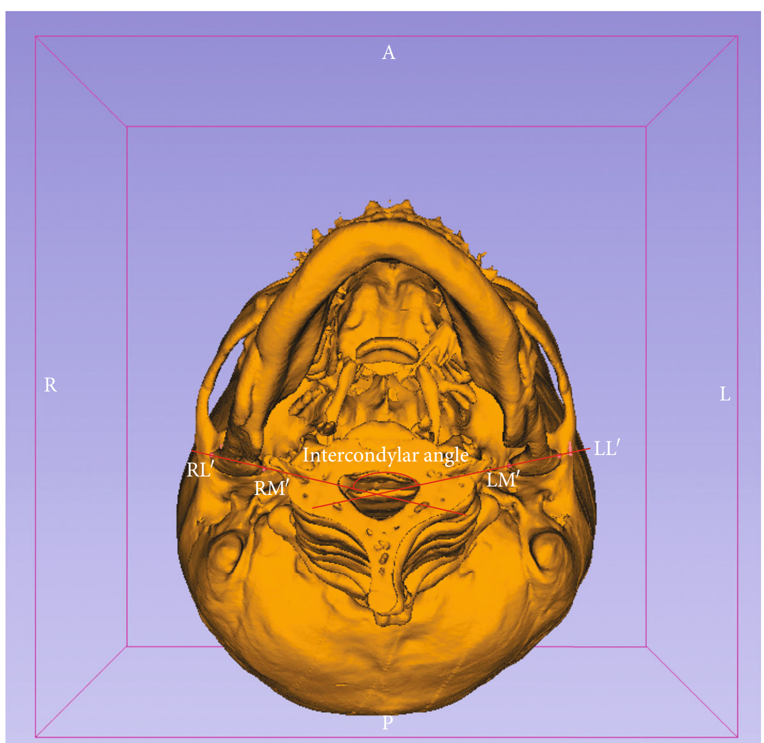


(b)

FIGURE 3: The bottom view of the mandible and cranial base. The cutting angle between the axes (intersection between RL-LM and RM-LL: intercondylar angle) was calculated and measured ((a) presurgical intercondylar angle (161.61 ± 5.08°); (b) postsurgical angle (159.28 ± 4.92°); $p = 0.061$).

Table 1: Distribution of samples by sex and age.

Sex	Amount	Mean age (years)
Male	11	24.9 ± 4.5 years (range: 20.3~33.5 years)
Female	12	4.9 ± 4.5 years (range: 20.5~33.3 years)
Total	23	24.4 ± 4.8 years (range: 20.3~33.5 years)

Table 2: Cephalometric measurements at 3 weeks before surgery and 2 days immediately postsurgically.

Measurement	Mean value ± SD (before surgery)	Mean value ± SD (immediate after surgery)
SNA	79.31 ± 1.52°	83.72 ± 1.28°
SNB	86.12 ± 1.50°	81.13 ± 1.32°
ANB	−6.23 ± 1.91°	2.33 ± 1.54°
GoGn-SN	31.91 ± 3.22°	34.34 ± 4.91°
Gonial angle	127.21 ± 4.15°	127.23 ± 4.23°
A-Nv	0.47 ± 1.59 mm	2.5 ± 1.2 mm
Pog-Nv	10.65 ± 3.73 mm	1.25 ± 0.58 mm
Wits	−11.81 ± 3.34 mm	1.32 ± 3.22 mm

S: sella; N: nasion; point A: subspinale; point B: supramentale; SNA: sella-nasion-point A angle; SNB: sella-nasion-point B angle; ANB: point A-nasion-point B angle; Go: gonion; Gn: gnathion; GoGn-SN: mandibular plane-SN angle; gonial angle: Ar-GoGn angle; Ar: articulare; Nv: the line goes through N and is perpendicular to the FH plane; FH plane: the plane from Po (porion, the most superior positioned point of the external auditory meatus) to Or (orbitale, the lowest point on the inferior rim of the orbit); A-Nv: the distance from point A to the Nv line; Pog-Nv: the distance from Pog to the Nv line; Wits: the distance from AO to BO (the points of contact of the perpendicular line from points A and B onto the occlusal plane are defined as AO and BO).

13 mm). These average distances of maxilla advancement and distance of mandibular setback were revealed in Table 3.

The mean displacement of the right most lateral condylar point (RL-RL′) was 1.04 ± 0.42 mm, and the mean displacement of the left most lateral condylar point (LL-LL′) was 1.19 ± 0.41 mm. The mean displacement of the right most medial condylar point (RM-RM′) was 1.03 ± 0.39 mm, and the left most medial condylar point (LM-LM′) was 0.96 ± 0.39 mm (Table 4). The changes of the above targeted landmarks did not show any statistical significance between T1 and T2.

The angle between the condyles (intercondylar angle) was assessed by measuring the degrees of intersected angle formed by the two longitudinal axes of the condyles (Figures 3(a) and 3(b)). The mean angle was 161.61 ± 5.08° before and 159.28 ± 4.92° after surgery. The paired t-test did not reveal any significant change between the angles before and after the surgery ($p = 0.061$, Table 4).

The geographical discrepancies of TMJ position between T1 and T2 were measured by calculating the summation difference of superimposition over the overall surface contour of TMJ. This geographical summation mean error was 1.43 mm ± 0.29 mm (range: 0.62 mm to 1.86 mm; Figure 4).

Table 3: The distance of bony movements by the surgery.

Side	Maxillary advancement (mm)	Mandibular setback (mm)
Left	3.39 ± 1.47 mm (range: 1~5 mm)	7.04 ± 2.36 mm (range: 3~13 mm)
Right	3.67 ± 1.68 mm (range: 1~6.5 mm)	5.87 ± 2.51 mm (range: 2~11 mm)

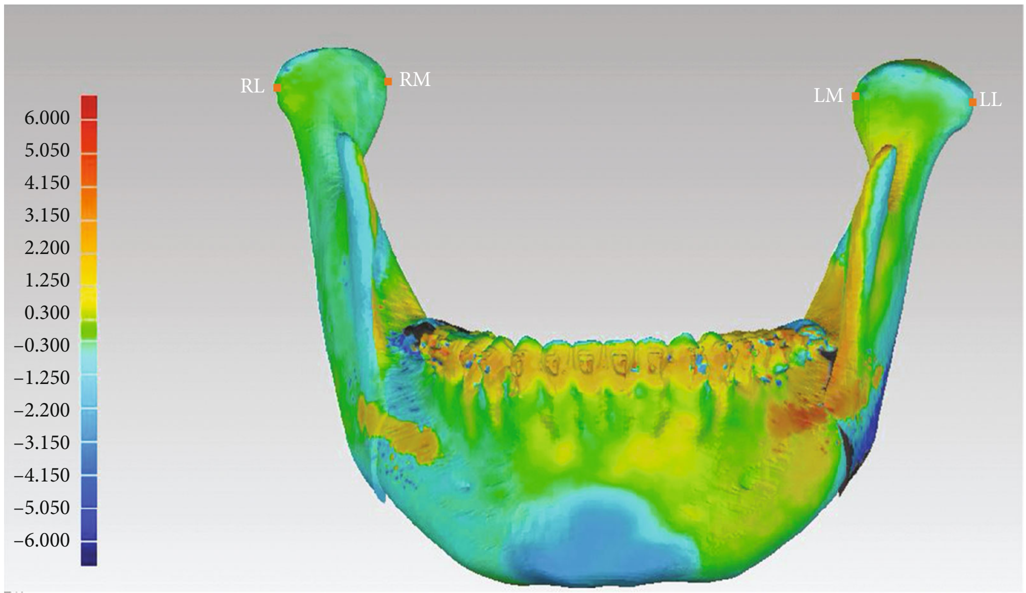
Table 4: The displacement of the most lateral and medial condylar points and the variation of intercondylar angles.

Parameter		
Condylar landmarks	Mean displacement (mm)	
RL-RL′	1.04 ± 0.42 mm	
LL-LL′	1.19 ± 0.41 mm	
RM-RM′	1.03 ± 0.39 mm	
LM-LM′	0.96 ± 0.39 mm	
Intercondylar angles	Mean value ± SD	p value
Presurgical	161.61 ± 5.08°	
Postsurgical	159.28 ± 4.92°	0.061

4. Discussion

The aim of this study was to assess the postsurgical stability of temporomandibular joint position in skeletal class III patients treating with 2-jaw surgery via the standard protocol of CASNOS. The accuracy of CASNOS protocol in transferring the simulation into the actual operation has been demonstrated [12]. Its benefits regarding blood loss and reduction of operation time in 2-jaw orthognathic surgery in correcting the dentoskeletal discrepancy have also been indicated [12]. All the skeletal class III patients in this study were surgically corrected into the desirable skeletal outcome which was indicated by the surgical change of ANB (from -6.23° to 2.33°) and other two linear parameters: point A and pogonion to N-perpendicular line were also improved. Point A to N-perpendicular line was corrected from 0.47 mm to 2.5 mm, and pogonion was set back from 10.65 mm to 1.25 mm relatively to the N-perpendicular line (Table 2). Nevertheless, the postsurgical stability of TM joints via 3D assessment has not yet been investigated. In this study, the position of TM joint condyles of 23 skeletal class III patients treated with combined surgical orthodontics between presurgical and 6-month postsurgical CT imaging was assessed with 3D imaging software.

In the surgical procedure of mandibular setback via bilateral sagittal split osteotomy, the proximal segments were distally moved and then fixed with the distal segments under the new designed occlusion. Under the fixation force and the vector from the temporomandibular ligaments, the condylar head rotation may occur. Several studies investigated the changes of condylar axis after mandibular osteotomies. In the previous studies, condylar axis was shown to be rotated inward in the axial view after BSSO [15–17]. However, in Katsumata's study, no obvious condylar axis rotation



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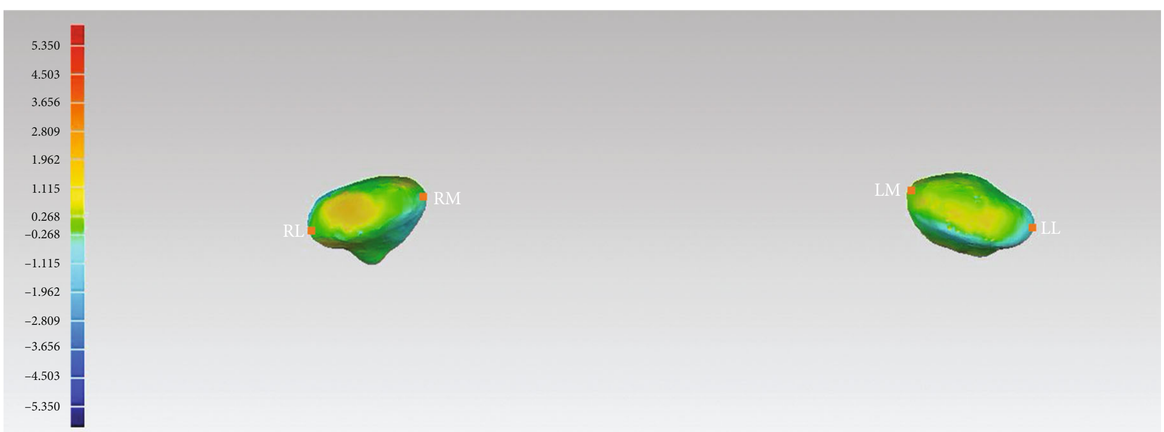

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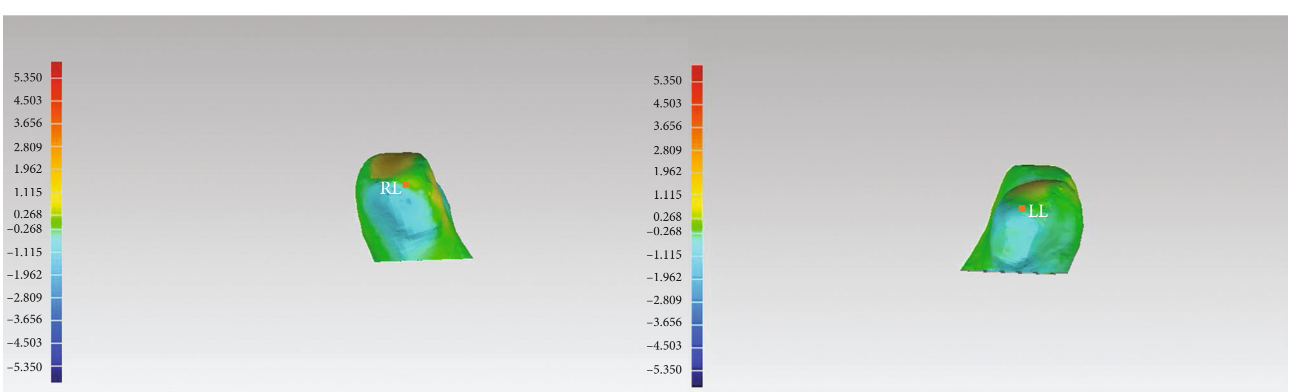

(c)

Figure 4: (a) The distribution of color zones indicates the means of mandibular position difference between T1 and actual T2 of the subjects. The mandibular mean differences of the patients were distributed in the green and blue zones (green: the absolute value < 0.300 mm; yellow: the absolute value < 1.250 mm). The landmarks of the most medial (RM and LM) and lateral point (RL and LL) were identified. (b) The distribution of color zones indicates the means of mandibular discrepancies on the right and left condylar heads between T1 and T2 of individual subjects. The mean discrepancies of the patients were distributed in the green and blue zones. The landmarks (RM, LM, RL, and LL) were identified from the top and lateral views. All the 3D displacements of the most lateral and medial condylar points are as follows: RL-RL′: 1.04 ± 0.42 mm; LL-LL: 1.19 ± 0.41 mm; RM-RM′: 1.03 ± 0.39 mm; and LM-LM′: 0.96 ± 0.39 mm ((b) the top view and (c) the lateral view; details in Table 4). (c) Lateral view of the condyle heads and the identified landmarks of RL and LL.

occurred after BSSO, but 85.9% of the condyles tended to rotate outward after IVRO [18]. Different rotation directions might be explained due to the different surgical techniques and incorporation of adjunctive procedures. In our study, no significant change between the angles of the lateral condyles before and after osteotomy was demonstrated. Our result echoes to Holzinger's study with samples treated by surgery-first orthognathic treatment [19].

The direction of immediate condylar displacement is variable. Anteroinferior, posteroinferior, and equal distributions in vertical direction were reported in the previous studies. The posterior displacement may be caused by manual manipulation over the proximal segments during the surgery, and the inferior displacement may result from intra-articular edema in the early stage after surgery [20]. Other conditions such as application of muscle relaxant under general anesthesia leading to condyle sag may also occur. After removal of surgical stent, the condyles tend to move back to the preoperative position under the force of masticatory muscles and the strain of temporomandibular ligament. With the resolution of edema, recovery change may occur [10].

The amount of condylar position change varies in each individual and is influenced by numerous factors indicated by other studies, such as surgical procedure, experience of the surgeon, and patient anatomy. In the present study, however, the position of TM joint condyles did not demonstrate any significant change postsurgically, when the recovery of masticatory function had already taken place. The stable postsurgical position of TMJ indicates the bimaxillary orthognathic surgery via 3D CASNOS protocol can achieve a desired and stable result in treating skeletal class III adult patients with retrognathic maxilla and prognathic mandible.

The findings in this study corresponded to the result in Chen et al.'s study. In Chen et al.'s study, condylar position was in a concentric position in glenoid fossa 3 months after orthognathic surgery and remained stable in one year [10]. In contrast, in the study of Harris et al., most condyles in the cases tended to displace medially, posteriorly, superiorly, and angle medially 2 months after BSSO advancement [21]. The different result might be due to the timing of assessment which was 4 months earlier than our study.

Some devices are developed for condyle stabilization during orthognathic surgery to prevent unwanted condylar movement from the original position [22]. In the present study, no such positioning device was used except the 3D surgical navigation plates which were fabricated according to the CASNOS protocol. The CASNOS protocol was demonstrated to enable orthodontists and surgeons to treat orthognathic patient precisely, especially during transferring the simulation into actual surgery via navigation procedures [12].

The limitations of our study are the sample size and the follow-up period. It is desirable to include sufficient samples with varied types of surgical modalities to assess the accuracy of CASNOS protocol in positioning the TMJ during orthognathic surgery. According to the study of meta-analysis by Jamilian et al., SNB showed significant increase in a 2-year follow-up while SNA and overbite increased significantly after a 2-year follow-up of the patients with skeletal class III malocclusion after bimaxillary surgery or mandibular setback. It was considered that the phenomenon was followed by residual growth of maxilla and mandible [23]. Though no obvious growth was revealed in the presurgical superimposition of the adult patient aged from 19 to 36 years (mean age 24.39 ± 4.8 years) in the present study, the long-term TMJ position brought by orthognathic surgery is to be evaluated. The other features to be investigated are the influence of different fixation methods on postsurgical position of TMJ.

5. Conclusions

The postsurgical position of TM joint condyles in our study presented only a mild change with the landmarks' displacement all within a range of 1.2 mm. This indicates the bimaxillary orthognathic surgery via 3D CASNOS protocol can achieve a desired and stable TMJ position in treating skeletal class III adult patients with retrognathic maxilla and prognathic mandible.

Data Availability

The 3D image data used to support the findings of this study are included within the article.

Ethical Approval

This study has been carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and has been approved by the Institutional Review Board of the Chang Gung Medical Foundation (IRB No: 201801488B0).

Consent

Written informed consent was obtained from all the patients before enrollment in the study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Postoperative Changes in Tongue Area and Pharyngeal Airway Space following Mandibular Setback Surgery through Intraoral Vertical Ramus Osteotomy

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Purpose. The aim of this study was to determine changes in the tongue area and pharyngeal airway space (PAS) after intraoral vertical ramus osteotomy (IVRO). *Materials and Methods*. Serial lateral cephalograms of 40 patients with mandibular prognathism who underwent IVRO were evaluated before (T1), immediately after (T2), and more than 1 year after (T3) surgery. Paired t-tests and Pearson's correlation analysis were used to evaluate the postoperative changes in the mandible, nasopharyngeal airway (NOP), retropalatal pharyngeal airway (RPP), retroglossal pharyngeal airway (RGP), hypopharyngeal airway (HOP), PAS, and tongue area (TA). The null hypothesis states that there are no significant correlations among the extent of mandibular setback and the changes in the TA and PAS after IVRO. *Results*. Immediately after the operation (T12), the mandible was set back by 12.6 mm. The NOP, HOP, and PAS were significantly reduced by 35.7 mm^2, 116 mm^2, and 185 mm^2, respectively. The TA was increased by 69.6 mm^2. The changes in PAS and TA revealed no significant difference between female and male patients at T12, T23, and T13. Moreover, no significant correlations were found among the extent of mandibular setback, TA changes, and PAS changes after IVRO. Thus, the null hypothesis was accepted. *Conclusions*. At the final follow-up (T13), no significant change was found in the PAS (including NOP, RPP, RGP, and HOP) and TA. The changes in PAS and TA revealed no significant difference between female and male patients at T12, T23, and T13.

1. Introduction

Mandibular prognathism is potentially a genetic disorder and characterized by protrusion of the mandible [1]. It is one of maxillofacial deformities and disfigures the facial appearance. Mandibular prognathism has prevalence as high as 15% in the Asian population and 1% in Caucasians [2, 3]. Surgery to correct mandibular prognathism alters skeletal and soft-tissue components and may cause changes in the tongue and pharyngeal airway space (PAS) [4, 5]. The pharynx is a tubular structure that extends from the cranial base to the sixth cervical spine. From top to bottom, the pharynx can be divided into 3 parts: the nasopharynx, oropharynx, and laryngopharynx (or hypopharynx). In the midsagittal plane, the nasopharynx and oropharynx are set apart by the hard palate. The oropharynx and laryngopharynx are set apart by the epiglottis. The oropharynx is located behind the nasal cavity and oral cavity and above the larynx, trachea, and esophagus [6]. The oropharynx can be further divided into the retropalatal pharynx and retroglossal pharynx set apart by the caudal margin of the soft palate.

The tongue is the most active functional part of the oropharyngeal system and is directly affected by any modification to the orodental environment, especially the mandible [7]. During mandibular setback surgery, the tongue is moved backward, which changes its morphorage. Therefore, the pharynx plays a crucial role in respiration and swallowing. Consequently, the PAS is reduced, which may lead to the onset of obstructive sleep apnea (OSA). OSA is characterized by intermittent and repeated upper-airway collapse during sleep and may lead to breathing cessation. OSA has detrimental effects on nighttime sleep quality and general health due to excessive sleepiness during the day. Riley et al. [8] reported 2 cases of OSA following mandibular setback surgery to correct mandibular prognathism. Therefore, surgeons should be cautious in planning for a large amount of setback in the treatment of mandibular prognathism. The purpose of the present study was to determine the postoperative changes in the tongue area (TA) and PAS following mandibular setback surgery through intraoral vertical ramus osteotomy. The study hypothesized that no significant correlations exist in the postoperative skeletal changes between the TA and PAS after mandibular setback surgery.

2. Materials and Methods

2.1. Patient Selection. Forty patients with mandibular prognathism who were receiving treatment from the Division of Oral Maxillofacial Surgery at Kaohsiung Medical University Hospital and who fulfilled the following criteria were selected: [1] an Angle Class III malocclusion with mandibular protrusion; [2] no history of trauma or other congenital craniofacial abnormality; [3] no growth of the mandible; and [4] receipt of IVRO alone. This retrospective case study was approved by the Human Investigation Review Committee at the Kaohsiung Medical University Hospital (KMUH-IRB-20140173).

2.2. Study Design. Patients were routinely examined using serial cephalograms preoperatively (T1), immediately postoperatively (T2), and more than 1 year postoperatively (T3) to evaluate the postoperative changes in the mandible, TA, and PAS. The reference points and definitions used in this study were as follows (Figure 1): S: sella; N: nasion; Me: menton—the most inferior point on the mandibular symphysis; ANS: anterior nasal spine; PNS: posterior nasal spine; H: the most superior and anterior point of hyoid bone; G: the most prominent point of the mandibular symphyseal posterior border; V: vallecula epiglottica; TT: tongue tip; U: tip of the uvula; E: the most superior point on the epiglottis; and C4: inferoanterior point on the fourth cervical vertebra. The following reference lines were considered: [1] X-axis: constructed by drawing a line through the nasion 7° above the SN line and [2] Y-axis: constructed by drawing a line through the sella (S) perpendicular to the X-axis.

2.3. Intervention. The following areas of airway spaces and the tongue were measured: the [1] nasopharyngeal airway (NOP; the area outlined by the roof of pharynx, an extended line of ANS-PNS, and the posterior pharyngeal wall); [2] retropalatal pharyngeal airway (RPP; the area outlined by the inferior border of the nasopharynx, posterior surface of the soft palate, a line parallel to the horizontal plane through point U, and the posterior pharyngeal wall); [3] retroglossal pharyngeal airway (RGP; the area outlined by the inferior border of the retropalatal pharyngeal airway, posterior surface of the tongue, a line parallel to the horizontal plane through point E, and the posterior pharyngeal wall); [4] hypopharyngeal airway (HOP; the area outlined by the inferior border of the retroglossal pharyngeal airway, posterior surface of the tongue and epiglottis, a line parallel to the horizontal plane through point C4, and the posterior pharyngeal wall); [5] PAS: sum of the NOP, RPP, RGP, and HOP; and [6] TA: sagittal tongue above the H-V and H-G lines. The areas of the tongue and PAS were measured using the NIH ImageJ software.

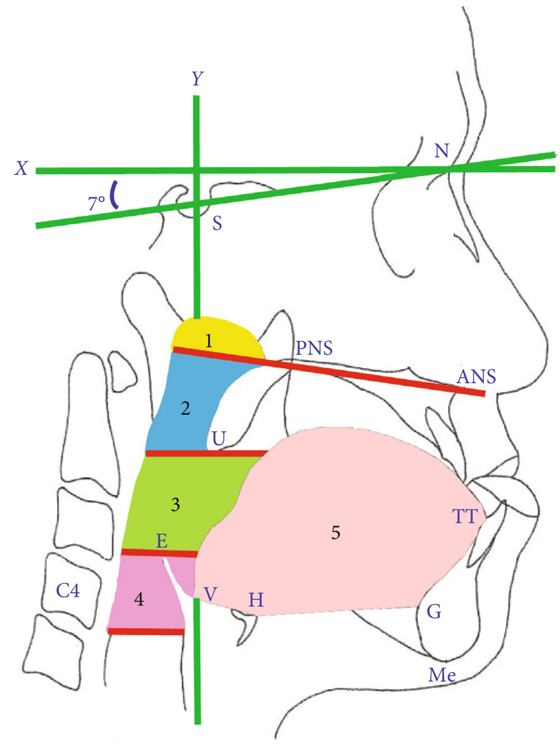

Figure 1: The reference points: S: sella; N: nasion; Me: menton: most inferior point on the mandibular symphysis; ANS: anterior nasal spine; PNS: posterior nasal spine; U: tip of uvula; E: most superior point on the epiglottis; C4: inferoanterior point on the fourth cervical vertebra. The reference lines: SN line; X-axis: constructed by drawing a line through the nasion 7° above the SN line; Y-axis: constructed by drawing a line through the S perpendicular to the X-axis. The pharyngeal airway spaces: (1) NOP: nasopharyngeal airway, yellow color; [2] RPP: retropalatal pharyngeal airway, blue color; [3] RGP: retroglossal pharyngeal airway, green color; [4] HOP: hypopharyngeal airway, pink color; [5] TA: tongue area, flesh color.

2.4. Study Size. To ensure appropriate sample size, at least 35 samples were included to provide a power of 0.8 (alpha = 0.05). The cephalometric landmarks were manually superimposed and identified twice by the author. The intrainvestigator reliability (correlation coefficient: 0.993, $P < 0.001$) was acceptable.

2.5. Statistical Analysis. Postoperative changes at the reference points at each time point (T12, T23, and T13) were quantified to estimate statistical parameters, including the mean value and standard deviation. Statistical analysis using

Table 1: Student's t-test for significance for the menton (Me), pharyngeal airway space (PAS), and tongue area (TA), in the T12, T23, and T13 periods.

Variable	Total patients ($n = 40$)			Female patients ($n = 26$)		Male patients ($n = 14$)		Intergender
	Mean	SD	P value	Mean	SD	Mean	SD	Comparison
Me (mm)								
Horizontal change								
T12	-12.6	4.34	<0.001*	-13.1	4.19	-11.6	4.75	0.318
T23	0.6	3.17	0.225	1.0	3.26	-0.1	3.07	0.266
T13	-11.9	4.02	<0.001*	-12.1	4.06	-11.7	4.23	0.797
Vertical change								
T12	0.6	1.85	0.059	0.8	1.95	0.3	1.74	0.413
T23	-0.5	1.80	0.098	-1.0	1.79	0.5	1.51	0.010*
T13	0.1	1.65	0.743	-0.3	1.64	0.7	1.61	0.084
PAS (mm^2)								
T12	-185.0	299.76	<0.001*	-189.5	243.28	-176.8	394.50	0.913
T23	91.6	341.87	0.098	128.9	296.28	22.2	416.94	0.406
T13	-93.5	282.32	0.043*	-60.6	316.99	-154.5	199.24	0.258
TA (mm^2)								
T12	69.6	290.04	0.137	94.0	289.00	7.8	290.93	0.378
T23	-93.5	253.94	0.025*	-113.3	234.10	-45.9	291.41	0.464
T13	-23.9	239.49	0.531	-19.3	264.89	-32.4	192.38	0.859

n: number of patients; T12: immediate surgical changes; T23: postoperative stability; T13: over 1-year surgical change. *Significant $P < 0.05$.

the paired t-test and Pearson's correlation coefficient was conducted at a confidence level of 95%. The null hypothesis was that no significant correlation exists among the changes in the mandible, TA, and PAS after mandibular setback surgery.

3. Results

3.1. Participants. The participants comprised 26 female and 14 male patients, with a mean age of 20.5 years (range, 17-34 years). The mean duration of postoperative follow-up was 28.5 months (range, 24-60 months).

3.2. Comparisons. As detailed in Table 1, the preoperative areas (Figure 2) were as follows: NOP, 328 mm^2; RPP, 495 mm^2; RGP, 452 mm^2; HOP, 380 mm^2; PAS, 1655 mm^2; and TA, 3118 mm^2. Postoperatively, the Me at T12 and T13 was set back by 12.6 mm ($P < 0.001$) and 11.9 mm, respectively. The Me was significantly more upward (by 1 mm) in the female patients compared with the male patients (downward by 0.5 mm). At T21 (Tables 1 and 2), the NOP was reduced by 35.7 mm^2 ($P = 0.004$), HOP was reduced 116 mm^2 ($P < 0.001$), and PAS was reduced by 185 mm^2 ($P < 0.001$). The changes in the pharyngeal airway spaces (NOP, RPP, RGP, HOP, and PAS) are shown in Figure 3. The TA was increased by 69.6 mm^2, but the difference was without significance. The PAS and TA were not significantly different between the female and male patients at T12, T23, or T13.

The significant changes at T23 were as follows: NOP increased by 41.6 mm^2 ($P = 0.001$), HOP increased by

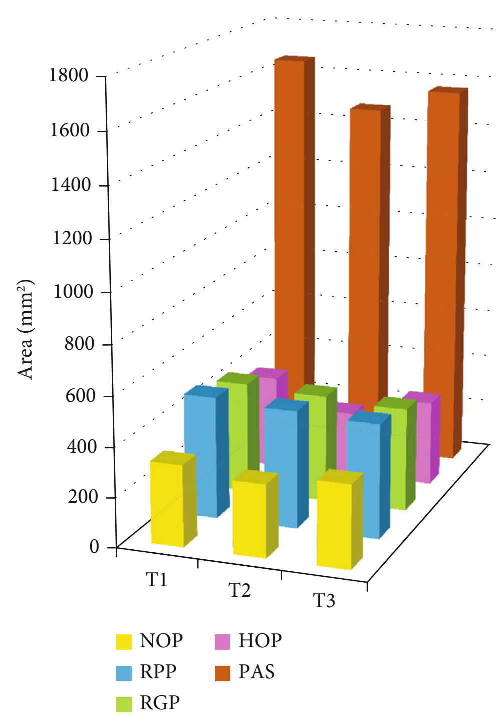

Figure 2: The pharyngeal airway spaces in the T1, T2, and T3 periods. NOP: nasopharyngeal airway (yellow color); RPP: retropalatal pharyngeal airway (blue color); RGP: retroglossal pharyngeal airway (green color); HOP: hypopharyngeal airway (pink color); PAS: pharyngeal airway space (brown color: sum of NOP, RPP, RGP, and HOP).

Table 2: Student's t-test for significance for NOP, RPP, RGP, and HOP airways in T12, T23, and T13.

Variable (mm^2)		Total patients Mean	SD	P value
NOP	T12	-35.7	74.51	0.004*
	T23	41.6	76.27	0.001*
	T13	5.9	95.17	0.696
RPP	T12	-17.6	115.03	0.338
	T23	-14.5	101.48	0.372
	T13	-32.1	117.63	0.092
RGP	T12	-15.5	161.43	0.546
	T23	-16.7	135.08	0.440
	T13	-32.2	148.92	0.179
HOP	T12	-116.2	121.98	<0.001*
	T23	81.1	142.68	0.001*
	T13	-35.1	141.77	0.126

T12: immediate surgical changes; T23: postoperative stability; T13: over 1-year surgical change; NOP: nasopharyngeal; RPP: retropalatal pharyngeal; RGP: retroglossal pharyngeal; HOP: hypopharyngeal. *Significant $P < 0.05$.

81 mm^2($P = 0.001$), and TA reduced by 93.5 mm^2 ($P = 0.025$). The significant changes at T13 were as follows: Me was moved backward by 11.9 mm ($P < 0.001$), and the PAS reduced by 93 mm^2 ($P < 0.001$). The decreases in the areas of RPP and RGP were similar at T12, T23, and T13. The areas of the NOP and HOP were decreased at T12 and were restored at T13.

3.3. Outcomes. As shown in Tables 3 and 4, horizontal and vertical movements of the Me had no significant correlations with the PAS and TA at T12 and T23. However, at T13, a significant correlation ($r = 0.409$, $P < 0.01$) was noted between horizontal changes in the Me and HOP (Table 5). This result indicates that a large extent of mandibular setback significantly reduced the HOP but had no significant effect on the NOP, RPP, RGP, PAS, or TA. No significant correlation was observed between the TA and PAS at T12, T23, or T13 (Table 6). Moreover, no significant correlations were found among the extent of mandibular setback, TA changes, and PAS changes after IVRO. Therefore, the null hypothesis was supported.

4. Discussion

Mandibular setback surgery for the treatment of mandibular prognathism can alter the position of the tongue base, hyoid bone, genioglossus muscle, and geniohyoid muscle, which may further narrow the PAS. In 1995, Deegan [9] claimed that the patency of the pharyngeal airway mainly depends on the effect of the oropharynx muscle. If the pressure exceeds the load of the oropharynx muscle, the pharynx cavity can collapse. Many studies [10–13] have shown that OSA reduces both tonic and phasic activities of the genioglossus, geniohyoid, tensor palatini, levator palatini, palatoglossus, and other respiratory muscles at sleep onset.

Whether the PAS can collapse severely to cause airway complications after mandibular setback surgery remains controversial. Efendiyeva et al. [14] found no significant change in the nasopharyngeal area postoperatively at 5-month follow-up compared with before the operation. Aydemir et al. [15] reported that the nasopharyngeal area was significantly increased by 13.1%. They concluded that the increase in the nasopharyngeal area occurred to compensate for the reduction in the oropharyngeal and hypopharyngeal airway collapse after mandibular setback surgery. In our study, the NOP was significantly reduced by 10.9% (35.7 mm^2) immediately after the operation. We found that the causes of NOP narrowing were postoperative swelling of the posterior nasopharyngeal wall due to intubation after a larger setback (12.6 mm). Because of the increased extent of setback following increased tissue dissection, more postoperative swelling and edema may have occurred. However, postoperative swelling and edema subsided during follow-up, and the recovery of the NOP area (T3) significantly increased by 12.7% (41.6 mm^2). Therefore, the NOP nonsignificantly increased by 1.8% (5.9 mm^2) from before the operation to the 1-year follow-up.

In the literature, Tselnik and Pogrel [5] reported that the immediate postoperation oropharyngeal area (retropalatal and retroglossal pharyngeal area) was significantly increased by 6.1% (70 mm^2). In our study, the oropharyngeal areas decreased nonsignificantly by 3.5% (33.1 mm^2). At the 6-month follow-up after mandibular setback surgery, Efendiyeva et al. [14], Jakobsone et al. [16],, and Park et al. [17] reported a nonsignificant decrease. Tselnik and Pogrel [5] reported that the oropharyngeal airway space was significantly decreased by 12.8% (152 mm^2) in the long-term follow-up. Aydemir et al. [15] found that the upper oropharyngeal area was significantly decreased by 16.6%, but the lower oropharyngeal area was nonsignificantly decreased by 18% after mandibular setback operation. Güven and Saraçoğlu et al. [18] revealed that the area of the oropharyngeal airway space was significantly decreased by 11.6%. In our study, the RPP and RGP areas nonsignificantly decreased by 6.5% (32.1 mm^2) and 7.1% (32.2 mm^2), respectively, over a 1-year follow-up.

Immediately after the operation, the HOP of our patients was significantly decreased by 30.5% (116 mm^2). Fortunately, the HOP significantly increased by 21.3% (81 mm^2) from T2 to T3 and nonsignificantly decreased by 11.4% (35 mm^2) over the 1-year follow-up (T13). Enacar et al. [4] reported a significant decrease in the hypopharyngeal airway space following mandibular setback surgery. They suggested that narrowing of the hypopharyngeal airway space due to posterior and inferior movement of the tongue can be permanent. By contrast, Jakobsone et al. [16] found no significant change in the hypopharyngeal airway space at final follow-up. Our results were similar to the report of Jakobsone et al. [16]

Postoperatively, the total PAS in our patients was significantly decreased by 11.2% (185 mm^2) and 5.6% (93 mm^2) immediately after surgery and over a 1-year follow-up, respectively. We also found that the HOP was majorly reduced in the total PAS immediately after the operation. During the follow-up period, the HOP also showed a major

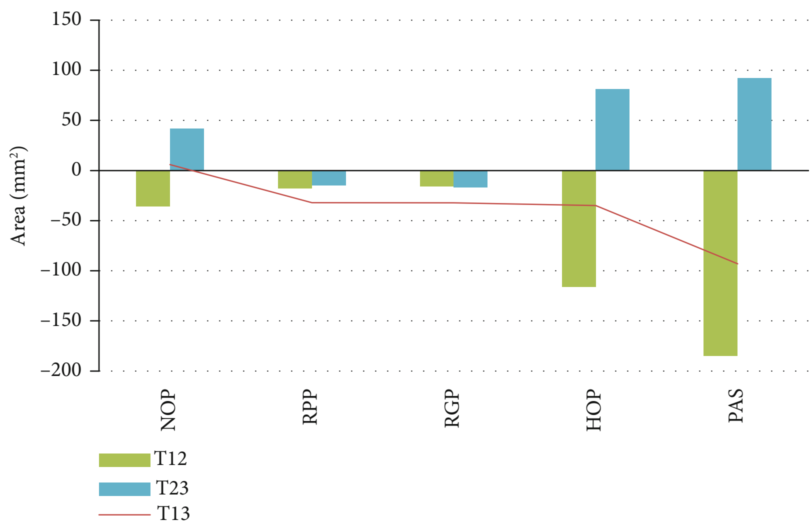

FIGURE 3: The area changes of pharyngeal airway space in the T12, T23, and T13 measurements. NOP: nasopharyngeal airway; RPP: retropalatal pharyngeal airway; RGP: retroglossal pharyngeal airway; HOP: hypopharyngeal airway; PAS: pharyngeal airway space, sum of NOP, RPP, RGP, and HOP.

TABLE 3: Pearson's correlation coefficient (r) test for the tongue area and pharyngeal airway space between menton (Me) in the T12.

Variable (mm^2)	Horizontal Me			Vertical Me		
	r	P value		r	P value	
NOP	0.016	0.921	—	0.011	0.947	—
RPP	-0.217	0.179	—	-0.153	0.345	—
RGP	-0.147	0.365	—	0.092	0.573	—
HOP	-0.146	0.368	—	0.016	0.923	—
PAS	-0.218	0.177	—	-0.001	0.996	—
TA	0.014	0.933	—	0	0.999	—

T12: immediate surgical changes. Significant $P < 0.05$; —: not significant. NOP: nasopharyngeal; RPP: retropalatal pharyngeal; RGP: retroglossal pharyngeal; HOP: hypopharyngeal; PAS: pharyngeal airway space, sum of NOP, RPP, RGP, and HOP; TA: tongue area.

TABLE 4: Pearson's correlation coefficient (r) test for the tongue area and pharyngeal airway space between menton (Me) in the T23.

Variable (mm^2)	Horizontal Me			Vertical Me		
	r	P value		r	P value	
NOP	0.153	0.347	—	0.204	0.206	—
RPP	0.237	0.14	—	0.080	0.625	—
RGP	0.101	0.534	—	0.106	0.514	—
HOP	0.071	0.665	—	0.144	0.374	—
PAS	0.174	0.283	—	0.171	0.29	—
TA	0.011	0.945	—	-0.095	0.558	—

T23: postoperative stability. Significant $P < 0.05$; —: not significant. NOP: nasopharyngeal; RPP: retropalatal pharyngeal; RGP: retroglossal pharyngeal; HOP: hypopharyngeal; PAS: pharyngeal airway space, sum of NOP, RPP, RGP, and HOP; TA: tongue area.

TABLE 5: Pearson's correlation coefficient (r) test for the tongue area and pharyngeal airway space between menton (Me) in the T13.

Variable (mm^2)	Horizontal Me			Vertical Me		
	r	P value		r	P value	
NOP	0.095	0.559	—	0.151	0.353	—
RPP	-0.192	0.236	—	0.217	0.178	—
RGP	-0.017	0.915	—	0.108	0.507	—
HOP	0.409	0.009	*	-0.056	0.733	—
PAS	0.148	0.361	—	0.170	0.293	—
TA	0.138	0.397	—	0.257	0.109	—

T13: over 1-year surgical change. *Significant $P < 0.05$; —: not significant. NOP: nasopharyngeal; RPP: retropalatal pharyngeal; RGP: retroglossal pharyngeal; HOP: hypopharyngeal; PAS: pharyngeal airway space, sum of NOP, RPP, RGP, and HOP; TA: tongue area.

TABLE 6: Pearson's coefficient (r) test between the tongue area and pharyngeal airway space in the T12, T23, and T13.

Variable (mm^2)	TA T12			TA T23			TA T13		
	r	P value		r	P value		r	P value	
NOP	-0.043	0.793	—	-0.147	0.365	—	-0.145	0.373	—
RPP	0.009	0.958	—	-0.127	0.434	—	0.090	0.583	—
RGP	-0.115	0.479	—	-0.201	0.214	—	0.106	0.516	—
HOP	-0.089	0.586	—	-0.136	0.404	—	0.120	0.459	—
PAS	-0.106	0.517	—	-0.207	0.201	—	0.105	0.520	—

T12: immediate surgical changes; T23: postoperative stability; T13: over 1-year surgical change. Significant $P < 0.05$; —: not significant. NOP: nasopharyngeal; RPP: retropalatal pharyngeal; RGP: retroglossal pharyngeal; HOP: hypopharyngeal PAS: pharyngeal airway space, sum of NOP, RPP, RGP, and HOP; TA: tongue area.

increase in the total PAS. Moreover, over a 1-year follow-up, the HOP presented a major reduction in the total PAS. Hochban et al. [19] explored the correlation between the extent of setback and change in the PAS and reported that the PAS area was significantly decreased but had no significant correlation with the extent of setback. Tselnik and Pogrel [5] reported a strong correlation between the extent of mandibular setback and the decrease in the PAS area. In our study, no significant correlation was found between the movement of the mandible and alternation of total PAS at T21, T32, and T13. However, the extent of setback had a significant effect on the narrowing of the HOP at T13.

Pae et al. [20] discovered that posterior tongue pressure and genioglossus muscle activity were significantly increased by a change from the upright to supine position in symptom-free controls. Therefore, immediately after mandibular setback surgery, patients may experience pressure from backward bending of the tongue in the supine sleeping position. Otherwise, respiratory distress would occur and potential to onset of OSA. Achilleos et al. [21] analyzed the change in tongue area after mandibular setback surgery and found no significant change at the postoperative 6-month follow-up and a significant increase at the 3-year postoperative follow-up. Jakobsone et al. [16] evaluated changes in the upper airway after bimaxillary correction of Class III malocclusion and found that the tongue length was increased significantly by 4.8 mm and tongue area reduced nonsignificantly by 62 mm^2. In our study, the tongue area was nonsignificantly increased by 69.6 mm^2 at T12 and then significantly decreased by 93.5 mm^2 at T23. Therefore, the tongue area was nonsignificantly decreased by 23.9 mm^2 at T13.

Tselnik and Pogrel [5] reported that in patients with other risk factors—for example, those who are overweight, with a short neck, or with a large tongue—a mandibular setback procedure can cause predisposal to the development of sleep apnea syndrome. Lowe et al. [22] analyzed the interaction between craniofacial structures and the upper PAS in patients with OSA through linear regression analysis and revealed that a high apnea index was associated with a large tongue volume. In our study, the reduction in RGP was not significantly correlated with the extent of mandibular setback. Many studies have considered OSA to most likely occur at the oropharyngeal (retropalatal and retroglossal) airway space. In a study by Shigeta et al. [23], patients with OSA had a longer soft palate in proportion to their oropharyngeal airway compared with normal controls. Pae et al. [20] emphasized that the vertical and anteroposterior position of the tongue and its relationship to airway size may be more important than the soft palate size in the pathogenesis of OSA. Even with larger extents of setback in our patients, no significant changes in the RPP and RGP were observed between before the operation and the final postoperative follow-up. Moreover, despite the extent of setback in our study being greater than that reported in the literature, no development of respiratory distress was reported in our patients.

Our study has some limitations. First, the mean duration of postoperative follow-up was 28.5 months. Airway complications may occur in patients who gain weight during the long-term follow-up after mandibular setback surgery. Regarding real postoperative PAS, another limitation of the present study was the lack of 3D analysis of the pharyngeal airway. The limitations of a 2D airway analysis are image enlargement issues, distortion, the overlap of bilateral craniofacial structures, and no information on the cross-sectional area. Future research should use 3D images for the assessment of the cross-sectional area and volume of the airway after mandibular setback surgery.

In conclusion, the PAS was not significantly affected by the changes in the mandible and tongue after mandibular setback surgery through IVRO. Although the pharyngeal airway areas were adversely affected after surgery, over the long-term follow-up, recovery and adaptation occurred.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Szu-Yu Hsiao and Kwei-Jing Chen contributed equally to this work.

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Research Article

Pharyngeal Airway and Craniocervical Angle among Different Skeletal Patterns

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Purpose. The aim of the present study was to investigate the pharyngeal airway dimensions and their correlations among the craniocervical angle and skeletal patterns. *Materials and Methods*. Cephalometric radiographs were obtained from 300 patients (≥15 years of age), of whom 150 were male patients and 150 were female patients. The patients were divided into three groups according to their skeletal patterns. The following dimensions were measured: NP: nasopharyngeal airway; PS: shortest distance from the soft palate to the pharyngeal wall; MP: Me-Go line intersecting the pharyngeal airway; TS: shortest distance from posterior tongue to pharyngeal wall; LP: laryngopharyngeal airway; UE length: shortest distance from the uvula to the epiglottis; PW: width of soft palate; PL: length of soft palate; ANB angle; palatal angle; and craniocervical angle. Paired t-test, one-way analysis of variance (ANOVA), and Pearson correlation were applied for statistical analysis. The null hypothesis was that there were no differences among skeletal patterns in terms of pharyngeal airway dimensions. *Results*. The C4C2-SN angle of the Class II pattern (108.1°) was significantly greater than that of the Class III pattern (104.4°). The Class II PL was significantly longer than the Class III PL in the all patients and female patients groups. The ANB angle exhibited moderate positive correlation with palatal angle (r: 0.462) and moderate negative correlation with TS (r: -0.400) and MP (r: -0.415) length. No significant differences were found in vertical hyoid lengths among all skeletal patterns. Class III (PS, TS, and MP) lengths were significantly greater than Class I and Class II in the all patients group. Regarding the LP length, no significant difference was found in the all patients group. Therefore, the null hypothesis was rejected. *Conclusion*. Class III had significantly greater pharyngeal airway dimensions (PS, TS, and MP) than Class I and Class II. In all skeletal patterns, NP length was moderately correlated with the palatal angle. The PS was weakly negatively correlated with the ANB and PL. The TS and MP were moderately negatively correlated with the ANB angle.

1. Introduction

The pharynx is crucial to respiration, deglutition, and vocalization. The pharynx is a cone-shaped passage that links the oral and nasal cavities to the esophagus and the trachea. The pharynx is primarily composed of the nasopharynx, oropharynx, and laryngopharynx. The nasopharynx and oropharynx are divided by the posterior soft palate of the upper jaw, whereas the oropharynx and laryngopharynx are divided by the tip of the epiglottis. The nasopharynx is the uppermost part of the pharynx, which comprises a cavity above the soft palate and posterior nasal cavity, where the nasal passages, inner ear channel, and pharynx meet. Handelman and Osborne [1] reported that the growth of the nasopharynx diameter continues to approximately 13 years of age. Vilella et al. [2] reported that nasopharynx and adenoidal development growth peak may be reached 15 years of age.

Regarding maxillary development, Nanda [3] suggested that maxillary growth is minimal beyond the age of 12 years.

Figure 1: Skeletal patterns from right to left: (a) Class I, (b) Class II, and (c) Class III.

Bae et al. [4] reported that the growth peak of the mandibular corpus occurs between the ages of 13 and 15 years and that males demonstrate considerably greater growth than females. Taylor et al. [5] investigated the pattern of bony and soft tissue growth of the oropharynx. They found that posterior nasal spine to pharyngeal wall and posterior soft palate to pharyngeal wall increased accelerate change (6–9 years and 12–15 years) and two periods of quiescence (9–12 years and 15–18 years) were identified. Therefore, pharynx airway development is nearly complete at the age of 15 years. This present study investigated skeletal patterns and pharyngeal airways with respect to the morphologies of the maxilla, soft palate, tongue, mandible, and hyoid bone.

2. Materials and Methods

Cephalometric radiographs (Department of Dentistry, Kaohsiung Medical University Hospital) were obtained from 300 patients (≥15 years of age), of whom 150 were male patients and 150 were female patients. The patients were divided into three groups (Figure 1) according to their skeletal patterns (specifically, the A point–nasion–B point (ANB) angle): Class I ($0^{\circ} < \text{ANB} < 4^{\circ}$), Class II ($\text{ANB} \geq 4^{\circ}$), and Class III ($\text{ANB} \leq 0^{\circ}$). Each group consisted of 100 patients, with a sex ratio of 50 male patients/50 female patients. The exclusion criteria were as follows: (1) patients with craniofacial symptoms or deformity, (2) patients who had experienced craniofacial bone surgeries, and (3) patients who had a history of maxillofacial trauma.

The following landmarks (Figure 2) were identified on each cephalogram: nasion (N); sella (S); anterior nasal spine (ANS); point A; posterior nasal spine (PNS); point B; menton (Me); tip of uvula (U); inferoanterior point on the fourth cervical (C4); inferoanterior point on the second cervical (C2); most superior and anterior point on the hyoid bone (H); most superior point on the epiglottis (E); and gonion (Go). The X-axis was constructed by drawing a line through the nasion, 7° above the SN line; the Y-axis was constructed by drawing a line through S, perpendicular to the X-axis. Linear and angular measurements included the following: NP: nasopharyngeal airway (ANS-PNS plane intersecting the pharyngeal wall); PS: shortest distance from the soft palate to the pharyngeal wall; MP: Me-Go line intersecting the pharyngeal airway; TS: shortest distance from posterior

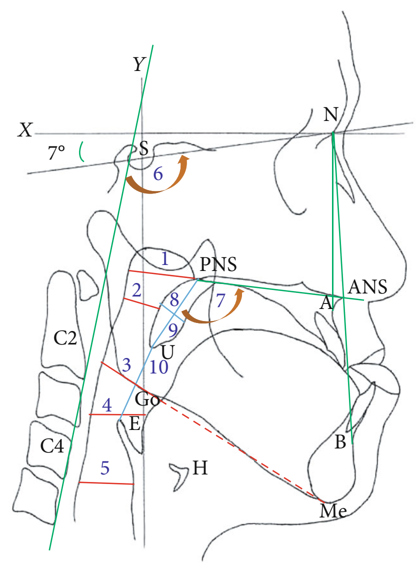

Figure 2: Cephalometric landmarks and linear measurements. Landmarks: nasion (N); sella (S); anterior nasal spine (ANS); point A; posterior nasal spine (PNS); point B; menton (Me); tip of uvula (U); inferoanterior point on the fourth cervical (C4); inferoanterior point on the second cervical (C2); most superior and anterior point on the hyoid bone (H); most superior point on the epiglottis (E); and gonion (Go). The X-axis was constructed by drawing a line through the N, 7° above the SN line; the Y-axis was constructed by drawing a line through S, perpendicular to the X-axis. Red line: 1: NP; 2: PS; 3: MP; 4: TS; 5: LP. Blue line: 8: PW; 9: PL; 10: UE. Angle measurement: 6: C2C4-SN; 7: palatal angle.

tongue to pharyngeal wall; LP: laryngopharyngeal airway (horizontal plane through C4, intersecting the pharyngeal wall); UE: shortest distance from the uvula to the epiglottis; PW: width of soft palate; PL: length of soft palate; ANB angle; palatal angle; C2C4-SN angle: angle between the C4C2 line and SN line; HH: horizontal position of hyoid; HV: vertical position of hyoid.

The data were processed by using IBM SPSS 20 (SPSS Inc., Chicago, IL, USA). In the cephalometric analysis, landmarks for soft and hard tissues were identified according to the results of paired t-test analyses of the male and female patients in each group. Intergroup comparison analysis was conducted with one-way analysis of variance (ANOVA),

Table 1: Patient characteristics in the skeletal classification (one-way ANOVA).

Variables	Class I (F = 50; M = 50)			Class II (F = 50; M = 50)			Class III (F = 50; M = 50)			Intergroup comparison		
	Mean	SD		Mean	SD		Mean	SD		p value		Significant
Age	23.9	6.20	—	24.2	5.95	—	23.4	5.97	—	0.671	—	
ANB	2.2	0.92	—	6.2	1.90	—	-2.9	2.73	—	<0.001	†	Class II > Class I > Class III
C2C4	106.5	7.42	∗(F > M)	108.1	6.49	—	104.4	8.16	—	0.002	†	Class II > Class III
Palate	124.3	6.02	∗(F > M)	127.4	6.45	∗(F > M)	120.4	7.72	—	<0.001	†	Class II > Class I > Class III
PW	8.7	1.87	—	8.6	1.94	∗(M > F)	9.2	2.02	∗(M > F)	0.073	—	
PL	35.5	4.17	∗(M > F)	36.6	4.50	—	34.4	4.01	∗(M > F)	0.001	†	Class II > Class III
UE	27.9	20.77	∗(M > F)	27.3	6.10	∗(M > F)	25.7	7.74	∗(M > F)	0.471	—	
Pharyngeal airway												
NP	24.0	3.46	—	25.2	3.14	—	24.2	3.60	—	0.024	†	Class II > Class I
PS	11.0	3.08	—	9.9	2.91	—	12.7	3.62	—	<0.001	†	Class III > Class I, Class III > Class II
TS	12.4	3.37	—	11.3	3.27	—	14.5	4.39	∗(M > F)	<0.001	†	Class III > Class I, Class III > Class II
MP	13.8	3.70	—	12.3	3.56	—	16.1	4.86	—	<0.001	†	Class III > Class I > Class II
LP	16.4	3.51	∗(M > F)	16.7	3.30	∗(M > F)	17.5	4.09	∗(M > F)	0.079	—	
Hyoid												
HH	16.4	9.13	∗(M > F)	12.2	8.06	∗(M > F)	19.1	9.95	∗(M > F)	<0.001	†	Class III > Class II, Class I > Class II
HV	122.7	10.01	∗(M > F)	122.6	10.66	∗(M > F)	121.7	10.63	∗(M > F)	0.762	—	

F: female; M: male; —: not significant. ∗: intergender comparison: statistically significant, $p < 0.05$. †: intergroup comparison: statistically significant, $p < 0.05$.

Table 2: The characteristics of female patients in the skeletal classification (one-way ANOVA).

Variables	Class I ($n = 50$)		Class II ($n = 50$)		Class III ($n = 50$)		Intergroup comparison		
	Mean	SD	Mean	SD	Mean	SD	p value		Significant
Age	23.2	5.41	23.3	4.87	23.3	5.74	0.998	—	
ANB	2.3	0.95	6.3	2.12	-2.7	2.63	<0.001	∗	Class II > Class I > Class III
C2C4	108.6	6.57	108.4	6.84	104.4	8.38	0.006	∗	Class I > Class III ; Class II > Class III
Palate	125.9	5.75	128.9	6.07	121.6	6.88	<0.001	∗	Class II > Class I > Class III
PW	8.5	1.67	7.9	1.69	8.5	1.40	0.121	—	
PL	34.4	3.65	36.3	4.76	33.5	3.61	0.003	∗	Class II > Class I ; Class II > Class III
UE	23.3	5.66	24.3	4.94	21.3	5.05	0.015	∗	Class II > Class III
Pharyngeal airway									
NSP	24.0	3.50	25.5	2.73	24.1	3.48	0.040	∗	Class II > Class I
PS	10.5	3.05	10.3	2.86	12.2	3.62	0.006	∗	Class III > Class I ; Class III > Class II
TS	12.0	3.08	11.2	2.57	13.5	3.53	0.001	∗	Class III > Class II
MP	13.2	3.35	12.7	3.28	15.4	4.29	0.001	∗	Class III > Class I ; Class III > Class II
LGP	15.5	3.21	15.9	2.66	15.5	3.29	0.809	—	
Hyoid									
HH	12.9	7.41	9.6	6.17	17.3	8.90	<0.001	∗	Class III > Class I ; Class III > Class II
HV	116.2	7.44	114.9	6.07	113.3	6.02	0.098	—	

n: number of patient. ∗: statistically significant, $p < 0.05$; —: not significant.

and post hoc comparisons were performed by using Tukey's honest significant difference test. Correlations between variables were examined by using Pearson correlation analysis. Strengths of correlation were described for the absolute value of the ratio of the compared variables: very weak (0–0.19), weak (0.20–0.39), moderate (0.40–0.59), strong (0.60–0.79),

Table 3: The characteristics of male patients in the skeletal classification (one-way ANOVA).

Variables	Class I ($n = 50$)		Class II ($n = 50$)		Class III ($n = 50$)			Intergroup comparison	
	Mean	SD	Mean	SD	Mean	SD	p value		Significant
Age	24.6	6.89	25.1	6.79	23.6	6.25	0.505	—	
ANB	2.1	0.90	6.2	1.66	-3.2	2.83	<0.001	*	Class II > Class I > Class III
C2C4	104.5	7.71	107.7	6.17	104.3	8.01	0.062	—	
Palate	122.7	5.90	125.8	6.50	119.3	8.38	<0.001	*	Class I > Class III ; Class II > Class III
PW	8.9	2.05	9.2	1.99	9.8	2.35	0.107	—	
PL	36.7	4.36	36.8	4.25	35.2	4.25	0.105	—	
UE	32.6	28.22	30.2	5.76	30.1	7.52	0.718	—	
Pharyngeal airway									
NSP	23.9	3.47	24.9	3.51	24.3	3.75	0.375	—	
PS	11.4	3.09	9.6	2.94	13.1	3.60	<0.001	*	Class III > Class I > Class II
TS	12.7	3.63	11.5	3.87	15.6	4.93	<0.001	*	Class III > Class I ; Class III > Class II
MP	14.4	3.96	11.9	3.81	16.9	5.31	<0.001	*	Class III > Class I > Class II
LGP	17.4	3.59	17.5	3.69	19.5	3.84	0.005	*	Class III > Class I ; Class III > Class II
Hyoid									
HH	19.8	9.44	14.9	8.90	20.8	10.69	0.005	*	Class III > Class II ; Class II > Class I
HV	129.2	7.75	130.3	8.48	130.1	6.98	0.766	—	

n: number of patient. *: statistically significant, $p < 0.05$; —: not significant.

and very strong (0.80–1.0). The level of significance was set as $p < 0.05$. The null hypothesis was that there were no differences among skeletal patterns in terms of pharyngeal airway dimensions. This was a retrospective study, approved by the human investigation review committee at the Kaohsiung Medical University Hospital.

3. Results

As shown in Table 1, age was not significantly different among the skeletal patterns. The C4C2-SN angle of the Class II pattern (108.1°) was significantly greater than that of the Class III pattern (104.4°). In terms of sex comparison, the C4C2-SN angle in female patients with the Class I pattern was significantly greater than in their male counterparts. The palatal angle of the Class II pattern (127.4°) was significantly greater than that of the Class I pattern (124.3°), which was in turn significantly greater than that of the Class III pattern (120.4°). Furthermore, palatal angles in female patients with Class I and Class II patterns were significantly greater than in their male counterparts. As shown in Table 2, changes in the female patient group were similar to changes observed for all patients (Table 1). In contrast, male patients (Table 3) showed no differences in the C2C4-SN angle among all skeletal patterns.

The PW did not differ in the all patients group (Table 1), female patients group (Table 2), or male patients group (Table 3). The Class II PL was significantly longer than the Class III PL in the all patients and female patients groups. The PL did not differ in the male patient group. The Class II UE length (24.3 mm) was significantly longer than the Class III UE length (21.3 mm) in female patients. The UE length did not differ in the all patients and male patients groups. Class III and Class I horizontal hyoid lengths (19.1 mm and 16.4 mm, respectively) were significantly greater than the corresponding Class II lengths (12.2 mm); horizontal hyoid lengths among male patients were significantly greater than those of female patients. No significant differences were found in vertical hyoid lengths among all skeletal patterns; however, male patients exhibited significantly greater vertical hyoid lengths, compared with female patients.

Comparison of the various pharyngeal airway lengths revealed the following results: Class II NP length (25.2 mm and 25.5 mm) was significantly greater than Class I NP length in the all patients (24 mm) and Class I NP female patients (24 mm) groups, but no significant difference was observed in the male patients group. Class III PS length was significantly greater than Class I and Class II PS length in the all patients group (Class III: 12.7 mm, Class I: 11 mm, and Class II: 9.9 mm), female patients group (Class III: 12.2 mm, Class I: 10.5 mm, and Class II: 10.3 mm), and male patients group (Class III: 13.1 mm, Class I: 11.4 mm, and Class II: 9.6 mm). Class III TS length was significantly greater than Class I and Class II TS length in the all patients group (Class III: 14.5 mm, Class I: 12.4 mm, and Class: 11.3 mm), female patients group (Class III: 13.5 mm, Class I: 12 mm, and Class II: 11.2 mm), and male patients group (Class III: 15.6 mm, Class I: 12.7 mm, and Class II: 11.5 mm). Class III MP length was significantly greater than Class I and Class II MP length in the all patients group (Class III: 16.1 mm, Class I: 13.8 mm, and Class II: 12.3 mm), female patients group (Class III: 15.4 mm, Class I: 13.2 mm, and Class II: 12.7 mm), and male patients group (Class III: 16.9 mm, Class I: 14.4 mm, and Class II: 11.9 mm). Regarding the LP length, no significant difference was found in the all patients group, but the value of the male patients group was significantly greater than that

Table 4: Pearson correlation (r) test for craniofacial angles and linear distances in all patients.

Variables	ANB angle	C2C4-SN angle	Palatal angle	PW	PL	UE	NP	PS	TS	MP	LP
ANB angle	1	0.210*	0.462*	-0.117*	0.206*	0.057	0.113	-0.382*	-0.400*	-0.415*	-0.117*
C2C4-SN angle	0.210*	1	0.364*	-0.135*	0.071	-0.087	-0.036	-0.086	0.085	0.003	0.124*
Palatal angle	0.462*	0.364*	1	-0.072	0.061	-0.016	0.439*	-0.186*	-0.148*	-0.184*	-0.043
PW	-0.117*	-0.135*	-0.072	1.000	-0.047	0.099	0.055	0.049	0.035	0.061	0.057
PL	0.206*	0.071	0.061	-0.047	1	-0.096	0.101	-0.376*	-0.084	-0.113	0.094
UE	0.057	-0.087	-0.016	0.099	-0.096	1	-0.030	0.040	-0.072	-0.076	0.091
HH	-0.327*	-0.696*	-0.491*	0.235*	-0.054	0.032	-0.079	0.055	0.082	0.148*	0.075
HV	-0.006	-0.014	-0.294*	0.259*	0.325*	0.249*	-0.091	-0.007	0.087	0.040	0.279*

*: statistically significant, $p < 0.05$.

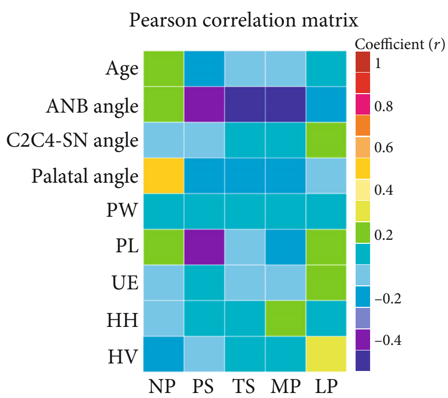

Figure 3: Pharyngeal airway in the Pearson correlation matrix. Absolute value of correlation ratio: very weak (0-0.19), weak (0.20-0.39), moderate (0.40-0.59), strong (0.60-0.79), and very strong (0.80-1.0). White circle: statistically significant, $p < 0.05$.

of the female patients group in each class. In the male patients group, Class III LP length (19.5 mm) was significantly greater than Class II (17.5 mm) and Class I (17.4 mm) LP lengths. Therefore, the null hypothesis was rejected.

Table 4 and Figure 3 showed the results of Pearson's correlation test in the all patients group. The ANB angle exhibited moderate positive correlation with palatal angle (r: 0.462) and moderate negative correlation with TS (r: -0.400) and MP (r: -0.415) length. Palatal angle exhibited moderate positive correlation with NP (r: 0.439) length. Horizontal distance of hyoid bone exhibited strong negative correlation with C2C4-SN angle (r: -0.696) and moderate negative correlation with palatal angle (r: -0.491).

4. Discussion

The nasopharynx is the uppermost part of the pharynx. Deepthi et al. [6] evaluated the airway in the Class I and Class II skeletal pattern. They found a strong association between the airway and skeletal pattern showing a reduced nasopharyngeal airway in Class II patients with a high ANB angle compared to Class I. In the present study, NP of Class II was significantly greater than Class I in the all patients and female patients groups. Moreover, Pearson correlation analysis indicated that, of all the pharyngeal airway lengths, NP had a moderate positive correlation with the palatal angle. Thus, it can be inferred that the palatal angle is an optimal predictor of NP length because the palatal angle increases as NP lengthens. Conversely, NP length was not correlated with the C2C4-SN angle, the degree of ANB, width and length of soft palate, or the horizontal and vertical hyoid positions. Hoffstein et al. [7] examined the flow-volume curves in snoring patients with and without obstructive sleep apnea. They found no significant difference in the midvital capacity flow ratio between the two groups. Therefore, we inferred that the correlation between NP length and occurrence of obstructive sleep apnea was not significant.

Abu Allhaija and Al-Khateeb [8] reported no significant difference in the PW and PL among different anteroposterior skeletal patterns. Muto et al. [9] measured anteroposterior diameter of the pharyngeal airway space in patients with mandibular retrognathia and prognathia, and normal subjects. They reported no difference in PW but mandibular retrognathia was significantly greater than Class I and Class III in PL. In our study, PW also showed no difference in all patients, female patients, or male patients groups. The PL of Class II was significantly greater than Class III in the all patients and female patients groups. Among different skeletal patterns, PL showed no difference in the male patients group. Abu Allhaija and Al-Khateeb [8] also reported no sex differences at the PW and PL among skeletal patterns. In our study, we found that PW of the males group had greater than the females group in Class II and Class III. The PL of the males group had greater than the females group in Class I and Class III. In terms of hyoid position, a more inferior position of the hyoid could significantly increase the dimensions of PW and PL. An anterior position of the hyoid also could significantly increase PW, but not PL.

Moreover, we found that there was no significant correlation between PW and PL. In Pearson's correlation analysis, PW had no effect on the pharyngeal airway dimensions. Therefore, PW was not a risk factor leading to occurrence of obstructive sleep apnea. Muto et al. [9] found that PL was a significant negative correlation with PS in the normal mandible, mandibular retrognathism, and all patients groups. In our study, PL was significantly and positively correlated with ANB angle and HV, indicating that downward growth of the hyoid bone increases the PL. PL was also a significant negative correlation with PS in all patients groups. In terms of the correlation of the ANB angle with features of palatal-related anatomy, all features exhibited a significant correlation with the ANB angle. In Pearson's correlation analysis, PS airway was significantly and negatively correlated with ANB. Therefore, Class III had the shortest palatal length and greatest PS length, whereas Class II had the greatest PL and shortest PS length. However, PL was only weakly negatively correlated with PS length (PL increased as PS length decreased). Therefore, we could not infer that PL was strongly correlated with PS length.

Muto et al. [9] reported that the palatal angle of Class II was significantly greater than Class I and Class I was significantly greater than Class III. Our finding was similar to the report of Muto et al. [9] The palatal angle was strongly positively correlated with the ANB angle and C4C2 angle; however, we found that the palatal angle showed no significant correlation with PW and PL. Moreover, the palatal angle was a significant correlation with pharyngeal airway dimensions except LP. The incremental palatal angle increased the NP but decreased PS, TS, and MP.

The UE length revealed a trend where a more inferior position of the hyoid caused greater UE length. In our study, UE presented no difference in the male patients and all patients groups. In the female patients group, UE of Class II was significantly greater than Class III. The present study also found a significant and positive correlation between UE and hyoid bone growth, indicating that downward growth of the hyoid bone increases UE. This suggests that the epiglottis also grows downward to increase the length of UE. Therefore, UE cannot predict the Class I and Class II patients that are most likely to exhibit obstruction of the pharyngeal airway.

The ANB angle was negatively correlated with HH. Therefore, a greater ANB angle corresponded to a shorter horizontal hyoid length and a relatively retracted hyoid bone position. The role of the C4C2 angle was similar to that of the ANB angle; however, the C4C2 angle was even more strongly correlated with the hyoid bone position (-0.696), such that the cervical spine position was closely related to the hyoid bone position (a retracted hyoid bone position corresponds to a greater C4C2 angle). This may be attributed to the physiological regulation of respiration, because a retracted hyoid bone can constrict the respiratory tract, compelling the C4C2 angle to increase to maintain smooth breathing. This is typically achieved by raising the head slightly.

A reduction or increase of the oropharyngeal cavity can be induced by tongue retraction or tongue protrusion. Because the base of the tongue is connected with the hyoid bone, the pharyngeal-airway muscle groups are connected to the soft palate and tongue [10]. Adamidis and Spyropoulos [11] compared the hyoid bone positions in Class I and Class III and found that the hyoid bone position in Class III was set relatively forward. Yamaoka et al. [12] found that the tongue root in Class II was relatively retracted, compared with that in Class III. Battagel et al. [13] examined patients with obstructive sleep apnea and noticed that they exhibited Class II occlusion, with relatively retracted hyoid bone positions, which resulted in a narrower pharyngeal airway. These studies suggest that the hyoid bones of people with Class II features are relatively retracted, whereas the hyoid bones of people with Class III features are relatively forward. Our finding was similar to previous reports. The hyoid bone in Class III is set significantly forward, compared with that of Class I and Class II; thus, its position is negatively correlated with the ANB angle. However, the horizontal hyoid position was only weakly correlated with MP length and showed no correlation with PS, TS, and LP. Mortazavi et al. [14] reported that hyoid bone is positioned more superior and posterior in females than males and its location differs among different skeletal classes. Our study was similar to the report of Mortazavi et al. [14]

In a study of the relationship between the pharyngeal airway and skeletal patterns, Muto et al. [9] found the pharyngeal airway of Class III to possess the greatest space, followed by Class I and Class II. In our study, TS and MP were between the tongue and the pharyngeal airway. We found that both TS and MP lengths were significantly shorter in Class II, which echoes the findings of Muto et al. [9] The present study found the TS and MP lengths to be more significantly correlated with the ANB angle than with the C2C4 angle. That is, the TS and MP lengths were more related to the skeletal pattern than the position of the cervical spine. Furthermore, TS and MP lengths were not significantly correlated with palatal-related anatomy (PW, PL, and UE). Of particular interest is the hyoid bone position, whose correlation with the MP was weak and with TS was nonsignificant. Thus, the hyoid bone position cannot be used to estimate TS and MP lengths. In terms of LP length, which represents the distance from C4 to the front tracheal wall, no significant difference was observed among the skeletal patterns. Moreover, Pearson's correlation analysis revealed a weak correlation between LP length and the other factors, indicating that the influence of anatomical structure on LP length is minimal. The limitation of the present study is used to the two-dimensional (2D) cephalograph to represent the complex 3D pharyngeal structure. The major limitations of 2D cephalometric analysis are the lack of information of cross-sectional area and real pharyngeal volume (3D).

5. Conclusion

Among the pharyngeal airways of skeletal patterns, Class III had significantly greater pharyngeal airway dimensions (PS, TS, and MP) than Class I and Class II. Class II had the largest NP than Class I and Class III. The C4C2-SN angle of Class II was significantly greater than that of Class III. The C4C2-SN angle exhibited no significant correlation with pharyngeal airway dimensions (NP, PS, TS, and MP).

Data Availability

This is an original article. No any published data was available.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Review Article

Intraoperative Blood Loss and Postoperative Pain in the Sagittal Split Ramus Osteotomy and Intraoral Vertical Ramus Osteotomy: A Literature Review

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Purpose. The purpose of the present study was to review the literature regarding the blood loss and postoperative pain in the isolated sagittal split ramus osteotomy (SSRO) and intraoral vertical ramus osteotomy (IVRO). *Materials and Methods*. Investigating the intraoperative blood loss and postoperative pain, articles were selected from 1970 to 2021 in the English published databases (PubMed, Web of Science, and Cochrane Library). Article retrieval and selection were performed by two authors, and they independently evaluated them based on the eligibility criteria. The articles meeting the search criteria had especially at least 30 patients. *Results*. In the review of intraoperative blood loss, a total of 139 articles were retrieved and restricted to 6 articles (SSRO: 4; IVRO: 2). In the review of postoperative pain, a total of 174 articles were retrieved and restricted to 4 articles (SSRO: 3; IVRO: 1). The mean blood loss of SSRO and IVRO was ranged from 55 to 167 mL and 82 to 104 mL, respectively. The mean visual analog scale (VAS) scores of the first postoperative day were 2 to 5.3 in SSRO and 2.93 to 3.13 in IVRO. The mean VAS scores of the second postoperative day were 1 to 3 in SSRO and 1.1 to 1.8 in IVRO. *Conclusion*. Compared to traditional SSRO, IVRO had a significantly lower amount of blood loss. However, the blood transfusion is not necessary in a single-jaw operation (SSRO or IVRO). Postoperative pain was similar between SSRO and IVRO.

1. Introduction

Orthognathic surgery has a varying level of complexity and high technical requirements. Surgeons should pay attention to other main issues, such as preoperative assessment of the patient's medical condition, duration of operation, intraoperative blood loss, degree of postoperative pain, potential postoperative sequelae, and complications. Surgeons also take into consideration the anxiety of patients. Specifically, patients worry about the potential need for blood transfusion due to intraoperative blood loss and may question the safety of various risk factors related to blood transfusion. Therefore, estimations of operation time and blood loss must be precise which is beneficial to the promotion of communication between the surgeons, anesthesiologists, patients, and their families to have sufficient understanding of the overall operation process.

Postoperative pain management is a major concern for surgical patients. Poor postoperative pain control negatively affects patient's emotions, which in turn affect postoperative quality of life and appropriate expectations of the prognosis.

Sagittal split ramus osteotomy (SSRO) and intraoral vertical ramus osteotomy (IVRO) are the two most common surgical techniques for orthognathic surgery, and they vary in surgery-related variables such as operation time, blood loss, and postoperative pain. Studies [1–10] have mostly discussed the SSRO, with IVRO [11–14] being rarely addressed. The present review article conducted a literature review to compare SSRO and IVRO in terms of operation time, blood loss, and postoperative pain.

2. Materials and Methods

The databases (PubMed, Web of Science, and Cochrane Library) were searched for articles published in English since 1970 using the terms “sagittal split ramus osteotomy,” “intraoral vertical ramus osteotomy,” “blood loss,” and “pain.” The visual analog scale (VAS; 0, indicating no pain; 10, indicating excruciating pain) of postoperative pain was recorded. In addition, the references of the selected articles were manually searched for other relevant articles. Article retrieval and selection were performed by two authors, who then read the titles and abstracts of the studies and independently evaluated them based on the eligibility criteria. Articles meeting the criteria were selected for full-text reading. In case of a discrepancy between the authors regarding the inclusion of a study, full-text reading was chosen.

A study was included when it met the following criteria: (1) being a randomized controlled trial, case series, and observational study; (2) having at least 30 patients; and (3) involving only mandibular SSRO or IVRO. The following studies were excluded: case reports, reviews, studies involving patients with craniofacial syndromes, and studies including patients with a history of facial trauma. Demographic, methodological, intraoperative, and postoperative data were independently evaluated by two authors. Any discrepancies were resolved by discussion with other authors.

3. Results

A total of 96 articles were retrieved using the search terms “sagittal split ramus osteotomy” and “blood loss” in the PubMed ($n = 66$), Web of Science ($n = 23$), and Cochrane Library ($n = 7$) databases. IVRO had a total 43 articles using the search terms “intraoral vertical ramus osteotomy” and “blood loss” in the PubMed ($n = 13$), Web of Science ($n = 23$), and Cochrane Library ($n = 7$) databases. Of these, 139 articles were retained by further narrowing to 6 articles [15–20] (SSRO: 4; IVRO: 2) whose domain is in a single-mandibular operation (Table 1).

Investigating the postoperative pain, a total of 151 articles were retrieved using the search terms “sagittal split ramus osteotomy” and “pain” in the PubMed ($n = 73$), Web of Science ($n = 55$), and Cochrane Library ($n = 23$) databases. IVRO had a total of 23 articles using the search terms “intraoral vertical ramus osteotomy” and “pain” in the PubMed ($n = 13$), Web of Science ($n = 8$), and Cochrane Library ($n = 2$) databases. Of these, 174 articles were retained by further narrowing to 4 articles [21–24] (SSRO: 3; IVRO: 1) whose domain is in a single-mandibular operation (Table 2).

These studies of blood loss included a total of 350 patients (SSRO: 270; IVRO: 80). The mean operation time of SSRO and IVRO was ranged from 105 to 174 minutes and 61 to 349 minutes, respectively. The mean blood loss of SSRO and IVRO was ranged from 55 to 167 mL and 82 to 104 mL, respectively. These studies of postoperative pain included a total of 239 patients (SSRO: 197; IVRO: 42). The mean VAS scores of the first postoperative day were 2 to 5.3 in SSRO and 2.93 to 3.13 in IVRO. The mean VAS scores of the second postoperative day were 1 to 3 in SSRO and 1.1 to 1.8 in IVRO.

4. Discussion

Orthognathic surgery is performed to correct facial deformity, enhance masticatory function, and improve the facial appearance. Orthognathic surgical techniques must be precise to achieve the desired outcome. However, the maxillofacial region consists of complex and dense networks of blood vessels, and the view of the operation field may be limited in certain intraoral operations. Therefore, the management of surgical bleeding can sometimes be challenging. The methods for calculating blood loss had been reported as follows: (1) direct measurement: perioperative weighing of sponges and collection of suctioned fluids; (2) calculated blood loss (Nadler’s formula) [25]: taking into account height, weight, and sex; (3) postoperative loss of haemoglobin and hematocrit level; (4) colorimetric blood loss estimation [26]: calculating blood loss by taking photographs of the used surgical gauze and canisters; and (5) continuous noninvasive intraoperative haemoglobin monitoring [27].

Both the methods of anesthesia [28–30] and the surgical techniques [31–33] could affect the operation time and then control the amount of blood loss. Remifentanil is an ultrashort-acting opioid that can suppress the autonomic nervous response and produce an analgesic effect. Moreover, remifentanil possesses the parasympathetic activation contributing to hemodynamic depression (bradycardia and hypotension). Twersky et al. [34] compared the hemodynamic changes using either remifentanil or fentanyl in 2,438 surgical patients. They reported that remifentanil-treated patients exhibited lower systolic and diastolic blood pressures (by 10-15 mmHg) and lower heart rates (by 10-15 bpm) intraoperatively compared to the fentanyl-treated patients. Handa et al. [18] reported that there was no significant difference between propofol-remifentanil and propofol-fentanyl for anesthesia in the mean operation time (115.8 and 112 minutes) of traditional SSRO. However, propofol-remifentanil (118.4 mL) is also significantly effective in reducing intraoperative blood loss compared to propofol-fentanyl (171.7 mL) during SSRO.

In this literature review, it was indicated that the surgical instruments used in SSRO are mainly traditional chisels and few piezoelectric devices. Shirota et al. [16] reported that there was no significant difference between traditional SSRO and piezoelectric SSRO in the operation time. However, Koba et al. [35] indicated that osteotomy time and total operation time of piezoelectric SSRO were significantly shorter than those of the traditional SSRO. Shirota et al. [16] revealed

Table 1: Demographic and study characteristics in the operation time and blood loss of the included studies.

Author Year Country of origin	Technique	Subgroups Samples	Age Mean (years) Range (years)	Sex F (female) M (male)	Operation time Mean (minute) Range (minute)	Blood loss Mean (mL) Range (mL)	Operation time & blood loss correlation
Kuroyanagi et al. 2013 Japan	SSRO	$n = 50$	28 17-44	F: 32 M: 18	105 80-200	55 15-300	Significant
Shirota et al. 2014 Japan	SSRO	Piezoelectricity ($n = 30$) Traditional SSRO ($n = 29$)	28 ± 9 16-49	F: 35 M: 24	174 ± 37 107-255	189 ± 113 18-584	Significant
Chen et al. 2015 Taiwan	IVRO	$n = 80$	F: 23.31 ± 4.06 M: 22.42 ± 3.73	F: 49 M: 31	F: 229.39 ± 40.82 M: 249.52 ± 48.86	F: 86.12 ± 54.98 M: 104.03 ± 56.73	F: no significant M: significant
Handa et al. 2016 Japan	SSRO	Propofol-fentanyl ($n = 65$) Propofol-remifentanil ($n = 66$)	26.9 ± 8.1 25.8 ± 8.4	F: 45 M: 20 F: 47 M: 19	112 ± 29.5 115.8 ± 16.4	171.7 ± 130.2 118.4 ± 69.6	NA NA
Salma et al. 2017 Saudi Arabia	SSRO	$n = 30$			145.8 ± 43.8 120-300	167.67 ± 59.79 100-300	NA
Pedersen et al. 2021 Norway	IVRO	$n = 131$	23.5 18-73	F: 71 M: 62	61 31-144	82	No significant

n: number of samples; NA: not available.

Table 2: Demographic and study characteristics in the postoperative pain of the included studies.

Author Year Country of origin	Technique	Subgroups Sample	Age Mean (years) Range (years)	Sex F (female) M (male)	Operation time Mean (minute) Range (minute)	Postoperative pain (VAS) First day	 Second day	 Third day
Nagatsuka et al. 2000 Japan	SSRO	Multimodal analgesia group ($n = 41$)	22.4 ± 4.4	F: 25, M: 16	137.3 ± 44.9	2.5-3	2-2.5	2-2.5
		Control group ($n = 41$)	20.9 ± 3.7	F: 28, M: 13	136.0 ± 43.6	2.5-3	2.5-3	2-2.5
Kim et al. 2009 Korea	SSRO	Hegu group ($n = 28$)	27.7 ± 9.1	F: 14, M: 14	205.1 ± 30.4	2-2.5	1-1.5	0.5-1
		Sham group ($n = 28$)	28.6 ± 8.1	F: 13, M: 15	197.3 ± 26.5	4.5-5	2.5-3	1.5-2
		Control group ($n = 28$)	29.2 ± 9.3	F: 15, M: 13	195.8 ± 29.9	4.5-5	2.5-3	1.5-2
Chen et al. 2012 Taiwan	IVRO	$n = 42$	F: 24.3 ± 3.85 M: 23.2 ± 4.7	F: 26 M: 16	F: 237.12 ± 36.75 M: 276.25 ± 46.13	F: 2.96 ± 1.04 M: 3.13 ± 1.45	F: 1.1 ± 1.16 M: 1.8 ± 1.29	NA NA
Raschke et al. 2017 Germany	SSRO	$n = 31$	35.8 ± 12.8	F: 18 M: 13	107.5 ± 40.4	Maximum pain 5.3 ± 2.5 Minimal pain 2.06 ± 1.84	NA NA	NA NA

n: number of samples; NA: not available; VAS: visual analog scale.

that piezoelectric SSRO did not reduce intraoperative blood loss significantly. Nonetheless, Koba et al. [35] reported a mean blood loss of only 41.6 mL in piezoelectric surgery, which differs from the findings of Shirota et al. [16] and is significantly lower than the blood loss in traditional SSRO.

Kuroyanagi et al. [15] reported a mean blood loss of only 73.3 mL in traditional SSRO, significantly lower than those measured by Shirota et al. [16] (189 mL), Handa et al. [18] (propofol-remifentanil: 118.4 mL; propofol-fentanyl: 171.7 mL, and Salma et al. (176.67 mL). This result is ascribable to the discovery by Kuroyanagi et al. [15] that a medial ramus type significantly affects operation time and blood loss. In the study of Kuroyanagi et al. [15], 59% of patients had a moderately straight medial ramus whereas the rest (41%) had a concave medial ramus. The operation time for patients with a moderately straight medial ramus was significantly shorter, and a mean blood loss of 53 mL was discovered in patients with a moderately straight medial ramus. By contrast, the patients with a concave medial ramus had a mean blood loss of 102.5 mL. Statistically, patients with a moderately straight medial ramus led to significantly less blood loss than those with a concave medial ramus. In terms of the potential correlation between blood loss and operation time, Kuroyanagi et al. [15], Shirota et al. [16], Handa et al. [18], Salma et al. [19], and Ueki et al. [12] all found a significantly positive correlation between them, whereas Böttger et al. [36] deemed the correlation between them to be weak.

In the IVRO technique, Pedersen et al. [20] reported that the mean operation time and intraoperative blood loss were 61 min and 82 mL, respectively. Chen et al. [17] found that the mean operation time and blood loss had no significant difference between female (229 minutes and 86 mL) and male (249 minutes and 104 mL). Regarding the amount of blood loss in IVRO, no significant difference was observed in Pedersen et al. [20] and Chen et al. [17]; however, blood loss in IVRO was significantly smaller than that in traditional SSRO. Pedersen et al. [20] and Chen et al. [17] founded that there were no significant correlations between operation time and blood loss. Investigating the difference of gender, Rummasak et al. [37] reported that women tend to lose more blood in orthognathic surgery than do men, whereas Salma et al. [19] found the opposite. Chen et al. [17] reported that men tend to lose more blood in IVRO than do women—concurring with the finding of Salma et al. [19] Moreover, Chen et al. [17] revealed a significantly positive correlation between blood loss and operation time that was observed in men but not in women. Mayrovitz and Regan [38] presented that facial skin perfusion in male was significantly more than that in female principally due to a larger number of perfused microvessels. Kokovic et al. [39] assessed the blood perfusion of the posterior mandible using laser Doppler flowmetry. They found that male had more blood perfusion than female. Schwaiger et al. [40] investigated the blood loss in orthognathic surgery, and male was found to be associated with significantly increased bleeding volumes in the 2-jaw surgery. Moreover, male revealed more hidden blood loss than female in SSRO. By inference, intraoperative blood loss is greater in men than in women because men have more blood vessels and higher blood perfusion. Therefore, control of bleeding takes longer in men, and the operation time is longer in male patients than in female patients.

It is an important issue regarding the necessity of intraoperative blood transfusion. Moenning et al. [3] investigated 171 patients who received SSRO and discovered that their blood loss ranged from 50 to 750 mL, amounting to a mean blood loss of 176.6 mL; none of the patients required blood transfusion. Samman et al. [4] also discovered that orthognathic surgery involving one jaw does not require blood transfusion. Numerous methods are available for preventing intraoperative blood loss and minimizing the need for blood transfusion. For example, hypotensive anesthesia [2, 5, 7] is a well-established and effective technique that has been confirmed by research to reduce 40% of blood loss during orthognathic surgery. Hypotensive anesthesia can reduce the amount of bleeding, improve visibility in the surgical field, and increase the efficiency of surgical operations and hemostasis, all of which contribute to shorter operation time, less intraoperative blood loss, and lower likelihood of needing blood transfusion. According to existing data, a mean arterial pressure between 50 and 65 mmHg is safe in healthy young patients because it does not interfere with perfusion to the brain, heart, kidneys, and liver. However, hypotensive anesthesia is safe only if physical changes in the patient are closely monitored during the operation and communication between the doctor and anesthesiologist is adequate.

Pain is a complex reaction that involves the interaction between nerve conduction and various neuroregulatory factors of the central nervous system. The postoperative pain following orthognathic surgery is not simply caused by the surgical wound. Sources of postoperative pain include damage to the lingual nerve and inferior alveolar nerve, inflammation of the surgical area, muscle stiffness and discomfort caused by the muscle and osseous tissue adapting to the postoperative area, and contraction induced by injury to the surrounding soft tissues; all of the stimuli trigger changes in the response of the central nervous system. According to the literature review [21–24], the visual analog scale (VAS) value is approximately 3 on the first day following SSRO and IVRO and drops to 1–2 on the second day. The postoperative VAS values following SSRO and IVRO are similar. Nagatsuka et al. [21], Kim et al. [22], and Raschke et al. [24] all reported a strong correlation between operation time and postoperative pain, but Chen et al. [23] found no significant correlation between them. Moreover, Chen et al. discovered that blood loss was not significantly correlated with the amount of mandibular setback and postoperative pain and that there was no gender difference in postoperative pain.

Numerous methods and techniques are available for controlling postoperative pain. Evans et al. [1] investigated 45 patients undergoing orthognathic surgery and found that no narcotic analgesics were needed to control postoperative pain in most situations. Postoperative use of nonsteroidal anti-inflammatory drugs (NSAIDs) to relieve pain or reduce morphine needs has been widely proven to be effective. According to recent research reports [41–43], patient-controlled analgesia (PCA) can control postoperative pain caused by orthognathic surgery. PCA enables patients to self-administer their medication, thereby reducing postoperative anxiety and stress, which are the main determinants of post-operative pain. PCA is proven effective at mitigating discomfort during the postoperative recovery period and significantly shortening the period of hospitalization. Our clinical experience has also indicated that NSAIDs are sufficient for controlling postoperative pain. Specifically, when NSAIDs are employed after surgery, we discovered that the VAS value reported by patients was comparable to that measured during their orthodontic treatment. This finding facilitates communication between doctors and patients before the operation, enables the patient to understand postoperative pain, and reduces the anxiety and pressure of patients facing surgery.

5. Conclusion

From our review, we have concluded that the administration of anesthetic drugs, medial ramus type, and selection of surgical instruments could affect the operation time and blood loss in the orthognathic surgery. Compared to traditional SSRO, IVRO had a significantly lower amount of blood loss. However, the blood transfusion is not necessary in a single-jaw operation (SSRO or IVRO). Postoperative pain was similar between SSRO and IVRO.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Authors' Contributions

Kun-Tsung Lee and Kun-Jung Hsu equally contributed to this work.

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Research Article

Investigation of Immediate Postoperative Pain following Orthognathic Surgery

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Purpose. The purpose of this study was to compare postintervention pain related to orthodontic treatment and orthognathic surgery. *Material and Methods*. One hundred patients who received only orthodontic treatment are the nonsurgical group. One hundred other patients were separated equally into the following four orthognathic surgical subgroups. The visual analog scale (VAS) score was used to measure postoperative pain. Patient- and operation-related factors were compared among the four surgical subgroups. The null hypothesis was that there was no difference between orthodontic treatment and orthognathic surgery in terms of posttreatment pain. *Results*. There were no significant differences between the nonsurgical and surgical groups for gender ($P = 0.780$) or age ($P = 0.473$). The VAS scores of the nonsurgical group (mean: 3.59) were significantly ($P = 0.007$) higher than those of the surgical group (mean: 3.06). The null hypothesis was rejected. Within the surgical subgroups, no significant differences were observed between the men and women for age, operation time, blood loss volume, or blood laboratory values. *Conclusions*. The VAS scores of the orthodontic (nonsurgical) group were significantly higher than those of the surgical group. No significant differences in VAS scores were found between the four surgical subgroups.

1. Introduction

Deformities in the maxillary and mandibular bones, including variations in form, size, and position, can cause abnormalities in the jaw relationship, resulting in malocclusion and other problems associated with facial deformities. Prognathism refers to protrusion of the maxilla or mandible or to protrusion of both jawbones concomitantly [1]. The two variations most commonly seen in Asian populations are mandibular prognathism and bimaxillary prognathism [2, 3]. Mandibular prognathism is characterized by the notable protrusion of one-third of the lower face, whereas bimaxillary prognathism signifies distinct protrusion of one-third of the middle face. In both cases, there is disharmony in the overall facial morphology, and this can further affect a patient psychologically.

Orthognathic surgery (OgS) is widely used to improve the appearance of facial protrusion and malocclusion. Although surgical precision is important, clinicians should also consider other factors (e.g., operation time, perioperative blood loss, and postoperative pain) to minimize the occurrence of subsequent complications and other sequelae [4–6]. Most patients are particularly concerned about postoperative pain. Therefore, to optimize the overall satisfaction of patients undergoing orthognathic surgery, it is critical to ensure that they fully understand and are mentally prepared for the surgery. Furthermore, patients with an abnormal facial profile must receive combination therapy with orthodontic treatment and orthognathic surgery. These two interventions can trigger varying levels of perceived pain among patients.

Patients who received orthodontic treatment without surgery were selected to form the control group (nonsurgical group), whereas other patients who underwent orthognathic surgery were selected as the surgical group. The variables assessed were sex, age, operation time, perioperative blood loss, and the postoperative change in blood components. The null hypothesis of this study proposed that the visual analog scale (VAS) scores of the first day posttreatment would be the same in the control group as in the surgical group. This study further compared the differences in perceived postoperative pain and other relevant variables for treating mandibular and bimaxillary prognathism by 4 surgical subgroups.

2. Materials and Methods

The sample is comprised of 100 patients who underwent only orthodontic treatment as the controls (i.e., nonsurgical group) and 100 patients who underwent orthognathic surgery (surgical group). Patients in the nonsurgical group received a fixed orthodontic appliance without being given any analgesics for pain management, and their VAS scores were recorded on the first day postintervention. The surgical group is comprised of 50 patients with mandibular prognathism and 50 patients with bimaxillary prognathism. The surgical procedures included intraoral vertical ramus osteotomy (IVRO), anterior segmental osteotomy of the mandible (ASO Md) and maxilla (ASO Mx), and genioplasty (GeP). The surgical group was further divided into four groups of 25 patients. The patients with mandibular prognathism formed Group 1 (IVRO alone) and Group 2 (IVRO+GeP). Those with bimaxillary prognathism formed Group 3 (ASO Mx+ASO Md) and Group 4 (ASO Mx+ASO Md+GeP). Groups 1 and 2 received six weeks of intermaxillary fixation treatment, whereas Groups 3 and 4 did not.

All patients underwent orthognathic surgery under hypotensive anesthesia. Data on the operation time, perioperative blood loss, and postoperative changes in blood components were examined. Postoperation pain management is based on a standardized protocol regarding the schedule of medicine administration. During hospitalization, an intravenous nonsteroidal anti-inflammatory drug (NSAID, Aspegic, 0.5 g) was prescribed for pain control at 6-hour intervals. The dose of NSAID is equally applied to the gender and surgical subgroups. On the first day posttreatment, the VAS scores (0–10 cm) of the nonsurgical group and the surgical group were recorded. SPSS Statistics, version 20 (SPSS Inc., Chicago, IL), was used for statistical analysis, and a P value < 0.05 was considered significant. Scores in the control and surgical groups were compared using t-tests; the null hypothesis was that there would be no differences in VAS scores on the first day posttreatment between these two groups. In addition, the VAS scores of 4 surgical subgroups were analyzed using t-tests, and Tukey's HSD (honest significant difference) test was used for post hoc analysis. Pearson's correlation coefficients were used to evaluate the correlations for the variables of sex, age, operation time, blood loss volume, and changes in blood components. The purpose of the present study is to compare the pain severity between the nonsurgical orthodontic group without pain medication and the orthodontic-OgS group with pain medication on day one after the initial treatment either via orthodontic force application or surgical intervention.

Table 1: Summary of all patient characteristics.

Variables	Control group	Surgical group	P value
Total patients	$n = 100$	$n = 100$	
Female (n)/male (n)	(75/25)	(78/22)	0.780
Age (y)	26.11 ± 6.17	25.44 ± 6.68	0.473
VAS (cm)	3.59 ± 1.79	3.06 ± 1.03	0.007*
P value by gender	<0.001*	0.191	
Female patients			
Age (y)	26.00 ± 6.35	25.81 ± 7.00	0.859
VAS (cm)	3.95 ± 1.84	2.97 ± 0.94	<0.001*
Male patients			
Age (y)	26.4 ± 5.34	24.27 ± 5.21	0.178
VAS (cm)	2.52 ± 1.02	3.36 ± 1.29	0.019*

n: number of patient; VAS: visual analog scale. *Chi-squared tests or two-sample t-test; statistically significant, $P < 0.05$.

3. Results

Table 1 shows that our results revealed no significant differences between the nonsurgical and surgical groups for either sex or age. The female : male ratios of the two groups were 75 : 25 and 78 : 22, respectively, and the average age of the two groups was 26.1 and 25.4 years, respectively. Moreover, no significant differences were observed between the groups for the correlations of age and sex with the perceived postoperative pain levels. Where the first-day VAS scores for posttreatment pain were concerned, the nonsurgical group perceived a significantly higher level of pain than did the surgical group (mean VAS scores: 3.59 vs. 3.06 cm). The null hypothesis was rejected.

The values in Table 1 demonstrate that women in the nonsurgical group perceived a significantly higher level of pain on the first day posttreatment than those in the surgical group (mean VAS scores: 3.95 vs. 2.97 cm). However, men in the nonsurgical group perceived a significantly lower level of pain on the first day posttreatment than those in the surgical group (mean VAS score: 2.52 vs. 3.36). These results implied that the women who received orthodontic treatment perceived more intense pain than those who received orthognathic surgery, whereas their male counterparts perceived significantly greater pain in the surgical group than the nonsurgical group.

Within the surgical group, no significant differences were observed between the sexes in terms of age, operation time, blood loss volume, or reduction in postoperative hemoglobin (Hgb) and hematocrit (Hct) levels, as shown in Tables 2 and 3. In Tukey's honest significant difference test (Table 4), patients in Group 3 (mean age, 30 years) were significantly older than those in Group 4 (25.1 years), Group 1 (23.9 years), and Group 2 (22.9 years); the operation time for Group 1 (244.8 min) was significantly shorter than that for Group 2 (314.2 min), Group 3 (343.2 min), and Group 4 (391.2 min); the blood loss of Group 1 (107.8 mL) was significantly less than that of Group 3 (262.2 mL) and Group 4 (402.4 mL); and the postoperative decreases in Hgb and Hct

Table 2: Summary of surgical patient characteristics by gender.

Variables	Female ($n = 78$) Mean	SD	Male ($n = 22$) Mean	SD	P value
Age (y)	25.81	7.00	24.27	5.21	0.267
Operation time (min)	319.68	80.20	336.36	104.42	0.493
Blood loss (mL)	218.14	185.02	316.36	344.41	0.210
Postoperative reduction					
Hgb (g/dL)	2.48	1.03	2.60	0.98	0.641
Hct (%)	7.54	3.16	7.92	2.79	0.592
VAS (cm)	2.97	0.94	3.36	1.29	0.191

n: number of patient; VAS: visual analog scale. Two-sample t-test; statistically significant, $P < 0.05$.

levels in Group 1 (1.9 g/dL, 5.9%) were significantly lower than those in Group 3 (2.9 g/dL, 8.1%) and Group 4 (3.1 g/dL, 9.5%). When an intergroup (4 surgical subgroups) comparison was carried out, no significant differences were observed in the first-day postoperative VAS scores. The results laid out in Table 5 show that Pearson's correlation analysis of the four surgical subgroups revealed no association between each group's first-day postoperative VAS scores and sex, age, operation time, blood loss, or reduction in postoperative Hgb and Hct levels.

4. Discussion

Over the past decade, there has been an increasing trend emerging in the number of patients opting for surgical treatment to improve their malocclusion, a trend which may have been due to improved surgical techniques which alleviate perioperative and postoperative discomfort arising from the surgery. However, patients with maxillofacial abnormalities are often required to accept combination therapy with both orthodontic and orthognathic surgeries, which may involve different degrees of pain. Pain represents a highly complex response to intense stimuli and is accompanied by various effects on functioning. Importantly, pain is a highly subjective perception that differs significantly from person to person, and pain management has thus been a topic of considerable interest across the field of medicine.

During orthodontic treatment, pain is commonly observed as a side effect that varies according to the sex and age of patients, the magnitude and method of orthodontic force, and individual emotional responses to pain and tolerance of stress [7–10]. In the report of Kvam et al. [7, 9], 95% of patients presented pain during orthodontic treatment. After bonding fixed appliances, Kvam et al. [10] found that initial pain is perceived at posttreatment 2 h and peaks at 24 h. Fujiyama et al. [11] reported that the VAS score was more than 4 cm in treatment with the fixed appliance. In the present study, VAS of our patients was 3.59 cm. Postoperative pain can be caused not only by surgical wounds but also by neural injuries to the lingual nerve or inferior or superior alveolar nerves, surgical site inflammation, constrictive pain associated with soft tissue injury, and other problems induced by postoperative muscle and bone adaptation. This study focused mainly on patients who received nonsurgical orthodontic treatment and those who received orthognathic surgery and compared their perceived postoperative pain. Most patients who are offered orthognathic surgery usually accept orthodontic treatment, so a comparison of the results between the nonsurgical and surgical groups may be useful to inform future patients, helping to manage their expectations regarding the difference in the level of postinterventional pain (as well as other associated factors) which they might experience between orthodontic treatment and orthognathic surgery.

Because the two groups in this study showed no significant differences in sex or age, the results may be applicable to the general population. Notably, the first-day postintervention VAS scores of the nonsurgical group indicated that this group perceived a significantly higher level of pain than those who underwent orthognathic surgery. The possible reason for this outcome might be that no analgesic was given to the nonsurgical group, whereas the patients in the surgical group were periodically prescribed medication for pain relief. Another possible reason might be that the patients in the nonsurgical group may not have anticipated the degree of pain associated with fixed orthodontic appliances, which exert continuous force on the periodontal ligament through orthodontic tooth movement. This might suggest that the patients in the surgical group, who had undergone orthodontic treatment, were more mentally prepared for postoperative pain because they anticipated it prior to their surgery.

When stratified by sex, further analysis of the two groups revealed no difference in female : male ratios or age; however, differences in the VAS scores were noted between the two sexes in the nonsurgical group, where women perceived a significantly higher level of pain than did the men. Conversely, in the surgical group, no differences were observed in perceived pain levels between the sexes. Furthermore, when men and women in the nonsurgical group were compared with men and women in the surgical group, the analysis of the first-day posttreatment VAS scores revealed that women in the nonsurgical group reported a significantly higher level of pain than women in the surgical group, whereas the men in the surgical group reported a significantly higher level of pain than the men in the nonsurgical group.

Numerous studies [12, 13] have indicated the influence of postoperative satisfaction on patient stress levels. There have been assumptions that the greater preoperative stress levels a patient experiences, the greater his or her postoperative pain level will be. However, our findings reveal that women exhibited lower tolerance to the pain when the continuous orthodontic force was applied during initiation of the treatment, suggesting that they might be able to adapt mentally in their subsequent surgeries by accepting that postoperative pain would be an inevitable consequence. These results could be explored further to determine whether the preoperative stress levels between sexes differed significantly.

Niederhagen et al. [14] suggest that orthognathic surgery is the most postoperative pain among all oral and craniofacial surgeries, indicating that the duration of surgery and postoperative pain are closely correlated. In our study, operation-related factors (operation time, blood loss, and blood component reduction) and first-day postsurgical

Table 3: Patient characteristics according to the four surgical subgroups.

Variables	Group 1		Group 2		Group 3		Group 4	
Gender (female/male)	$n = 25$ (17/8)		$n = 25$ (17/8)		$n = 25$ (22/3)		$n = 25$ (22/3)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (y)	23.9	4.42	22.9	3.78	30.0	8.74	25.1	5.93
Operation time (min)	244.8	43.94	314.2	69.98	343.2	75.46	391.2	73.38
Blood loss (mL)	107.8	58.41	186.6	135.66	262.2	218.06	402.4	308.44
Postoperative reduction								
Hgb (g/dL)	1.9	0.75	2.3	0.96	2.7	1.03	3.1	0.90
Hct (%)	5.9	2.11	7.0	2.87	8.1	3.08	9.5	2.87
VAS (cm)	3.1	1.14	3.0	1.22	2.9	0.71	3.2	0.95

n: number of patient; VAS: visual analog scale. Group 1: IVRO; Group 2: IVRO+GeP; Group 3: ASO Mx+ASO Md; Group 4: ASO Mx+ASO Md+GeP. Mx: maxilla; Md: mandible; IVRO: intraoral vertical ramus osteotomy; ASO: anterior subapical osteotomy; GeP: genioplasty.

Table 4: Four surgical groups in the Tukey HSD post comparison.

Variables	*F*	*P* value	Tukey HSD post comparison
Gender	1.98	0.122	—
Age (y)	6.582	<0.001*	Group 3>4, 3>1, 3>2
Operation time (min)	20.107	<0.001*	Group 4>2, 4>1, 3>1, 2>1
Blood loss (mL)	9.181	<0.001*	Group 4>2, 4>1, 3>1
Postoperative reduction			
Hgb (g/dL)	7.202	<0.001*	Group 4>2, 4>1, 3>1
Hct (%)	7.443	<0.001*	Group 4>2, 4>1, 3>1
VAS (cm)	0.387	0.762	—

VAS: visual analog scale. *Statistically significant, $P < 0.05$; —not significant. Group 1: IVRO; Group 2: IVRO+GeP; Group 3: ASO Mx+ASO Md; Group 4: ASO Mx+ASO Md+GeP. Mx: maxilla; Md: mandible; IVRO: intraoral vertical ramus osteotomy; ASO: anterior subapical osteotomy; GeP: genioplasty.

Table 5: Intragroup comparisons by Pearson correlation coefficient (*r*).

VAS (cm)	Group 1		Group 2		Group 3		Group 4	
	r	*P* value	*r*	*P* value	*r*	*P* value	*r*	*P* value
Gender	0.378	0.062	0.118	0.573	-0.284	0.169	0.190	0.364
Age (y)	0.217	0.298	-0.121	0.565	-0.361	0.077	0.007	0.974
Operation time (min)	0.016	0.938	0.029	0.892	-0.313	0.127	-0.354	0.082
Blood loss (mL)	0.382	0.600	-0.143	0.494	-0.359	0.078	-0.148	0.480
Postoperative reduction								
Hgb (g/dL)	0.215	0.303	-0.374	0.065	-0.236	0.256	0.069	0.744
Hct (%)	0.249	0.229	-0.321	0.117	-0.326	0.111	0.077	0.715

VAS: visual analog scale. *Statistically significant, $P < 0.05$; —not significant. Group 1: IVRO; Group 2: IVRO+GeP; Group 3: ASO Mx+ASO Md; Group 4: ASO Mx+ASO Md+GeP. Mx: maxilla; Md: mandible; IVRO: intraoral vertical ramus osteotomy; ASO: anterior subapical osteotomy; GeP: genioplasty.

VAS scores were higher for the men than for the women. However, both male and female showed insignificantly in terms of age, operation-related factors, and first-day post-surgical VAS scores. Additionally, Tukey's honest significant difference test revealed that patients with bimaxillary protrusion (Groups 3 and 4) were significantly older than those with mandibular protrusion (Groups 1 and 2). This finding might imply that Asian patients have higher sensitivity toward visual abnormalities caused by mandibular protrusion, reverse overjet, and masticatory malfunction, whereas bimaxillary protrusion often has normal occlusion and does not affect masticatory function; hence, people with this condition may tend to postpone surgery until they are older.

Where the operation time and relevant blood components among the four groups were concerned, Group 4 demonstrated the largest and most significant changes. Comparisons of the operation time and blood loss during GeP surgery revealed that GeP surgery for mandibular prognathism had an operation time which was approximately 70 min longer and a 80 cc increase in blood loss; similarly, GeP surgery for bimaxillary protrusion showed an increase of approximately 50 min in operation time and a 140 cc increase in blood loss. The results of our study also demonstrated that there was greater blood loss during ASO for bimaxillary protrusion than that observed in bilateral IVRO. This might be because more bone marrow is involved in surgery to the maxillary and mandibular bones during ASO. No significant difference was observed in first-day postoperative pain between the four surgical groups.

The results of Pearson's correlation analysis of postoperative pain in each group challenged the generally held belief that first-day postoperative VAS scores correlate positively with operation time and blood loss; indeed, the results of the present study revealed no significant correlation in these variables among the four subgroups. This might be related to the sites of surgery. We presume that the prevalence of postoperative lower lip numbness in Groups 2, 3, and 4 may have been higher than that in Group 1 (from GeP surgery in Groups 2 and 4 and from anterior mandibular subapical osteotomy in Group 3). Lower lip numbness may relieve perceived pain even when considerable blood loss occurs, which may reduce the likeliness of observing a significantly positive relationship with the level of pain; by contrast, although the lowest amount of blood loss and lowest level of postoperative numbness were observed in Group 1, blood loss correlated significantly and positively with the level of pain.

Because tissue-level injury, inflammation, facial edema, and other harmful perioperative stimuli can affect the central nervous system, a variety of different methods and techniques can be used to control postoperative pain. Various research [15, 16] reports have indicated that patient-controlled analgesia (PCA) can control pain effectively following surgery; PCA allows patients to control the dose, and this helps to relieve postoperative anxiety and stress, which are the key factors contributing to postoperative pain. Similarly, related studies have shown that patients who have access to the PCA report improved levels of comfort and require shorter hospitalizations after orthognathic surgery. After assessing 45 patients who underwent orthognathic surgery, Evans et al. [17] found that their postoperative pain was not severe enough to require a high dose of narcotic analgesics. In our study, PCA was not used, but nonsteroidal anti-inflammatory drugs were prescribed to the patients who underwent surgery for pain control; the analgesic effect was similarly satisfactory.

The VAS is a unidimensional tool to measure pain intensity. However, pain is a multidimensional nature, made up of unpleasant sensory, emotional experience, cognitive, and behavioral elements. Therefore, VAS cannot reflect the overall aspects of a patient's pain experience. Without comparing the VAS baseline of a patient's pain tolerance, the present study revealed a weak point to interpret the difference of VAS scores between the control group and the surgical subgroups.

5. Conclusion

The results of this study demonstrate that the pain after orthognathic surgery, when appropriate analgesia is administered, is significantly lower than that from orthodontic treatment. Consequently, attaining a more complete understanding of orthognathic-orthodontic treatment with improved surgical techniques is expected to help meet patients' needs for preoperative psychosocial support and to reduce their postoperative pain.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Han-Jen Hsu designed the research, collected the data, and wrote the paper. Kun-Jung Hsu performed the analysis, interpreted the results, and wrote the paper. Han-Jen Hsu and Kun-Jung Hsu discussed the results and contributed to the final manuscript.

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Research Article

Analysis of Facial Skeletal Morphology: Nasal Bone, Maxilla, and Mandible

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The growth and development of facial bones are closely related to each other. The present study investigated the differences in the nasomaxillary and mandibular morphology among different skeletal patterns. Cephalograms of 240 participants were divided into 3 groups based on the skeletal pattern (Class I, Class II, and Class III). The dimensions of nasomaxilla (nasal bone length, nasal ridge length, nasal depth, palatal length, and maxillary height) and mandible (condylar length, ramus length, body length, symphysis length, and entire mandibular length) were measured. One-way analysis of variance and Pearson's correlation test were used for statistical analysis. No significant differences were observed among the skeletal patterns in terms of nasal bone length, palatal length, maxillary height, or condylar length. Class II had a significantly shorter ramus, mandibular body, and entire mandibular length compared with those of Class I and Class III. Nasal ridge length exhibited a significant moderate correlated with nasal bone length (correlation coefficient: 0.433) and maxillary height (correlation coefficient: 0.535). The entire mandibular length exhibited a significant moderate correlated with ramus length (correlation coefficient: 0.485) and body length (correlation coefficient: 0.536). In conclusion, nasal and maxillary dimensions exhibited no significant difference among the 3 skeletal patterns. Mandibular body and entire mandibular lengths were significantly positively correlations with Class III skeletal patterns.

1. Introduction

Craniofacial development is regulated by dynamic and complex mechanisms that involve various signaling cascades and gene regulation pathways [1]. Manlove et al. [2] concluded that the development of the craniofacial skeleton occurs as a result of a sequence of normal developmental events in the brain, the optic pathway, speech and swallowing function, the pharyngeal airway, muscles, and teeth. The growth and development of facial bones are closely related processes. The nasomaxillary complex comprises numerous bones that articulate with each other at sutures. The frontal bone and ethmoid bone meet the maxilla on both sides and protrude from the upper-middle portion of the face. The upper third of the nose is supported by the nasal bones that articulate with the frontal bone at the superior border and with the frontal process of the maxilla at the lateral border. The lower two-thirds of the nose is supported by the lateral nasal cartilage [3]. In addition, bone resorption at the inner surface of the nasomaxillary complex enlarges the maxillary sinus. Thus, nasomaxillary growth and development occur by bone apposition, bone resorption, and remodeling. [4–6]

Growth centers of the mandible include the mandibular body, mandibular angle, condylar process, coronoid process, symphysis, and alveolar process. Growth of the condylar process takes place from its tip to the mandibular canal and foramen and is affected by the position of the petrous portion of the temporal bone. Growth of the mandibular condylar cartilage increases the mandibular ramus length, entire mandible length, and the bilateral condylar distance. Additionally, the development of dentition and alveolar bone growth also increases the mandibular body length. Enlow [5] noted that the forward-downward growth of the maxilla and mandible has an expanding V configuration and defined such growth pattern as relocation. The extent and direction of bone growth varies among individuals. Changes in the pattern and rate of bone growth can lead to abnormal bone morphology and malocclusion. The present study investigated the parameters of nasomaxillary and mandibular bone morphologies and their correlations. The null hypothesis was that no difference exists in the nasal, maxillary, or mandibular dimensions among different skeletal patterns.

2. Materials and Methods

Cephalograms of 240 individuals (120 male and 120 female) were obtained for this study. Participants were selected on the basis of the availability of cephalograms and whether they were 18 to 39 years old. The cephalograms were divided into 3 groups according to the skeletal pattern based on the A point–nasion–B point (ANB) angle as follows: Class I malocclusion ($0^\circ < \text{ANB} < 4^\circ$), Class II malocclusion ($\text{ANB} \geq 4^\circ$), and Class III malocclusion ($\text{ANB} < 0^\circ$). Each group consisted of 80 participants (40 males and 40 females). The following participants were excluded from the study: (1) those with a pathologic disease in the facial bone, (2) those that had undergone craniofacial surgery, and (3) those with a history of maxillofacial trauma.

We followed the methods proposed by Hsiao et al. [7] in 2020. The following landmarks (Figure 1) were identified on the cephalogram: nasion (N); orbitale (Or); porion (Po); rhinion (R); the most anterior and inferior point on the tip of the nasal bone; frontomaxillary nasal suture (MS); the superior-most point of the suture where the maxilla articulates with the frontal and nasal bone; pronasale (Prn); anterior nasal spine (ANS); point A; posterior nasal spine (PNS); prosthion (Pr); infradentale (Id); point B; condylion (Cd); antegonial notch (Ag); sigmoid notch (SIG); and menton (Me). Nasal dimensions were calculated according to the nasal bone length (N to R), nasal ridge length (N to Prn), and nasal depth (Prn vertical to the MS-Pr line). Maxillary dimensions were calculated according to the palatal length (ANS to PNS) and maxillary height (MS to Pr). Mandibular dimensions were calculated according to the condylar length (the longest distance from Cd to a line parallel to Or-Po line through SIG), ramus length (SIG to Ag), body length (Ag to Me), symphysis length (Me to Id), and entire length (Cd to Me). Regarding the measurement error of our cephalometric study, the intraclass correlation coefficient (0.982) was >0.9, thus confirming consistency in the repeated measurements.

Data were analyzed using SPSS version 20 (IBM, Armonk, NY, USA). Intragroup and intergroup comparisons were performed using Student's t-test and one-way analysis of variance, respectively. Post hoc comparisons were performed using Tukey's honestly significant difference test. Pearson's correlation test was used to compare correlations among the variables in each group. We describe the correlation strength for the absolute value of the ratio as follows: very weak (0-0.19), weak (0.20-0.39), moderate (0.40-0.59), strong (0.60-0.79), and very strong (0.80-1.0). A P value < 0.05 was considered statistically significant. This retrospective study was approved by a human investigation review committee (KMUHIRB-E(II)-20180200).

3. Results

Table 1 presents the results of the analysis of the 3 skeletal patterns (Class I, Class II, and Class III). Intergroup comparison revealed no significant correlation between age and skeletal pattern ($P = .216$). Furthermore, no significant difference in nasal bone length, nasal ridge length, nasal depth, palatal length, or maxillary height was noted among the skeletal patterns. Intergroup comparisons of condylar length and symphysis length among the 3 skeletal patterns revealed no significant differences. However, the patients in Class II had a significantly shorter ramus length (52.8 mm), mandibular body length (59.8 mm), and entire mandibular length (117.9 mm) than those of the patients in Class I (55.7, 62.4, and 125.1 mm, respectively) and Class III (55.8, 66.1, and 131.7 mm, respectively). Therefore, the null hypothesis was accepted for the nasal and maxillary morphology and rejected for the mandibular morphology.

As indicated in Table 2, no significant intergroup differences were observed in the nasomaxillary, condylar, or symphysis lengths among male patients. However, among the male patients, those in Class II had significantly shorter mandibular ramus, body, and entire lengths than those in Class III. Among the female patients, those in Class II had greater maxillary lengths than those in Class III (Table 3). Analysis of all skeletal patterns revealed no significant difference among female patients in terms of condylar and symphysis lengths. However, female patients in Class II had a significantly shorter ramus length than those in Class I and a significantly shorter mandibular body and entire mandible length than those in Class III.

Table 4 lists the nasomaxillary and mandibular lengths for each skeletal classification compared using Pearson's correlation coefficient. Age exhibited no significant correlation with maxillary or mandibular lengths. The mandibular body length (correlation coefficient: 0.279) and entire length (correlation coefficient: 0.236) exhibited a significant positive correlation with skeletal classification; for example, an individual with a Class III skeletal pattern had a longer mandibular body and entire lengths. A significant negative correlation was noted between variations of the ANB angle and the mandibular body length (correlation coefficient: -0.524) and entire mandibular length (correlation coefficient: -0.544). A highly significant positive correlation was observed between maxillary height and ridge length (correlation coefficient: 0.535). The Pearson correlation matrix was shown in Figure 2.

The condylar length had significant positive correlations with the mandibular body, symphysis, entire mandibular, maxillary, nasal bone, and nasal ridge lengths. Ramus length exhibited no correlation with condylar length but had a

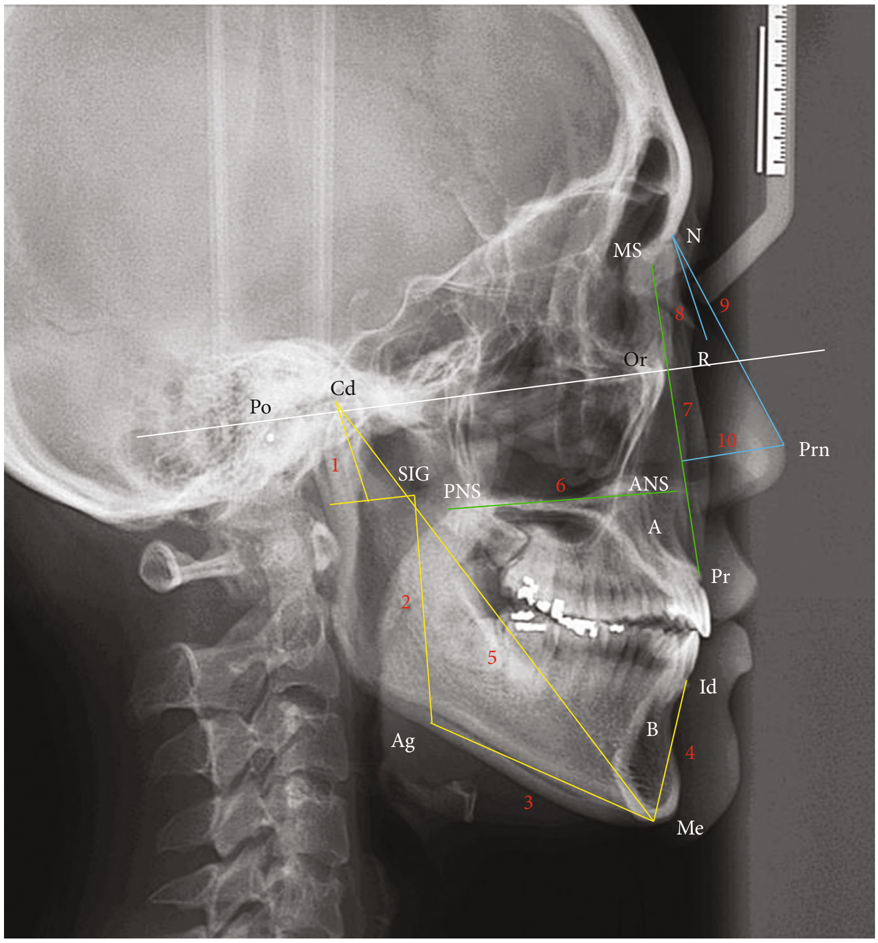

Figure 1: Cephalometric landmarks and linear measurements. N: nasion; Or: orbitale; Po: porion; R: rhinion; MS: frontomaxillary nasal suture; Prn: pronasale; ANS: anterior nasal spine; point A; PNS: posterior nasal spine; Pr: prosthion; Id: infradentale; point B; Cd: condylion; Ag: antegonial notch; SIG: sigmoid notch; Me: menton. Yellow line (mandible): 1: condylar length; 2: ramus length; 3: body length; 4: symphysis length; 5: entire length. Green line (Maxilla): 6: palatal length; 7: maxillary height. Blue line (nose): 8: nasal bone length; 9: nasal bridge length; 10: nasal depth.

significant positive correlation with all other variables. Mandibular body length was not correlated with symphysis length or nasal bone length but was significantly correlated to all other variables. The entire mandibular length had a significant positive correlation with all variables.

4. Discussion

Facial profile pattern is closely associated with nasal development. Heijden et al. [8] noted that the growth rate of the nose is related to body height; that is, the nose develops as the height increases. They also indicated that the nose reaches its maximum growth rate between the age of 10 and 11 years in the female population and between 12 and 13 years in the male population [8]. Posen [9] reported that 90% of nasal bone development is usually completed by the age of 13 years, at which age male and female nasal bone growth patterns are fundamentally similar. Heijden et al. [8] also reported that 95% of nasal bones have developed by the age of 16 and 15 years in male and female populations, respectively. Posen [9] reported that 91% of nasal ridge (length of the dorsum of the external nose) growth is completed by the age of 16 years, and the development takes longer in male patients than in female patients; however, the difference is not statistically significant.

Nasal depth begins to increase by the age of 6 months, with growth in the nasal cartilage accounting for much of the increase in nasal depth. In general, the nasal depth stops increasing by the age of 15 years, although it could continue in some cases until the age of 17–18 years. According to Posen [9], more time is required for the growth for each part of the male nose compared with that required for the growth of the female nose. At equivalent ages, nasal development in females is more mature than in males, but no significant sex difference exists. On the basis of the aforementioned research, the present study selected participates aged >18 years because the nose has nearly or completely developed by this age. According to our findings, there were no significant differences in nasal dimensions in relation to skeletal patterns. Therefore, the null hypothesis was accepted for the nasal morphology. According to Pearson's correlation analysis of age, no significant difference existed among the

Table 1: Patients characteristics in the skeletal classification (one-way ANOVA).

Variables	Class I (F/M = 40/40) Mean	SD		Class II (F/M = 40/40) Mean	SD		Class III (F/M = 40/40) Mean	SD		F		Intergroup comparison Significant
Age	24.4	4.71	–	24.7	4.76	–	23.5	4.48	–	1.540	–	
ANB	2.1	0.93	–	6.3	1.90	–	-3.6	2.97	–	447.404	*	Class II > Class I > Class III
Nasomaxillary												
Nasal bone length	28.1	4.00	–	27.7	2.95	–	28.4	3.82	–	0.775	–	
Nasal ridge length	57.8	5.73	†	58.5	3.71	†	58.5	4.67	†	0.510	–	
Nasal depth	28.2	4.54	†	27.7	3.35	†	28.0	3.04	†	0.305	–	
Palatal length	52.2	3.86	–	52.8	3.50	†	51.5	3.69	†	2.302	–	
Maxillary height	73.6	7.82	†	74.9	4.64	†	73.5	5.71	†	1.317	–	
Mandible												
Condylar length	21.2	2.91	–	21.1	3.27	†	22.0	3.50	†	2.034	–	
Ramus length	55.7	5.56	†	52.8	5.43	†	55.8	6.09	†	7.552	*	Class III > Class II, Class I > Class II
Body length	62.4	5.43	–	59.8	4.00	–	66.1	4.91	†	34.855	*	Class III > Class I > Class II
Symphysis length	36.4	5.51	–	36.5	4.00	†	36.2	4.54	†	0.095	–	
Entire length	125.1	6.81	†	117.9	12.96	–	131.7	9.23	†	38.378	*	Class III > Class I > Class II

F: Female; M: Male. †: intergender comparison (M > F): statistically significant, $P < 0.05$; *: intergroup comparison: statistically significant, $P < 0.05$; –: not significant.

Table 2: The characteristics of male patients in the skeletal classification (one-way ANOVA).

Variables	Class I ($n = 40$) Mean	SD	Class II ($n = 40$) Mean	SD	Class III ($n = 40$) Mean	SD	F		Intergroup comparison Significant
Age	24.8	4.38	24.7	5.23	23.2	4.27	1.413	—	
ANB	2.0	0.96	6.0	1.62	-4.1	2.89	257.542	*	Class II > Class I > Class III
Nasomaxillary									
Nasal bone length	27.8	3.20	27.9	2.94	29.2	3.78	2.225	—	
Nasal ridge length	59.4	6.65	59.9	3.84	60.6	3.81	0.538	—	
Nasal depth	30.3	4.96	29.0	3.80	29.2	2.59	1.387	—	
Palatal length	52.8	3.31	54.4	3.31	53.2	3.34	2.674	—	
Maxillary height	75.5	5.48	76.0	5.41	76.7	4.64	0.535	—	
Mandible									
Condylar length	21.4	2.86	21.9	3.70	22.8	2.85	2.255	—	
Ramus length	57.5	5.28	55.4	5.00	59.2	5.87	4.979	*	Class III > Class II
Body length	62.7	4.50	59.5	3.65	68.1	4.33	43.447	*	Class III > Class I > Class II
Symphysis length	37.2	6.41	38.3	4.11	38.7	3.90	1.016	—	
Entire length	127.5	7.03	120.0	17.08	137.4	6.88	23.586	*	Class III > Class I > Class II

n: number of patient. *: statistically significant, $P < 0.05$; —: not significant.

Table 3: The characteristics of female patients in the skeletal classification (one-way ANOVA).

Variables	Class I ($n = 40$) Mean	SD	Class II ($n = 40$) Mean	SD	Class III ($n = 40$) Mean	SD	F		Intergroup comparison Significant
Age	24.0	5.05	24.7	4.31	23.7	4.73	0.4	—	
ANB	2.2	0.90	6.6	2.12	-3.2	3.02	199.9	*	Class II > Class I > Class III
Nasomaxillary									
Nasal bone length	28.3	4.69	27.5	2.98	27.6	3.74	0.5	—	
Nasal ridge length	56.2	4.11	57.1	3.03	56.4	4.56	0.5	—	
Nasal depth	26.1	2.81	26.5	2.28	26.7	2.97	0.7	—	
Palatal length	51.6	4.30	51.1	2.88	49.9	3.28	2.6	—	
Maxillary height	71.6	9.28	73.8	3.45	70.2	4.79	3.3	*	Class II > Class III
Mandible									
Condylar length	21.1	2.99	20.3	2.59	21.2	3.92	1.1	—	
Ramus length	54.0	5.36	50.2	4.55	52.5	4.23	6.8	*	Class I > Class II
Body length	62.1	6.27	60.1	4.36	64.1	4.66	6.1	*	Class III > Class II
Symphysis length	35.6	4.37	34.7	3.02	33.6	3.63	2.8	—	
Entire length	122.8	5.77	115.8	6.26	126.0	7.66	25.1	*	Class III > Class II

n: number of patient. *: statistically significant, $P < 0.05$; —: not significant.

nasomaxillary and mandibular dimensions. Thus, it can be concluded that facial bone development had probably stabilized at the age of 18 years. Hwang et al. [10] reported that nasal bone length was not significantly different between Korean male and female populations. Park et al. [11] also reported no significant intersex difference in the nasal septum and external nose growth processes. In our study, nasal bridge length and nasal depth were significantly greater in male patients than in female patients. However, nasal bone length was not significantly different between male and female patients.

Nehra [12] also revealed that nasal length and nasal depth are not significantly correlated with the sella-nasion to A point (SNA) angles. Our results also revealed that nasal ridge length and nasal depth were not significantly correlated with ANB angle. However, a significant negative correlation with nasal bone length was observed upon examining the ANB angles. A negative ANB angle results in a long nasal bone. Therefore, the Class III skeletal pattern had a longer nasal bone than the Class II pattern. Park et al. [11] reported that nasal bone growth is significantly correlated with nasal ridge length and nasal depth throughout an individual's life. Moreover, Nehra [12] reported the existence of a significant positive correlation between the nasal ridge length and nasal depth; similar results were observed in our study. Moreover, we found that nasal bone length was significantly and moderately correlated (correlation coefficient: 0.433) with nasal ridge length.

Table 4: Pearson's correlation coefficient test in the nasomaxillary and mandibular dimensions.

	Age	Skeletal pattern	ANB	Nasal bone	Nasal ridge	Nasal depth	Palatal length	Maxillary height	Condyle	Ramus	Body	Symphysis	Entire length
Nasomaxillary length													
Palatal length	0.084	-0.074	0.178*	0.237*	0.164*	0.204*	1	0.016	0.062	0.340*	-0.029	0.292*	0.149*
Maxillary height	-0.115	-0.007	0.07	0.096	0.535*	0.298*	0.016	1	0.188*	0.279*	0.293*	0.272*	0.325*
Nasal bone	-0.099	0.04	-0.135*	1	0.433*	0.117	0.237*	0.096	0.151*	0.245*	-0.032	0.175*	0.168*
Nasal ridge	-0.011	0.057	-0.044	0.433*	1	0.248*	0.164*	0.535*	0.189*	0.311*	0.166*	0.223*	0.288*
Nasal depth	0.063	-0.024	-0.047	0.117	0.248*	1	0.204*	0.298*	0.089	0.331*	0.151*	0.140*	0.291*
Mandibular length													
Condyle	-0.034	0.098	-0.175*	0.151*	0.189*	0.089	0.062	0.188*	1	-0.073	0.134*	0.220*	0.303*
Ramus	0.017	0.007	-0.267*	0.245*	0.311*	0.331*	0.340*	0.279*	-0.073	1	0.157*	0.293*	0.485*
Body	-0.103	0.279*	-0.524*	-0.032	0.166*	0.151*	-0.029	0.293*	0.134*	0.157*	1	0.114	0.536*
Symphysis	-0.008	-0.019	0.02	0.175*	0.223*	0.140*	0.292*	0.272*	0.220*	0.293*	0.114	1	0.378*
Entire length	-0.08	0.236*	-0.544*	0.168*	0.288*	0.291*	0.149*	0.325*	0.303*	0.485*	0.536*	0.378*	1

*: Statistically significant, $P < 0.05$.

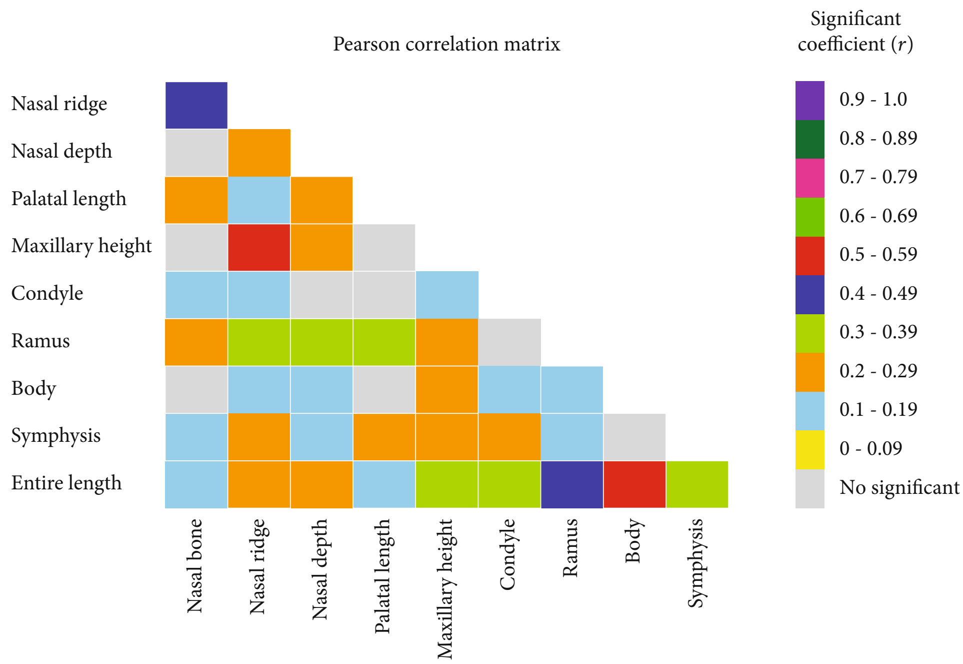

FIGURE 2: Pearson correlation matrix. Absolute value of correlation ratio: very weak (0-0.19), weak (0.20-0.39), moderate (0.40-0.59), strong (0.60-0.79), and very strong (0.80-1.0).

We found the nasal bone length was significantly and positively correlated with palatal length, indicating that when the palatal increases in length and extends forward, the maxilla is elongated, which in turn causes the nasal bone to grow forward. However, our study also revealed that the nasal bone length was not significantly correlated with maxillary height. This may be because only a smaller portion of the maxillary and nasal bones are connected on both sides, leading to weaker effects on growth potency. Nehra [12] concluded that nasal ridge length has a significant positive correlation with upper anterior facial height and palatal length, which implies that the anteroposterior length of the maxilla strongly affects nasal ridge length; the same study also reported a significant positive correlation between nasal depth and upper anterior facial height. Our study showed a similar result; there was a significant moderate correlation (0.535) between the nasal ridge length and maxillary height. In our study, Pearson's correlation test revealed that compared with palatal length, maxillary height had a significant positive correlation with the development of each mandibular part. Thus, maxillary height develops at a similar rate as mandibular length, and both may begin to increase in late adolescence. All these findings allow us to make inferences regarding the relationship between palatal length, maxillary height, skeletal pattern, and occlusal condition. An increase in maxillary height is induced by alveolar bone development and tooth eruption and occurs later than an increase in palatal length.

Regarding maxillary development, Nanda et al. [13] suggested that maxillary growth over the age of 12 years is small, with $<1^{\circ}$ change to the SNA angle. Nahhas et al. [14] studied the growth and development of the maxilla and found that maxillary growth onset, peak, and cessation occurred relatively later in the male population than in the female population. Peak growth occurred at the age of 10.8 years in girls and 13.4 years in boys, by the age of 16 years, over 90% of maxillary development and growth had ceased in both male and female populations. Nahhas et al. [14] also showed that palatal lengths are greater in the male population than in the female population. In the present study, we found that the palatal length was significantly greater in male patients than in female patients for both Class II and Class III skeletal patterns; this might be the result of abnormal occlusion induced by the overgrowth of the maxilla and mandible during late adolescence. Because development in the male population occurs during late adolescence, men have a greater maxillary height than women in all skeletal patterns. Our study identified no significant differences in palatal length or maxillary height among any of the skeletal patterns. Therefore, the null hypothesis was accepted for the maxillary morphology.

Gomes and Lima [15] showed that no significant difference in mandibular development exists between the sexes or Class I and II skeletal patterns. Bjork [16] reported that during the adolescent growth spurt, condylar growth peaked at the age of approximately 14.5 years. The condylar growth rate is greater during adolescence than during childhood and in male than in female populations. With regard to mandibular growth, our study revealed that condylar length was not significantly different for the various skeletal patterns; Class II and III male patients had a significantly greater condylar length than those of female patients. This result is consistent with that observed for palatal length, which means that an increase in condylar length in both male and female populations is necessary for skeletal formation with Class I features. In other words, Class I skeletal patterns are related to maxillary palatal and mandibular condylar lengths.

Gomes and Lima [15] reported that the ramus length in Class I and II skeletal patterns has no correlation with mandibular development or sex. Compared with the lengths of other mandibular structures (i.e., mandible body and entire mandibular lengths), ramus length has the least variability in annual growth rate. Our study showed that the ramus length in Class II was significantly shorter than that in other classes. Therefore, ramus length is a key factor for identifying the Class II skeletal pattern. Growth of the ramus in Class II may be complete at an earlier stage than that in Class I and Class III. Therefore, ramus length in Class I and III is substantially greater than that in Class II. Unlike Gomes and Lima [15], we noted that the ramus length is significantly greater in the male population than in the female population for all skeletal patterns.

Singer et al. [17] and Lambrechts et al. [18] suggested that the depth of the antegonial notch can be used to predict the potential and direction of mandibular growth. Singer et al. [17] stated that patients with a deep mandibular notch have a more retrusive mandible, shorter mandibular body, and shorter ramus height. These patients also have a longer total facial height, longer lower facial height, and less mandibular growth than patients with a shallow notch, indicating that the chin bone does not shift forward. We agree with these studies [17, 18] and believe that the antegonial notch is an essential growth center. Muscular movements affect the mandibular growth process through functional shaping and reinforcement [4–6]. The antegonial notch is the attachment site of the masseter and medial pterygoid muscles; hence, it is strongly affected by muscular movements. On the basis of the physiology of mandibular bone development, our study used the antegonial notch as the separation growth point for the mandibular ramus and body.

Bae et al. [19] reported that the growth of the mandibular body peaks between the ages of 13 and 15 years, and the extent of growth is remarkably greater in the male population than in the female population. Gomes and Lima [15] noted no significant differences in mandibular body length between Class I and Class II skeletal patterns. In our study, we noted the longest mandibular body length in the Class III skeletal patterns and the shortest in the Class II pattern. Aki et al. [20] estimated the pattern and size of the mandibular symphysis to predict the direction and potential of mandibular growth and concluded that symphysis length and depth increase with age, and their growth rates increase during puberty. The growth spurts of symphysis length and depth occur during and after adolescence, with a greater increase in symphysis length than in symphysis depth, although the increases are less pronounced in the female population than in the male population. Ricketts [21] proposed that symphysis morphology could be used to predict the direction of mandibular growth. Our study revealed that symphysis development exhibited no significant difference in all skeletal patterns.

Although the growth of each mandibular structure often has a significant positive correlation with that of another, condylar growth is negatively correlated with ramus growth. This negative correlation, although not significant, suggests that the ramus tends to be short when the condyle is long. The entire mandibular length has a significant positive correlation with the growth of each mandibular structure and with the length of nasal and maxillary structures. These results indicate a close relationship between the growth and development of facial bones. Moreover, the entire mandibular length was significantly and moderately correlated with the mandibular ramus (correlation coefficient: 0.485) and body (correlation coefficient: 0.536) lengths.

5. Conclusion

Nasal measurements (nasal bone length, nasal ridge length, and nasal depth) exhibit no correlation with skeletal patterns. Palatal length and maxillary length, which represent maxillary development, have no correlation with skeletal patterns. Neither condylar length nor symphysis lengths are correlated with skeletal patterns. Notably, Class III has the greatest ramus, mandibular body, and entire mandibular lengths, whereas Class II has the shortest ramus, mandibular body, and entire mandibular lengths. The present study provides a comprehensive understanding of the relationships among the nasal bone, maxilla, and mandible. Our findings may be useful to physicians for the analysis of craniofacial development and selection of appropriate treatment plans. However, the main limitation of this study is that it involved two-dimensional cephalometric analysis, but comparisons were performed among the participants' actual three-dimensional anatomical features.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Importance in the Occurrence Distribution of Minimum Oropharyngeal Cross-Sectional Area in the Different Skeletal Patterns Using Cone-Beam Computed Tomography

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Purpose. Obstructive sleep apnea is a condition involving repetitive partial or complete collapse of the pharyngeal airway, especially in patient with mandibular hypoplasia. The present study investigated the differences between the volume of the oropharyngeal airway and the minimum axial area in three skeletal patterns through the use of cone-beam computed tomography (CBCT). *Materials and Methods*. CBCT scans of 147 patients were collected to measure the upper oropharyngeal airway volume (UOV), lower oropharyngeal airway volume (LOV), upper oropharyngeal airway area (UOA), minimum upper oropharyngeal airway area (MUOA), lower oropharyngeal airway area (LOA), minimum lower oropharyngeal airway area (MLOA), anatomical structures (orbitale, Or; porion, Po; pogonion, Pog; hyoid, H; second cervical vertebra, C2; fourth cervical vertebra, C4), and relevant angles. Statistical analysis was performed using analysis of variance and Pearson's test. *Results*. Compared with patients in Class II, those in Class III and Class I exhibited a significantly anterior position of H and Pog. The vertical positions of H and Pog revealed no significant difference between the three skeletal patterns. Patients in skeletal Class III exhibited significantly larger oropharyngeal area (UOA, MUOA, LOA, MLOA) and oropharyngeal airway (UOV and LOV) than those in skeletal Class II did. The horizontal position of Pog had a moderately significant correlation with UOA ($r = 0.471$) and MUOA ($r = 0.455$). *Conclusion*. Patients in skeletal Class II had significantly smaller oropharyngeal airway areas and volumes than those in Class III did. The minimum oropharyngeal cross-sectional area had a 67% probability of occurrence in the upper oropharyngeal airway among patients in Class I and Class II and a 50% probability of occurrence among patients in Class III.

1. Introduction

The pharynx is a conical channel linking the oral and nasal cavity to the esophagus and trachea. It is located at the intersection of the digestive and respiratory tracts and serves as the passage for food and air. Thus, the pharynx plays a crucial role in swallowing and breathing functions [1, 2]. The pharyngeal airway is divided into three parts, namely, the nasopharynx, oropharynx, and laryngopharynx. The nasopharynx and the oropharynx are demarcated by the soft palate to the rear of the palate, and the oropharynx and laryngopharynx are demarcated by the apex of the epiglottis. The structure of the pharynx affects the volume of the respiratory tract, facial growth pattern, masticatory pattern, and the risk of obstructive sleep apnea. The anatomical structure of the pharyngeal airway space varies according to the diverse growth patterns of the maxilla and mandible.

Face-driven orthodontics and mandibular setback surgery can cause the backward movement of teeth, leading to changes in the pharyngeal airway space [3]. Thus, evaluating and measuring the pharyngeal airway space of patients are important before orthodontic treatment and orthognathic surgery. Such precautions can avoid the backward movement of teeth and prevent the mandible from pushing the tongue further backward, which ultimately oppresses and reduces the pharyngeal airway space, causing obstructive sleep apnea in more serious cases. Compared with the nasopharyngeal and laryngopharyngeal airways, the oropharyngeal airway is more likely to be influenced by the surrounding organs. The dimensions of the oropharyngeal airway are mainly affected by the anteriority or posteriority of the mandibular position and tongue size. The front and rim of the tongue are attached to the mandible, and the base of the tongue is linked to the hyoid bone; connections also exist between the tongue and the soft palate as well as the palatoglossus muscles.

In the present study, cone-beam computed tomography (CBCT) was used to explore differences in the volume and minimum cross-sectional area of the individual parts of the oropharyngeal airway in terms of skeletal patterns. In addition, this study involved evaluation of the relationships between the maxilla and mandible; the relationships between sex, age, and the cervical spine; other anatomical structures (including the mandible and hyoid bone positions); the related distances or angles (head and cervical spine positions) that might affect oropharyngeal airway dimensions; and relationships between oropharyngeal airway volume and the minimum cross-sectional area.

2. Materials and Methods

The CBCT scans (New Tom VGi evo, Imola, Italy) of 147 patients were collected from the dental department of Kaohsiung Medical University Chong-Ho Memorial Hospital. Patients with craniofacial disorders or malformation, those with pharyngeal or laryngeal pathology, and those with craniofacial injuries were excluded from the study. The patient characteristics included age, ANB angle, and body mass index (BMI). For analysis, the patients were divided into three groups according to their skeletal pattern: 30 patients (19 female and 11 male) in Class I ($0^\circ \leq \text{ANB} \leq 4^\circ$; average age: 25.3 years), 40 patients (28 female and 12 male) in Class II ($\text{ANB} > 4^\circ$; average age: 25.8 years), and 77 patients (44 female and 33 male) in Class III ($\text{ANB} < 0^\circ$; average age: 23.8 years).

CBCT images were imported using the Digital Imaging and Communications in Medicine into Dolphin® 11.0 software (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA). The reference points (Figure 1) included sella (S), nasion (N), A point (A), B point (B), pogonion (Pog), the most superior and anterior point of the hyoid bone (H), tip at the end of the uvula (U), upper tip at the end of the epiglottis (E), inferoanterior point on the second cervical vertebra (C2), and inferoanterior point on the fourth cervical vertebra (C4). The coordinate system consisted of the X-axis (constructed by drawing a line through nasion 7° up from the SN line) and Y-axis (constructed by drawing a line through the S point perpendicular to the X-axis) [4]. The horizontal and vertical positions of H and Pog were investigated. The related angles were measured and included the head positions (Or–Po–Pog angle, Or–Po–H angle, and Or–Po–C2 angle) and cervical spine positions (Po-C2-Pog angle, Po-C2-H angle, and Po–C2–C4 angle).

As shown in Figure 2, the Frankfort horizontal (FH) plane was defined as the plane connecting the right orbitale (Or) and porion (Po) on both sides. The oropharyngeal airway space was divided into the upper oropharyngeal airway (velopharyngeal airway) and lower oropharyngeal airway (glossopharyngeal airway). In the upper oropharyngeal airway, the upper bound of the pharyngeal airway passes through the posterior nasal spine (PNS) and is parallel to the standard horizontal plane, and the lower bound passes through the tip at the end of the uvula and is parallel to the standard horizontal plane. In the lower oropharyngeal airway, the upper bound of the pharyngeal airway passes through the tip at the end of the uvula and is parallel to the standard horizontal plane, and the lower bound passes through the upper tip at the end of the epiglottis and is parallel to the standard horizontal plane.

In Figure 3, three-dimensional (3D) model of airway space was obtained by Dolphin® 3D software. Airway semiautomatic segmentation (including borders and landmarks) was defined as aforementioned. The airway volume and airway area were automatically calculated by the Dolphin® 3D software. The upper oropharyngeal airway volume (UOV), lower oropharyngeal airway volume (LOV), and total oropharyngeal airway volume (TOV = UOV + LOV) were measured. The oropharyngeal airway areas (axial view) were measured as follows: upper oropharyngeal airway area (UOA: passes through the tip at the end of the uvula), minimum upper oropharyngeal airway area (MUOA: the minimum cross-sectional area of UOV), lower oropharyngeal airway area (LOA: passes through the upper tip at the end of the epiglottis), minimum lower oropharyngeal airway area (MLOA: the minimum cross-sectional area of LOV), and minimum total oropharyngeal airway area (MTOA: the minimum cross-sectional area of TOV).

The present study investigated the differences between the various skeletal patterns in terms of the volume and area of the oropharyngeal airway. Statistical analysis was performed using SPSS (version 20; IBM, Armonk, NY, USA), and $p < 0.05$ was the criterion for statistical significance. The mean values among the groups were compared using one-way analysis of variance with post hoc Tukey HSD test. Pearson's correlation coefficient was used to compare the correlations among the variables of the groups. Regarding the absolute value of the correlation coefficient (r), 0–0.19 indicated a very weak correlation, 0.2–0.39 indicated a weak correlation, 0.40–0.59 indicated a moderate correlation, 0.6–0.79 indicated a strong correlation, and 0.8–1 indicated a very strong correlation. This study was approved by the Institutional Review Board of Kaohsiung Medical University Hospital (KMUHIRB-E(II)-20160066).

3. Results

No significant difference was observed between the patients in the three groups in terms of age or BMI (Table 1). In terms of the horizontal distance of H and Pog, that of patients in Class II (27.1 mm and 63.7 mm, respectively) was

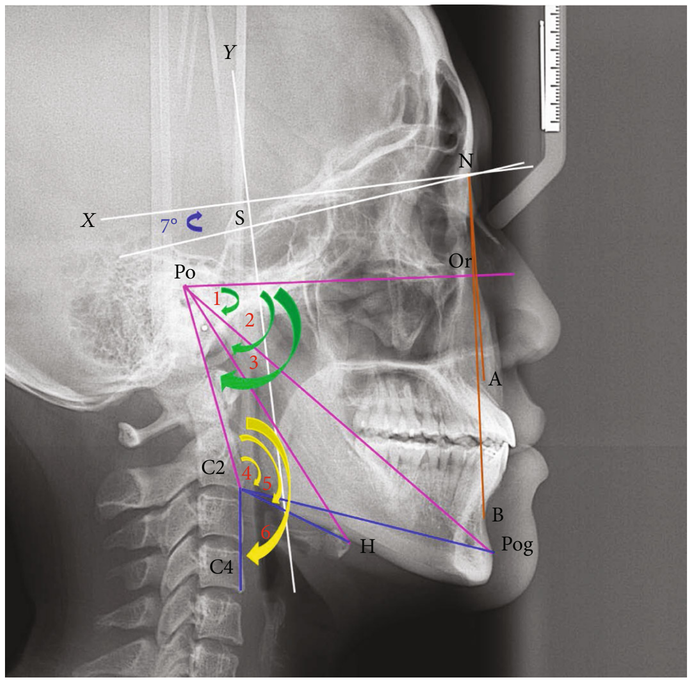


Figure 1: Landmarks: sella (S), nasion (N), A point (A), B point (B), pogonion (Pog), hyoid bone (H), second cervical vertebra (C2), and fourth cervical vertebra (C4). X-axis (white line): constructed by drawing a line through nasion 7° up from SN line. Y-axis (white line): a line through sella (S) perpendicular to the X-axis. The measured angles: brown color, ANB angle; green color, (1) Or–Po–Pog angle, (2) Or–Po–H angle, (3) Or–Po–C2 angle; and yellow color, (4) Po-C2-Pog angle, (5) Po-C2-H angle, (6) Po–C2–C4 angle.

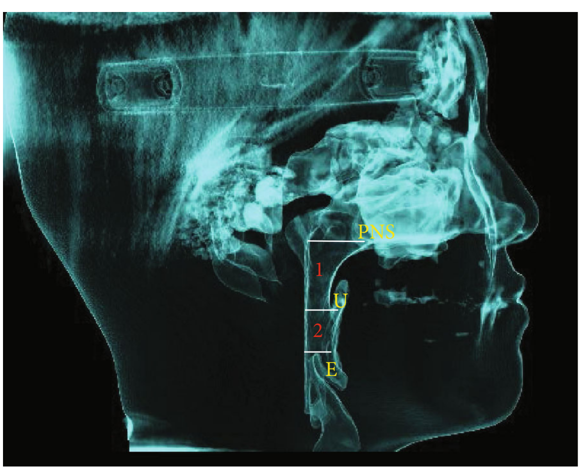
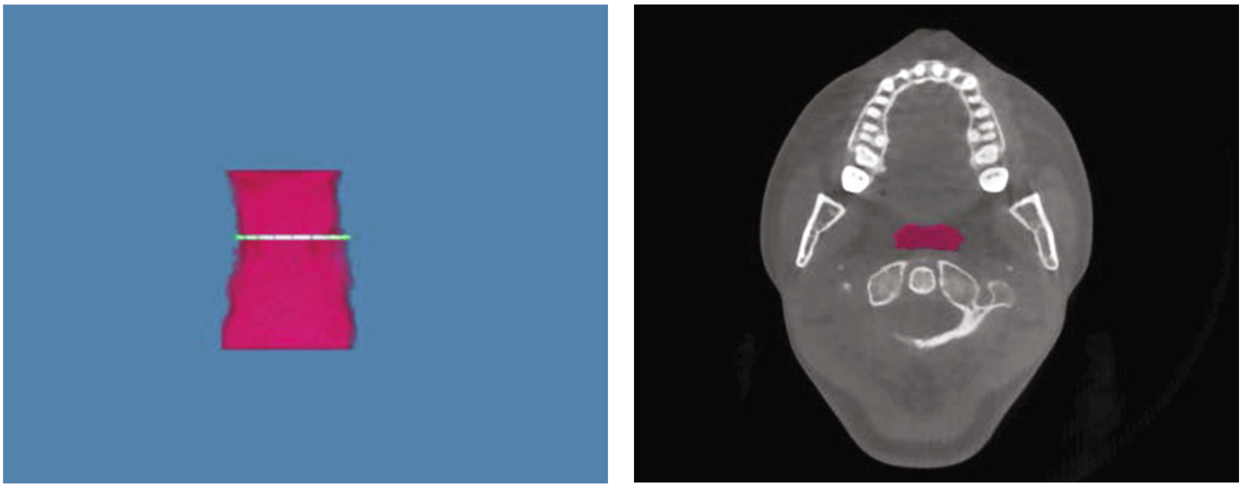


Figure 2: Landmarks: posterior nasal spine (PNS), uvula (U), epiglottis (E). The measured pharyngeal airway volume: (1) upper oropharyngeal airway volume: UOV; (2) lower oropharyngeal airway volume: LOV.

significantly smaller than that of patients in Class I (33.7 mm and 74.3 mm, respectively) and Class III (36.1 mm and 80.2 mm, respectively). No significant difference was observed between the groups with respect to the vertical position of H and Pog. The Or–Po–Pog and Or–Po–C2 angles (Table 2) of patients in Class II (48.9° and 87.3°, respectively) were significantly larger than those of patients in Class I (45.6° and 83.8°, respectively) and Class III (44.5° and 82.5°, respectively). The Po–C2–H angle of patients in Class I (130.6°) was significantly greater than that of patients in Class II (124.8°). The Po–C2–C4 angle of patients in Class III (189.4°) was significantly smaller than that of patients in Class I (192.7°) and II (193.2°).

Table 3 presents a comparison of oropharyngeal airway space in the three skeletal patterns. The UOA of patients in Classes III (468.5 mm^2) and I (443.9 mm^2) was significantly greater than that of patients in Class II (377.2 mm^2). The MUOA (118.3 mm^2), LOA (289.7 mm^2), MLOA (113.4 mm^2), UOV (13801.9 mm^3), LOV (7773.5 mm^3), MTOA (96 mm^2), and TOV (21575.4 mm^3) of patients in Class III were significantly greater than the corresponding values of patients in Class II (78.8 mm^2, 225.4 mm^2, 86.0 mm^2, 10658.7 mm^3, 6051.5 mm^3, 69.6 mm^2, and 16710.1 mm^3, respectively). Evaluation of the distribution of MTOA revealed that 20 patients in Class I had MUOA and 10 had MLOA, 27 patients in Class II had MUOA and 13 had MLOA, and 39 patients in Class III had MUOA and 38 had MLOA. The MUOA represented the MTOA of the oropharyngeal airway in a two-thirds of patients in Class I (66.7%), a two-thirds of patients in Class II (67.5%), and one-half (50.6%) of patients in Class III.

On the basis of patient characteristics (Table 4), Pearson's test was performed to evaluate the correlations of pharyngeal airway space. Both the area and volume of each airway space were significantly positively correlated with sex: male patients had larger airways, indicating a positive correlation. Skeletal pattern had a significant positive correlation with MUOA and MTOA: the MUOA and MTOA of patients in Class III were larger, indicating a positive correlation. Age exhibited a significant negative correlation with MUOA, LOA, and MTOA; higher age was associated with



(a) (b)

Figure 3: (a) In the 3D image, the minimum cross-sectional area (green color) of upper oropharyngeal airway in the oropharyngeal airway (pink color). (b) The minimum cross-sectional area (pink color) of upper oropharyngeal airway in the axial view.

Table 1: Patient's characteristics in the skeletal patterns using one-way ANOVA with Tukey's HSD post hoc test.

Variables	Class I		Class II		Class III				Intergroup comparison
	Mean	SD	Mean	SD	Mean	SD	F	p value	
Age	25.3	5.70	25.8	5.95	23.8	5.54	1.897	0.154	—
ANB	2.2	1.21	7.1	2.05	-4.4	3.10	279.543	<0.001*	Class II > I > III
BMI	21.9	3.44	20.9	2.87	21.7	3.34	1.152	0.319	—
Hyoid									
Horizontal	33.7	6.18	27.1	5.95	36.1	7.09	24.721	<0.001*	Class III > II, Class I > II
Vertical	74.1	10.37	71.7	8.80	70.8	8.14	1.522	0.222	—
Pogonion									
Horizontal	74.3	7.84	63.7	8.42	80.2	10.43	40.442	<0.001*	Class III > I > II
Vertical	77.5	9.87	74.6	8.74	74.0	8.46	1.684	0.189	—

BMI: body mass index. *Intergroup comparison: statistically significant, $p < 0.05$.

Table 2: The measured angles in the skeletal patterns using one-way ANOVA with Tukey's HSD post hoc test.

Angles	Class I		Class II		Class III				Intergroup comparison
	Mean	SD	Mean	SD	Mean	SD	F	p value	
Or-Po-Pog	45.6	4.13	48.9	4.29	41.5	3.41	51.371	<0.001*	Class II > I > III
Or-Po-H	65.7	4.70	69.3	4.72	69.1	58.65	0.077	0.926	—
Or-Po-C2	83.8	5.86	87.3	5.15	82.5	4.90	11.318	<0.001*	Class II > I, Class II > III
Po-C2-Pog	113.0	8.78	108.9	6.58	110.6	6.97	2.832	0.062	—
Po-C2-H	130.6	12.54	124.8	12.00	124.8	10.56	3.09	0.049*	Class I > II
Po-C2-C4	192.7	5.44	193.2	7.30	189.4	4.67	7.307	0.001*	Class II > III, Class I > III

Or: orbitale; Po: porion; Pog: pogonion; H: hyoid bone; C2: second cervical vertebra; C4: fourth cervical vertebra. *Intergroup comparison: statistically significant, $p < 0.05$. —: not significant.

a smaller MUOA, LOA, and MTOA. No significant correlation was observed between BMI and the area and volume of oropharyngeal airway space. Greater ANB angle was associated with a significantly smaller area and volume of oropharyngeal airway space. Except for PogY (vertical position) and MLOA, which were not significantly correlated, the positions of H and Pog were positively correlated with the areas and volumes of all of the other oropharyngeal airway spaces. The horizontal position of Pog was moderately correlated with UOA ($r = 0.476$) and MUOA ($r = 0.455$).

As shown in Table 5, the Or–Po–Pog angle was significantly negatively correlated (weak or very weak) with UOA,

Table 3: Oropharyngeal airway spaces in the skeletal patterns using one-way ANOVA with Tukey's HSD post hoc test.

Angles	Class I		Class II		Class III				
	Mean	SD	Mean	SD	Mean	SD	F	p value	Intergroup comparison
UOA (mm^2)	443.9	92.46	377.2	91.29	468.5	121.77	9.342	<0.001*	Class III > II, Class I > II
MUOA (mm^2)	95.1	45.36	78.8	42.41	118.3	55.94	8.489	<0.001*	Class III > II
UOV (mm^3)	12682.9	4100.43	10658.7	3425.23	13801.9	5466.62	5.823	0.004*	Class III > II
LOA (mm^2)	272.8	89.49	225.4	91.94	289.7	111.49	5.237	0.006*	Class III > II
MLOA (mm^2)	110.6	33.23	86.0	38.79	113.4	51.72	5.117	0.007*	Class III > II
LOV (mm^3)	7159.7	3020.93	6051.5	3215.32	7773.5	3912.60	3.070	0.049*	Class III > II
MTOA (mm^2)†	85.5	34.12	69.6	33.83	96.0	42.35	6.200	0.003*	Class III > II
TOV (mm^3)	19842.6	5952.78	16710.1	6007.16	21575.4	8638.67	5.535	0.005*	Class III > II

UOA: upper orophyngeal area; MUOA: minimum upper oropharyngeal area; UOV: upper oropharyngeal volume; LOA: lower oropharyngeal area; MLOA: minimum lower phsryngeal area; LOV: lower oropharyngeal volume; MTOA: minimum total oropharyngeal area; TOV: total oropharyngeal volume. †MTOA: Class I (20 MUOA + 10 MLOA); Class II (27 MUOA + 13 MLOA); Class III (39 MUOA + 38 MLOA). *Intergroup comparison: statistically significant, $p < 0.05$. —: not significant.

Table 4: Pearson test of oropharyngeal airway in the patient's characteristics.

	UOA	MUOA	UOV	LOA	MLOA	LOV	MTOA	TOV
Gender	0.253*	0.247*	0.235*	0.400*	0.322*	0.371*	0.247*	0.322*
Skeletal	0.161	0.231*	0.149	0.123	0.072	0.111	0.163*	0.146
Age	-0.149	-0.164*	-0.104	-0.221*	-0.091	-0.150	-0.171*	-0.136
BMI	0.038	-0.030	-0.075	0.118	0.054	-0.007	-0.041	-0.051
ANB	-0.348*	-0.349*	-0.272*	-0.294*	-0.237*	-0.234*	-0.292*	-0.281*
HX	0.386*	0.341*	0.288*	0.232*	0.224*	0.211*	0.265*	0.280*
HY	0.281*	0.237*	0.296*	0.388*	0.198*	0.392*	0.219*	0.370*
PogX	0.476*	0.455*	0.387*	0.333*	0.318*	0.293*	0.384*	0.381*
PogY	0.202*	0.217*	0.229*	0.202*	0.090	0.192*	0.186*	0.234*

UOA: upper oropharyngeal area; MUOA: minimum upper oropharyngeal area; LOA: lower oropahryngeal area; MLOA: minimum lower oropharyngeal area; UOV: upper oropharyngeal volume; LOV: lower oropharyngeal volume; MTOA: minimum total pharyngeal area; TOV: total oropharyngeal volume; BMI: body mass index; HX: hyoid (horizontal); HY: hyoid (vertical); PogX: pogonion (horizontal); PogY: pogonion (vertical). *Statistically significant, $p < 0.05$.

MUOA, UOV, LOA, TOV, and MLOA. The Or–Po–H angle was significantly positively correlated (weak or very weak) with MUOA, UOV, TOV, and LOV. None of the oropharyngeal airway spaces (areas and volumes) exhibited a significant correlation with the Or–PO–C2, Po–C2–Pog, or PO-C2-H angle. The Po–C2–C4 angle was significantly negatively correlated (weak or very weak) with UOA, MUOA, UOV, LOA, MTOA, and TOV.

4. Discussion

The volume of the pharyngeal airway can be affected by anatomical anomalies in both the soft tissue and craniofacial skeleton. According to functional matrix theory, proposed by Moss [5], the growth and development of the craniofacial area can be controlled by the functional activity of the soft tissue around the craniofacial skeleton. Thus, a direct interaction exists between the pharyngeal airway space and craniofacial morphology, and any anomaly in these spaces could affect the position of the surrounding bones. Related literature [6, 7] has reported rapid and ongoing growth of the pharyngeal structure before the age of 13 years that ceases between 14 and 18 years of age. On the basis of relevant research results, this study focused on the pharyngeal airways of patients aged over 16 years, which constitutes the most mature and stable period.

BMI is generally used to represent a patient's physical characteristics. In this study, no significant difference was observed between the age and BMI of the patients in the three groups, signifying similar demographic characteristics of all patients. Therefore, the results of this study were unaffected by differences in the physical characteristics of the patients, thereby revealing their actual oropharyngeal airway statuses with objective measurements. It is as expected that BMI exhibited no significant correlation with the area or volume of the oropharyngeal airway. Claudino et al. [8] and Tseng et al. [9] indicated that airway volume was significantly correlated with ANB angle, whereas Kula et al. [10] and Alves et al. [11] found no significant correlation between these elements. The current study confirmed the findings of Claudino et al. [8] and Tseng et al. [9] that the ANB angle is a crucial factor affecting airway dimensions. Alves et al. [11] reported significant differences between the airway volumes of male and female participants. However, a study by Solow et al.

Table 5: Pearson test of measured angles and oropharyngeal airway.

Variables	UOA	MUOA	UOV	LOA	MLOA	LOV	MTOA	TOV
Or-Po-Pog	-0.307*	-0.275*	-0.196*	-0.190*	-0.249*	-0.142	-0.244*	-0.190*
Or-Po-H	0.157	0.202*	0.185*	0.113	0.038	0.168*	0.086	0.195*
Or-Po-C2	-0.099	-0.094	-0.023	-0.002	0.030	0.013	-0.015	-0.009
Po-C2-Pog	-0.021	-0.038	-0.069	-0.113	-0.150	-0.129	-0.086	-0.104
Po-C2-H	0.002	-0.051	-0.030	0.039	-0.082	0.039	-0.055	-0.001
Po-C2-C4	-0.295*	-0.230*	-0.251*	-0.180*	0.153	0.118	-0.182*	-0.213*

UOA: upper oropharyngeal area; MUOA: minimum upper oropharyngeal area; LOA: lower oropharyngeal area; MLOA: minimum lower oropharyngeal area; UOV: upper oropharyngeal volume; LOV: lower oropharyngeal volume; MTOA: minimum total oropharyngeal area; TOV: total oropharyngeal volume; Or: orbitale; Po: porion; Pog: pogonion; H: hyoid bone; C2: second cervical vertebra; C4: fourth cervical vertebra. *Statistically significant, $p < 0.05$.

[12] revealed that sex did not significantly affect airway dimensions. The current study also noted a significant correlation between the oropharyngeal airway space and sex; the oropharyngeal airway space of male patients was larger than that of female patients.

El and Palomo [13] indicated that the relation between the position of the mandible and skull base also affects the oropharyngeal space. Kim et al. [14] indicated that compared with patients with normal skeletal anterior–posterior relationships, patients with a mandible positioned more to the rear had a smaller airway volume. Research reports [15, 16] have highlighted the crucial role of the hyoid bone and the muscle tissue attached to it in maintaining a normal airway space, and different positions of the mandible are often accompanied by diverse hyoid bone positions. Yamaoka et al. [16] revealed that the tongue base of patients with skeletal Class II malocclusion was positioned farther back compared with that of patients with skeletal Class III malocclusion. In general, mandibles that are shorter and/or located farther back might push the tongue and soft palate back into the pharyngeal space, thus reducing the oropharyngeal volume. Patients in Class III had a more protruded mandible; thus, the hyoid bone had a more anterior position, accounting for the larger distance between the back of the tongue and the posterior pharyngeal wall. Therefore, patients in Class III had the largest airway volumes. Consistent with the aforementioned reports [14, 16], the current study also found that the horizontal distance of the hyoid bone and Pog among patients in Class II was significantly smaller than that among patients in Class I and Class III.

When the related structural positions of Pog, H, and C2 on the FH plane were evaluated in terms of Or–Po–Pog and Or–Po–C2 angles, the angles of patients in Class II were significantly larger than those of patients in Class I and Class III. No significant difference was observed in the Or–Po–H angle between the three groups; however, the horizontal position of H in patients in Class II was significantly farther back than that in patients in Class I and Class III, indicating that patients in Class II would raise their heads to elevate the FH planes more to compensate for smaller airways, which explains the absence of a significant difference between the Or–Po–H angles of the patients in the three groups. When the airway was examined through the cervical spine and related structural positions through C2, no significant difference was observed in terms of the Po–C2–Pog and Po–C2–H angles of patients in Class I and Class III, reflecting that the pharyngeal airway spaces of those in Class I and III also showed no significant difference. By contrast, the angles of patients in Class II were the smallest, and their airways were also the smallest, probably representing a compensation mechanism for maintaining an airway patency and function when the glossopharyngeal airway volume decreases.

The minimum cross-sectional area is an important factor in the evaluation of the obstruction potency of the pharyngeal airway. Pharyngeal airway obstruction in patients with sleep apnea manifests through not only reduced airway volume but, more crucially, also compressed area (the minimum cross-sectional area). Trudo et al. [17] had shown by state-dependent imaging that the mean minimal cross-sectional airway area was reduced by 228% ($p = 0.004$) in the retropalatal region (UOA) and by 22% ($p = 0.02$) in the retrolingual region (LOA) during sleep in normal subjects. Therefore, both of UOA and LOA collapse partially and cause the changes of airflow dynamic during sleep, especially in UOA. Alves et al. [11] observed significant differences between the minimum cross-sectional areas of the airways of patients in Class I and Class II. Claudino et al. [8] reported that the minimum cross-sectional areas of the lower pharynx, velopharynx, and oropharynx as well as the mean cross-sectional area of patients in Class II were all smaller than those of patients in Class III. The current research revealed that in terms of the minimum cross-sectional area (MUOA, MLOA, and MTOA) of the oropharyngeal airway, no significant difference was observed between patients in Class I and II. However, the minimum cross-sectional area (MUOA, MLOA, and MTOA) of patients in Class III was significantly greater than that of patients in Class II. More importantly, the present study revealed the area with the highest frequency of MTOA during pharyngeal airway obstruction. Two-thirds of the patients in Class I and Class II had an MTOA in the UOV, and approximately 50% of patients in Class III had an MTOA in both the UOV and LOV. This indicates that the position of Pog in patients in Class III could enlarge the MUOA and UOA more than the MLOA and LOA. Therefore, different obstruction areas of the pharyngeal airways were observed in the three skeletal patterns.

Grauer et al. [18] reported that the glossopharyngeal airway volumes of patients in Class II were smaller than those of patients in Class I. This reduction in pharyngeal airway volume was mainly due to the mandible position being farther back. Moreover, Castro-Silva et al. [19] reported that the mean volume of the pharyngeal airway space among patients in Class III was significantly greater than that among patients in Class I and Class II. The current results are consistent with those reported by Castro-Silva et al., [14] in which the oropharyngeal airway volumes of patients in Class III were significantly larger than those of patients in Class II. Contrary to the findings of Grauer et al. [18], those of the present study revealed that no significant difference existed in oropharyngeal airway volume between patients in Class I and Class II.

Analysis using Pearson's correlation coefficient revealed significant correlations between sex and airway space in terms of both oropharyngeal area and oropharyngeal volume; the values for airways were significantly higher in male patients than in female patients, and ANB was significantly negatively correlated with all of the airway spaces. In addition, when the correlation of airway space alone was considered with respect to the three skeletal pattern types, a significant positive correlation was observed in MUOA and MTOA, whereas a significant negative correlation was observed between the ANB and the oropharyngeal airway variables. The positions of the hyoid bone and Pog were nearly significantly correlated with the area or volume of the oropharyngeal airway space, and the correlation strength of PogX (horizontal position) was greater than that of HX (horizontal position). Moreover, the correlation strength of HY (vertical position) was greater than that of PogY (vertical position). From the Or–Po–Pog angles of the head position (FH plane), significant negative correlations were observed with the measurements of all of the oropharyngeal airways; that is, the airway space was smaller when the Pog was farther back. Moreover, when observed from the cervical spine, several negative correlations with Po–C2–C4 were observed, indicating that the angle of the cervical spine affected the volume and area of the oropharyngeal airway space.

5. Conclusion

The oropharyngeal airway areas and volumes of patients in Class II were significantly smaller than those of patients in Class III. The positions of the mandible, head, and cervical spine were important factors affecting the oropharyngeal airway area and volume. The minimum oropharyngeal cross-sectional area had a 66%–67% probability of occurrence in the upper oropharyngeal airway among patients in Class I and Class II and a 50% probability of occurrence among patients in Class III.

Data Availability

The data used to support the findings of this study are included within the article. The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Research Article

Antilingula as a Surgical Reference Point for Vertical Ramus Osteotomy

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Purpose. This study investigated the antilingula and its related landmarks, the mandibular rami, by using cone-beam computed tomography (CBCT). *Methods*. CBCT images of 37 patients (74 sides of the mandibular ramus) were collected. The landmarks of antilingula (AntiL), anterior ramus (A), posterior ramus (P), superior ramus (S), and inferior ramus (I) were identified. The distances (A-AntiL, P-AntiL, S-AntiL, and I-AntiL) were statistically evaluated according to gender, side (right and left), and skeletal patterns. *Results*. The distance from the antilingula to the anterior (A-AntiL) border of the ramus was significantly longer on the right side (14.69 mm) than on the left side (13.97 mm). Male patients had longer AntiL-P, AntiL-I, and S-I distances (18.96, 40.07, and 54.94 mm, respectively) than did female patients (16.66, 35, and 47.54 mm, respectively). Regarding skeletal patterns, the classes can be ordered as follows in terms of the measurements: class III>class II>class I. However, the differences between the classes were nonsignificant. Pearson correlation analysis revealed that gender and S-I distance were strongly correlated ($r = 0.667$); specifically, male patients had a longer S-I distance. A-AntiL and A-P also exhibited a strong correlation ($r = 0.796$). *Conclusion*. Antilingula-related distances did not differ between skeletal patterns. Among antilingula-related variables, A-AntiL could serve as a favorable measuring point during operation.

1. Introduction

Most patients with class III malocclusions seek corrective treatment to improve their appearance, social confidence, and interpersonal relationships, among other reasons. Sagittal split ramus osteotomy (SSRO) and intraoral vertical ramus osteotomy (IVRO) are the most commonly adopted surgical techniques for treating mandibular protrusions. SSRO involves making a horizontal cut from above the mandibular foramen on the inner surface of the ramus, specifically at or above the lingula, continuing forward and outward to the external oblique ridge and then to the buccal side of the molar. In SSRO, the mandible is divided into two segments: lingual and buccal parts (distal and proximal segments). By contrast, IVRO involves making vertical or oblique cut behind the mandibular foramen on the ramus buccal side. In IVRO, the mandible is divided into two segments: anterior and posterior parts (distal and proximal segments).

Identifying and accessing the lingula in IVRO technique is difficult from buccal side of ramus. To resolve this difficulty, Aziz et al. [1] revealed that the antilingula is an acceptable landmark for the safe placement of IVRO to prevent damage to the inferior alveolar nerve in the mandibular foramen. Such damage can lead to complications associated with sensory disorders, particularly in the lower lip [2–4].

However, Monnazzi et al. [5] reported no statistically significant correlation between the mandibular foramen entrance and the antilingula position. The antilingula is a small bony protuberance on the buccal surface of the mandibular ramus; it is not an independent point of protuberance and is thus sometimes difficult to identify. Moreover, whether the antilingula differs with respect to the three classes of skeletal patterns (class I, class II, and class III) is critical for surgeons; however, this question has not been thoroughly investigated by researchers. Accordingly, the present study investigated the differences in the position of the antilingula between patients with skeletal class I, class II, and class III malocclusions and determined their related variables.

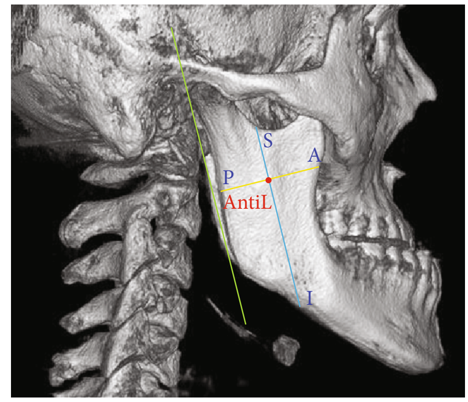

Figure 1: Red point: AntiL (antilingula); S: superior point of ramus; I: inferior point of ramus; A: anterior point of ramus; P: posterior point of ramus. Green line: axis of ramus (a tangent line passing through most posterior borders of condyle and ramus). Blue line: a line through AntiL and parallel to green line. Yellow line: a line through AntiL and perpendicular to blue line.

2. Materials and Methods

This study obtained cone-beam computed tomography (CBCT; NewTom VGi EVO, Imola, Italy) images of 37 patients (15 men and 22 women)—with a total of 74 face sides—from the Department of Dentistry of Kaohsiung Medical University Hospital. These images were used for analysis. The exposure parameters were as follows: tube voltage, 110 kV; tube current, 4.59 mA; and slice thickness, 0.2 mm. Patients with the following characteristics were excluded from the sample: (1) congenital craniofacial symptoms, (2) orthognathic surgery, or (3) facial bone injury. The reference plane for the 3D images, namely, the Frankfort horizontal plane, was defined as the plane connecting the lower margin of the right orbit and the uppermost points of the external auditory meatus on each side. For consistency and replicability, this study calibrated all patients' CBCT images with respect to the following positions: (1) the sagittal plane was positioned at the orbit to divide the skull evenly into the right and left parts, (2) the horizontal plane was positioned parallel to the Frankfort horizontal plane, and (3) the coronal plane was positioned perpendicular to the aforementioned planes.

The collected images (DICOM format) were imported into RadiAntViewer (version 4.6.9, Medixant, Poznan, Poland), after which RadiAntViewer's 3D image reconstruction function was used to extract and reconstruct 3D images of the mandibular ramus. The reconstructed images were then used to examine the antilingula (AntiL) on the buccal surface of the mandibular ramus. Each patient's gender and skeletal pattern were recorded, and images of both sides of the patient's mandible were taken. Patients were categorized into three groups according to their skeletal patterns: class I ($0^\circ <$ A point – nasion – B point angle $[\text{ANB}] < 4^\circ$), class II ($\text{ANB} \geq 4^\circ$), and class III ($\text{ANB} \leq 0^\circ$). The axis of ramus was set as a tangent line passing through the posteriormost borders of the condyle and ramus (Figure 1). Through the AntiL point, a line parallel to the ramus axis and another line perpendicular to this axis were considered. This study measured the distances from the antilingula to the anterior (A-AntiL) and posterior (P-AntiL) borders of the ramus as well as those from the antilingula to the superior (S-AntiL) and inferior (I-AntiL) borders of the ramus. The study also determined the relative positions of the antilingula on the path between the anterior and posterior (A-P) borders and the path between the superior and inferior (S-I) borders.

This study also investigated the differences in A-AntiL, P-AntiL, S-AntiL, and I-AntiL between the left and right sides of the mandible, between female and male patients and between the three skeletal patterns. Moreover, the correlation of these distances with sex and skeletal patterns was investigated. IBM SPSS 20 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis, and a P value of 0.05 was considered statistically significant. One-way analysis of variance was used to examine the differences between the three skeletal pattern classes, followed by post hoc analysis using the Tukey method. The Pearson correlation analysis was used to determine the correlations between variables (gender, skeletal patterns (classes I, II, III), and AntiL-related distances). Different facial skeletal patterns may differ significantly in terms of the anatomical structures of the mandible. Therefore, the null hypothesis was that the AntiL-related distances would not differ between the three skeletal patterns. The strengths of the correlations were determined as follows: very weak (0–0.19), weak (0.20–0.39), moderate (0.40–0.59), strong (0.60–0.79), and very strong (0.80–1.0). This retrospective study was approved by the Institutional Review Board of Kaohsiung Medical University Hospital (KMUH-IRB-20160066).

3. Results

As presented in Table 1, A-AntiL was significantly longer on the right side of the mandible (14.69 mm) than it was on the left side (13.97 mm). The other linear distances (P-AntiL, A-P, S-AntiL, I-AntiL, and S-I) did not differ significantly between the sides of the mandible. Overall, the antilingula was located along the A-P border at the point extending 45% backward from the anterior border of the ramus and along the S-I border at the point extending 27% downward from the superior border of the ramus. As listed in Table 2, male patients had longer AntiL-P, AntiL-I, and S-I (18.96, 40.07, and 54.94 mm, respectively) than did female patients (16.66, 35, and 47.54 mm, respectively).

Table 1: Antilingula-related distances with their hemiarch comparisons.

Variables	Total patients ($n = 37$)		Right side		Left side		Right/left comparison	
	Mean	SD	Mean	SD	Mean	SD	P value	Significant
A-AntiL	14.32	2.62	14.69	2.61	13.97	2.61	0.030	Right>left
P-AntiL	17.59	2.12	17.47	2.14	17.72	2.13	0.483	—
A-P	31.92	3.51	32.2	3.50	31.7	3.55	0.157	—
S-AntiL	13.48	3.07	13.33	2.89	13.63	3.27	0.455	—
I-AntiL	37.06	4.33	37.54	4.16	36.57	4.48	0.064	—
S-I	50.54	5.49	50.9	5.15	50.2	5.85	0.224	—

AntiL: antilingula; A: anterior ramus; P: posterior ramus; S: superior ramus; I: inferior ramus. n: number of patient; significant: $P < 0.05$; —: not significant.

Table 2: Antilingula-related distances with their gender comparisons.

Variables	Male ($n = 30$)		Female ($n = 44$)		Gender comparison	
	Mean	SD	Mean	SD	P value	Significant
A-AntiL	14.92	3.10	13.90	2.18	0.540	—
P-AntiL	18.96	1.98	16.66	1.68	0.021	Male>female
A-P	33.90	3.86	30.57	2.50	0.078	—
S-AntiL	14.87	3.17	12.53	2.63	0.408	—
I-AntiL	40.07	3.16	35.00	3.79	0.002	Male>female
S-I	54.94	4.25	47.54	4.03	0.001	Male>female

AntiL: antilingula; A: anterior ramus; P: posterior ramus; S: superior ramus; I: inferior ramus. n: number of side; significant: $P < 0.05$; —: not significant.

Table 3: Antilingula-related distances with their skeletal patterns.

Variables	Class I ($n = 28$)		Class II ($n = 24$)		Class III ($n = 22$)		Interclass comparison		
	Mean	SD	Mean	SD	Mean	SD	F value	P value	Significant
A-AntiL	14.03	2.43	14.04	2.39	14.98	3.07	1.005	0.371	—
P-AntiL	16.98	2.19	17.67	1.98	18.29	2.05	2.485	0.091	—
A-P	31.00	3.28	31.73	2.62	33.30	4.29	2.814	0.067	—
S-AntiL	13.01	2.71	13.27	3.29	14.30	3.22	1.175	0.315	—
I-AntiL	36.58	4.29	36.45	3.79	38.32	4.82	1.357	0.264	—
S-I	49.60	4.51	49.74	5.13	52.62	6.57	2.338	0.104	—

AntiL: antilingula; A: anterior ramus; P: posterior ramus; S: superior ramus; I: inferior ramus. n: number of side; significant: $P < 0.05$; —: not significant.

Table 4: Gender and skeletal patterns of antilingula-related distances in the Pearson test.

Variables	Gender	Skeletal	A-AntiL	P-AntiL	A-P	S-AntiL	I-AntiL	S-I
Gender	1	0.418*	0.192	0.534*	0.468*	0.376*	0.579*	0.667*
Skeletal	0.418*	1	0.143	0.256*	0.265*	0.169	0.158	0.219
A-AntiL	0.192	0.143	1	0.084	0.796*	-0.135	0.280*	0.145
P-AntiL	0.534*	0.256*	0.084	1	0.670*	0.255*	0.297*	0.377*
A-P	0.468*	0.265*	0.796*	0.670*	1	0.054	0.387*	0.336*
S-AntiL	0.376*	0.169	-0.135	0.255*	0.054	1	0.075	0.617*
I-AntiL	0.579*	0.158	0.280*	0.297*	0.387*	0.075	1	0.831*
S-I	0.667*	0.219	0.145	0.377*	0.336*	0.617*	0.831*	1

AntiL: antilingula; A: anterior ramus; P: posterior ramus; S: superior ramus; I: inferior ramus. Significant: $P < 0.05$; —: not significant.

As shown in Table 2, male patients' antilingula was located along the A-P border at the point extending 44% backward from the anterior border of the ramus and along the S-I border at the point extending 27% downward from the upper border. Female patients' antilingula was located along the A-P border at the point extending 45% backward from the anterior border and along the S-I border at the point extending 26% downward from the upper border.

Accordingly, the location of male patients' antilingula was slightly ahead of and below that of female patients' antilingula.

Regarding the skeletal patterns (Table 3), the three classes can be ordered as follows in terms of the measurements for the A-P and S-I distances: class III>class II>class I. However, the differences between the classes were nonsignificant. Therefore, the null hypothesis was accepted. According to the Pearson correlation analysis (Table 4), gender and S-I were strongly correlated ($r = 0.667$); specifically, male patients had a longer S-I. A-AntiL and A-P were strongly correlated ($r = 0.796$). Moreover, S-AntiL and S-I were strongly correlated ($r = 0.617$). I-AntiL and S-I were very strongly correlated ($r = 0.831$).

4. Discussion

The term "antilingula" was introduced in the study by Levine and Topazian [6] and was used a reference point for inverted-L osteotomy; according to Levine and Topazia, the antilingula is formed by the inferior alveolar nerve entering the mandibular ramus, which causes a protuberance on the outer surface of the bone. However, other researchers have proposed different views. Reitzik et al. [7] proposed that the protuberance on the outer surface of the mandibular ramus is the attachment point for the masseter muscle; the researchers also described the protuberance as a masseteric apical bump. Furthermore, subsequent studies [8–10] on humans and other mammals have confirmed that the protuberance on the outer surface of the mandibular ramus is the attachment point for the deep head of the masseter muscle. The pattern of attachment of the masseter muscle on the mandibular ramus and the force of the masseter muscle can both affect the formation of the antilingula and the size of the protuberant area. However, the antilingula is not always noticeable or identifiable on the mandible.

Previous studies [11–13] have demonstrated the relationship between the position of the antilingula and that of the lingula and mandibular foramen. Scholars [13–15] have suggested that the position of the antilingula—which can be seen during operation—exhibited a stable relationship with the position of the mandibular foramen. Accordingly, these scholars [13–15] have recommended that the position of the bone cut in IVRO could be determined with reference to the position of the antilingula; specifically, the osteotomy line should be placed behind the antilingula to prevent damage to the inferior alveolar nerve. By contrast, the relative position of the antilingula to the lingual and mandibular foramen is characterized by a high degree of uncertainty. Studies [16, 17] have indicated that the position of the antilingula is not fixed relative to the position of the lingula and mandibular foramen; therefore, the use of the antilingula as the surgical reference point for IVRO has been discouraged. Nevertheless, Aziz et al. [1] reported that in most cases, the lingula is located inferior to and behind the antilingula. Pogrel et al. [17] also reported a 68.3% probability of the lingula being located inferior to and behind the antilingula, with the average distance between them being 5.39 mm. Furthermore, Park et al. [13] revealed that on average, the lingula was located 4.19 mm backward and 0.54 mm upward relative to the antilingula. The mandibular foramen was located 4.98 mm backward and 6.95 mm downward relative to the antilingula.

The aforementioned research findings [1, 13–17] are all consistent in that the osteotomy line in IVRO should be placed behind the antilingula to prevent damage to the inferior alveolar nerve. Park et al. [13] reported that to completely avoid the inferior alveolar nerve in IVRO, the osteotomy line should be in the posterior region at a point located at 29% of the total horizontal length of the ramus. However, simply using the antilingula as the primary reference point for the osteotomy line could increase the possibility of damage to the inferior alveolar neurovascular bundle. Therefore, locating the positions of the lingula and mandibular foramen on the anterior-posterior and superior-inferior dimensions of the mandibular ramus may be the only approach to determining the safe osteotomy line in IVRO. Because a complete anatomical structure measurement for IVRO has yet to be developed, the position of the antilingula cannot serve as the absolute reference point for such surgical operations.

Hosapatna et al. [18] studied 50 dry mandibles and observed that the antilingula was located on the right side of 25 of the mandibles and on the left side of 28 of the mandibles. Hsiao et al. [19] reported the bilateral presence of the antilingula in 67.8% of those studied. The present study revealed diverse antilingula patterns; specifically, the antilingula can manifest as a marked protuberance or a plateau-shaped protuberant area without a single point of protuberance, which can result in misjudgment. In particular, cases of plateau-shaped protuberant areas are not rare, and any resulting misjudgment can damage the neurovascular bundle. Accordingly, the present study selected patients who exhibited a single point of protuberance on both the left and right sides of the mandible for observation and comparison; they were selected because the antilingula can be adopted as the reference point for surgery only in these patients. According to the study results, the left and right sides of the mandible did not differ significantly with respect to A-P or S-I distances; this finding signifies that the lengths of the mandibular rami on the left and right sides were similar in these patients, which can facilitate a relatively consistent determination of bone cut position regardless of the side of the mandible, thus increasing the safety of surgical operations.

Male patients' A-P and S-I distances were both greater than those of female patients, a finding that is consistent with the clinical observation that male mandibles tend to be larger than female mandibles. Moreover, male patients' AntiL-P, AntiL-I, and S-I distances (18.96, 40.07, and 54.94 mm, respectively) were significantly longer than those of female patients (16.66, 35, and 47.54 mm, respectively). Male patients' antilingula was located along the A-P border at the point extending 44% backward from the anterior border and along the S-I border at the point extending 27% downward from the superior border of the mandibular ramus. Female patients' antilingula was located along the A-P border at the point extending 45% backward from the anterior border and along the S-I border at the point extending 26% downward from the superior border of the mandibular ramus. Accordingly, male patients' antilingula was located slightly ahead of and below that of female patients. However, whether male patients' mandibular foramen is—similar to their antilingula—located at a similar position to that of female patients requires further research; answering this question can prevent misjudgment and damage to the neurovascular bundle in surgical operations.

Regarding the skeletal patterns, the three classes can be ordered as follows in terms of their A-P and S-I distances: class III>class II>class I. This finding is consistent with the clinical observation that class III patients had noticeably larger mandibles. Nevertheless, the different skeletal patterns had nonsignificant differences with respect to various relevant measurements. Gender exhibited a more significant correlation with S-I than it did with A-P. Therefore, the male sex had a stronger correlation with ramus height than it did with ramus width.

The significant relationships of P-AntiL involved more factors (gender, skeletal pattern, A-P, S-AntiL, I-AntiL, and S-I) than did those of A-AntiL, which involved only the factors A-P and I-AntiL. However, using AntiL-P to determine the position of the antilingula is difficult in clinical surgery because the posterior border of the mandible ramus is usually curved and inward. Measuring tools used in surgical operations cannot be bent for precise measurement of the posterior border of the ramus; this difficulty leads to high measurement errors. Therefore, measurements should be performed from the anterior border of the ramus (i.e., A-AntiL) to reduce measurement errors.

The significant relationships of I-AntiL involved more factors (sex, A-AntiL, AntiL-P, A-P, and S-I) than did those of S-AntiL, which involved only the factors P-AntiL and S-I. In clinical surgery, the sigmoid notch is used to determine the position of the antilingula. However, because the sigmoid notch is semicircular, the measuring tool can slip during operation, which can lead to an inaccurate determination of the antilingula position relative to the sigmoid notch. By contrast, the mandibular inferior border has a relatively flat shape and can thus facilitate relatively stable measurement. Accordingly, compared with S-AntiL, using I-AntiL to determine the position of the antilingula is more practicable and results in fewer errors. Considering surgical accessibility and convenience, A-AntiL is a more favorable measuring point than I-AntiL.

5. Conclusion

The antilingula cannot be the sole reference point for IVRO. Antilingual distances do not differ according to skeletal patterns. Among antilingula-related variables, A-AntiL can serve as a favorable measuring point during operation.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

There is no conflict of interest.

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Research Article

Sagittal Split Ramus Osteotomy in the Shortest Buccal Bone Marrow Distances of the Mandible on the Coronal Plane

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Purpose. This study investigated the relationship between the shortest buccal bone marrow of the ramus and skeletal patterns. *Materials and Methods*. Using cone-beam computed tomography data (specifically, the A point-nasion-B point (ANB) angle), we divided patients into three groups as follows: skeletal class I (0° < ANB < 4°), class II (ANB: ≥4°), and class III (ANB: ≤0°). Sixteen vertical sections in the coronal plane were taken starting from slice 0 (original intact mandibular canal) anteriorly at 2 mm intervals to slice 15 (30 mm). The thickness of the mandible (M) and shortest buccal bone marrow (SBM) were measured. The data of SBM were divided into two groups (SBM ≥ 1 mm and SBM < 1 mm). For each skeletal pattern, an SBM value < 1 mm was considered to indicate a high possibility of postoperative nerve paresthesia and bad split. *Results*. The three skeletal pattern groups also did not significantly differ in their M values for all sections. The mean SBM values of class III (0.91–2.11 mm) at 6–16 mm anterior to the mandibular foramen were significantly smaller than those of class II (1.53–3.17 mm). Comparing the occurrence ratio of SBM < 1 mm, the highest and lowest probabilities in class III (55% and 21.7%, respectively) were significantly larger at 6–20 mm anterior to the mandibular foramen than those in class II (28.3% and 5%, respectively). *Conclusion*. Class III had a significantly shorter SBM distance and higher SBM occurrence probability than class II at the mandibular ramus region, implying that class III participants are more likely than class II participants to have nerve paresthesia and bad split after sagittal split ramus osteotomy.

1. Introduction

Malocclusion is frequently accompanied by facial deformities, which considerably affects not only respiration, eating, and speech but also social interaction. Facial deformities have a significant negative effect on perceptions of social functionality, including employability, honesty, and trustworthiness [1]. Sagittal split ramus osteotomy (SSRO) is commonly used to correct mandibular protrusion, retrusion, and asymmetry. Its advantages include enhanced bone healing because of larger overlapping segments, better and easier postoperative airway management, immediate postoperative jaw mobilization, leading to better oral hygiene and quicker improvement to a regular diet, and better speech and social activity [2]. The major complications of SSRO include inferior alveolar nerve injury, resulting in lower lip paresthesia; a bad or unfavorable split, leading to bony malunion; and unpredictable condylar position, leading to an undesired postsurgical shift in the occlusion.

The sagittal osteotomy line of SSRO starts at the buccal cortex of the mandibular ramus and body. The osteotomy incision is made through the cortex into the buccal bone marrow, and the osteotomes are then inserted into the marrow to engage the lower border of the mandible, followed by mandibular splitting. Many researchers [3–6] have reported the postoperative complications of SSRO, especially inferior alveolar nerve damage and poor mandibular split. However, the shortest buccal bone marrow (SBM) distance of the mandible is the most critical risk factor contributing to inferior alveolar nerve injury and poor or unfavorable split. No study has focused on the relationship between SBM distance and skeletal patterns (classes I, II, and III). Therefore, we investigated whether the three skeletal pattern groups differed in SBM values and speculated the occurrence possibility of SBM < 1 mm in the different skeletal patterns.

2. Material and Methods

In this study, we collected the cone-beam computed tomography data of 90 participants at the Department of Dentistry, Kaohsiung Medical University Hospital, Kaohsiung, Taiwan. NNT viewer software was used to view the captured images. Ninety participants were divided into three skeletal classes (I, II, and III) according to their A point-nasion-B point (ANB) angle, with 30 participants per class. Participants with symptoms such as craniofacial injury, tumors, and congenital craniofacial deformities were excluded. The reference plane of the three-dimensional image was the FH plane (horizontal plane), which is defined as the plane constituted by the three points that pass through the right orbitale and bilateral porion.

Section 0 was set as the vertical section in the coronal plane that enables observation of the complete mandibular foramen anteriorly from the posterior border of the ramus (Figure 1). The section 2 mm anterior to section 0 was considered to be section 1, the section 2 mm anterior to that was considered section 2, and so on until a position 30 mm anterior to the start of section 0. Thus, 16 sections were demarcated in total. In clinical observation, section 16 (at 30 mm) includes the vertical osteotomy line of SSRO at the second and first molar areas. We defined a horizontal line segment (M) that passes through the center of the inferior alveolar nerve; M starts from the buccal side of the mandible and ends at the lingual cortical bone (Figure 2). Landmarks on M were then identified, and the following line segments were defined: buccal cortex of the mandibular canal sheath (A), dimension of the mandibular canal (B), and lingual cortex of the mandibular canal sheath (C). We then measured the SBM located between the inner side of the mandibular buccal cortical bone and the buccal side of the mandibular canal sheath. The data of SBM were divided into two groups (SBM ≥ 1 mm and SBM < 1 mm).

All statistical analyses were conducted using IBM SPSS 20 (SPSS Inc., Chicago, IL, USA). Analysis of variance was used to examine the differences between the three skeletal pattern groups, with the Tukey *post hoc* analysis. For each skeletal pattern, an SBM value < 1 mm was considered to indicate a high possibility of postoperative nerve paresthesia and poor split. A chi-square test was used to examine the intergroup differences, with the Bonferroni *post hoc* analysis. A Wilcoxon signed-rank test was used to examine, for all three groups, the left- and right-side measurement values.

The null hypothesis was that there is no significant difference in the occurrence probability of SBM < 1 mm among the skeletal patterns. This retrospective study was approved by the clinical trial committee of Kaohsiung Medical University Hospital (IRB No. KMUH-IRB-20160066).

3. Results

The 90 participants included 30 men and 60 women. Of them, 30 participants (9 men and 21 women) were in the skeletal class I group (mean age, 25.2 years; ANB angle, 1.73°), 30 (6 men and 24 women) were in the skeletal class II group (mean age, 27.8 years; average ANB angle, 7.1°), and 30 (15 men and 15 women) were in the skeletal class III group (mean age, 22.8 years; average ANB angle, −4.1°).

Analysis of variance was used to determine if the skeletal pattern groups differed in their anatomical structures in the buccal-lingual direction of the mandibular canal. In Table 1, the buccal cortex of the mandibular canal sheath (A) and the lingual cortex of the mandibular canal sheath (C) were <1 mm. In the same section, A was always larger than C within a skeletal class. The dimensions of the mandibular canal (B) were similar in the three skeletal patterns. The mean B value ranged from 2.15 mm to 2.86 mm. We found that the dimensions of the mandibular canal and sheath (A + B + C) were approximately 3.5–5 mm. In Table 2, the M value was the mandibular thickness; for most sections, the mean M value was 10–13 mm. The three skeletal pattern groups also did not significantly differ in their M values for all sections. The mean SBM values of class III (0.91–2.11 mm) at 6–16 mm anterior to the mandibular foramen were significantly smaller than those of class II (1.53–3.17 mm; Figure 3).

A Wilcoxon signed-rank test was used to examine, for all three groups, whether the left- and right-side measurement values significantly differed (Table 3). Relative to the left-side measurement values, the right-side measurement values were significantly larger only for class I patients in section 10 (20 mm) and class II patients in section 14 (28 mm). The rate of occurrence of SBM < 1 mm was significantly higher in class III participants at 6–20 mm anterior to the mandibular foramen than in class II participants (Table 4). Therefore, the null hypothesis was rejected. The highest and lowest SBM probabilities at all sections were 55% and 21.70%, respectively, for the class III group and 28.30% and 5.00%, respectively, for the class II group.

4. Discussion

Mandibular deformities can be categorized as either deficiency or protrusion. SSROs are frequently used to correct both types of mandibular deformities through mandibular advancement or setback, respectively. The mandibular canal contains the inferior alveolar neurovascular bundle, which is the most critical anatomical structure for SSRO. Pogrel et al. [7] reported that the inferior alveolar vein lies superior to the nerve and the artery lies on the lingual side of the nerve. Ozturk et al. [8] indicated that most mandibular canals are either in contact with or close to the lingual cortical plate in the molar region, which is consistent with our findings. From section 11 to 16 (third to the first mandibular molar region), the inferior alveolar canal was close to the mandibular lingual cortical plate. Using magnetic resonance imaging, Ikeda et al.

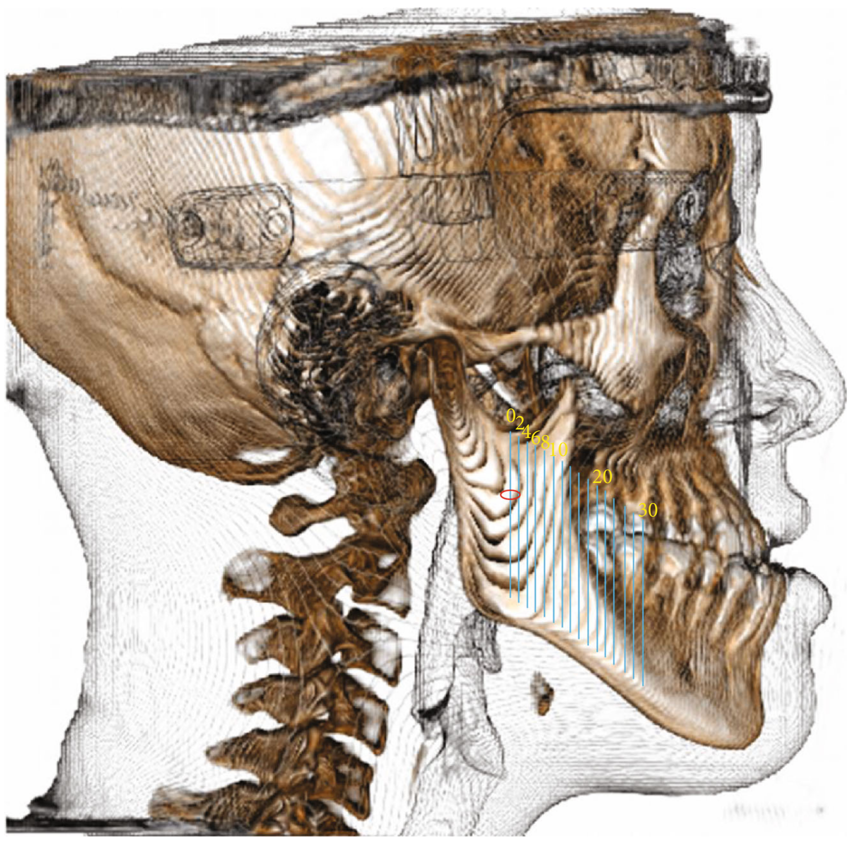

FIGURE 1: Red circle: mandibular canal (base plane: 0 mm). Sixteen vertical slices (blue lines) from 0 mm forward to 30 mm.

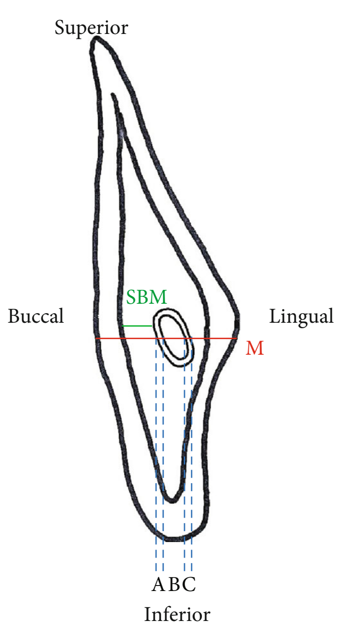

FIGURE 2: Red line distance (M: thickness of mandible). (a) Buccal cortex of the mandibular canal sheath. (b) Dimension of the mandibular canal. (c) Lingual cortex of the mandibular canal sheath. Green line distance (SBM: shortest buccal bone marrow distance).

[9] reported that the greater diameter of the mandibular canal with the bony cortex averaged 4.1 mm near the mandibular foramen and 3.4 mm in the middle of the canal; these findings are similar to our results (A + B + C = 3.5–5 mm). In our study, mandibular width (M value) was not significantly different among the three skeletal patterns. Therefore, the diameter of the mandibular canal and its surrounding cortex could be consistent with real expectations.

The SBM is a critical anatomical location when considering the safety of SSROs. Damage to the inferior alveolar nerve can be caused not only by actual contact with the surgical drills but also by excessive drilling pressure, mechanical stress, and thermal effects. Marenzi et al. [10] reported that the surface micromorphology of the bone drill bur, which influences the contact area between the drill bur and bone, can contribute to thermal necrosis of bone. These aspects can cause permanent or transient sensory alterations. Shirota et al. [11] investigated the effectiveness of piezoelectric and conventional bur methods in reducing surgical complications after SSRO for mandibular setback. They reported that piezoelectric surgery reduced neither blood loss nor the incidence of neurosensory disturbance in SSRO. By contrast, Kokuryo et al. [12] stated that ultrasonic surgery may be more effective than conventional surgery to reduce the incidence of neurosensory disturbance after SSRO and promote recovery from neurosensory disturbance.

The SBM thickness and split techniques play crucial roles in preventing nerve damage during surgery treatment. If the

Table 1: The thickness of the mandibular canal and its sheaths from slice 0 (0 mm) to slice 15 (30 mm) with their skeletal patterns in the one-way ANOVA with the post hoc Tukey HSD test.

Variables	A (mean ± SD, mm)	p value	B (mean ± SD, mm)	p value	C (mean ± SD, mm)	p value
0 mm						
Class I	0.92 ± 0.30	0.336	2.41 ± 0.51	<0.001*	0.51 ± 0.26	0.062
Class II	0.85 ± 0.34		2.29 ± 0.58	Class III > I > II	0.47 ± 0.24	
Class III	0.85 ± 0.26		2.86 ± 0.73		0.41 ± 0.16	
2 mm						
Class I	0.87 ± 0.31	0.219	2.45 ± 0.60	0.001*	0.61 ± 0.30	0.026*
Class II	0.77 ± 0.31		2.37 ± 0.63	Class III > I > II	0.55 ± 0.29	Class I > III
Class III	0.82 ± 0.29		2.80 ± 0.67		0.47 ± 0.22	
4 mm						
Class I	0.79 ± 0.30	0.758	2.48 ± 0.58	0.247	0.62 ± 0.31	0.217
Class II	0.75 ± 0.36		2.35 ± 0.67		0.53 ± 0.28	
Class III	0.77 ± 0.33		2.55 ± 0.77		0.59 ± 0.29	
6 mm						
Class I	0.81 ± 0.37	0.863	2.30 ± 0.65	0.684	0.71 ± 0.37	0.836
Class II	0.77 ± 0.30		2.37 ± 0.60		0.67 ± 0.38	
Class III	0.79 ± 0.38		2.39 ± 0.66		0.69 ± 0.32	
8 mm						
Class I	0.76 ± 0.32	0.958	2.43 ± 0.62	0.253	0.67 ± 0.33	0.102
Class II	0.77 ± 0.34		2.36 ± 0.70		0.56 ± 0.28	
Class III	0.75 ± 0.39		2.56 ± 0.68		0.65 ± 0.27	
10 mm						
Class I	0.81 ± 0.35	0.240	2.54 ± 0.58	0.524	0.72 ± 0.35	0.652
Class II	0.75 ± 0.35		2.45 ± 0.62		0.65 ± 0.39	
Class III	0.70 ± 0.37		2.58 ± 0.69		0.69 ± 0.34	
12 mm						
Class I	0.82 ± 0.32	0.689	2.51 ± 0.69	0.037*	0.68 ± 0.29	0.196
Class II	0.78 ± 0.33		2.40 ± 0.73	Class III > II	0.58 ± 0.32	
Class III	0.77 ± 0.37		2.72 ± 0.63		0.61 ± 0.29	
14 mm						
Class I	0.93 ± 0.36	0.004*	2.45 ± 0.63	0.392	0.68 ± 0.36	0.355
Class II	0.76 ± 0.37	Class I > II	2.36 ± 0.66		0.63 ± 0.35	
Class III	0.72 ± 0.36	Class I > III	2.51 ± 0.56		0.59 ± 0.34	
16 mm						
Class I	0.83 ± 0.33	0.649	2.32 ± 0.56	0.452	0.62 ± 0.33	0.377
Class II	0.79 ± 0.33		2.29 ± 0.57		0.55 ± 0.29	
Class III	0.78 ± 0.31		2.42 ± 0.59		0.61 ± 0.33	
18 mm						
Class I	0.88 ± 0.36	0.238	2.41 ± 0.59	0.515	0.60 ± 0.32	0.940
Class II	0.77 ± 0.39		2.38 ± 0.74		0.59 ± 0.32	
Class III	0.78 ± 0.37		2.52 ± 0.67		0.60 ± 0.31	
20 mm						
Class I	0.76 ± 0.31	0.562	2.48 ± 0.72	0.440	0.58 ± 0.28	0.950
Class II	0.69 ± 0.35		2.36 ± 0.77		0.58 ± 0.32	
Class III	0.71 ± 0.36		2.52 ± 0.63		0.59 ± 0.34	

Table 1: Continued.

Variables	A (mean ± SD, mm)	p value	B (mean ± SD, mm)	p value	C (mean ± SD, mm)	p value
22 mm						
Class I	0.88 ± 0.40	0.194	2.41 ± 0.68	0.287	0.56 ± 0.28	0.600
Class II	0.76 ± 0.43		2.28 ± 0.66		0.52 ± 0.29	
Class III	0.76 ± 0.35		2.46 ± 0.63		0.57 ± 0.31	
24 mm						
Class I	0.75 ± 0.36	0.767	2.26 ± 0.46	0.009*	0.57 ± 0.29	0.541
Class II	0.73 ± 0.35		2.25 ± 0.57	Class III > I	0.50 ± 0.27	
Class III	0.70 ± 0.35		2.55 ± 0.72	Class III > II	0.54 ± 0.36	
26 mm						
Class I	0.78 ± 0.33	0.208	2.44 ± 0.73	0.183	0.57 ± 0.30	0.030*
Class II	0.72 ± 0.37		2.41 ± 0.71		0.51 ± 0.28	Class III > II
Class III	0.83 ± 0.35		2.22 ± 0.67		0.67 ± 0.39	
28 mm						
Class I	0.83 ± 0.35	0.119	2.17 ± 0.50	0.700	0.53 ± 0.28	0.205
Class II	0.71 ± 0.31		2.24 ± 0.66		0.63 ± 0.34	
Class III	0.79 ± 0.31		2.26 ± 0.62		0.57 ± 0.31	
30 mm						
Class I	0.72 ± 0.35	0.138	2.31 ± 0.55	0.070	0.51 ± 0.25	0.528
Class II	0.61 ± 0.33		2.50 ± 0.84		0.53 ± 0.30	
Class III	0.70 ± 0.34		2.20 ± 0.73		0.57 ± 0.39	

A: buccal cortex of the mandibular canal sheath; B: dimension of the mandibular canal; C: lingual cortex of the mandibular canal sheath. ∗: significant, $p < 0.05$.

SBM value is too small for osteotome manipulation, the osteotome may split directly toward the inferior alveolar neurovascular bundle, damage it, and result in lower lip paresthesia. Moreover, an unanticipated osteotome run laterally or medially may lead to unfavorable splits. Möhlhenrich et al. [13] evaluated the lingual fracture patterns after SSRO with Hunsuck–Epker modifications by an additional inferior border osteotomy using a bur or ultrasonic device. They observed no relationship between the split technique and the fracture pattern. The bone cut on the inferior border did not improve split control but rather increased the risk of unwanted fractures and extended the operation time. Furthermore, the SSRO technique relies on a directed fracture involving bone thickness, bone density, and various SSRO-related biomechanical properties. Rougier et al. [14] measured the hardness of the ramus and conducted traction-to-fracture tests. They recommended using a Lindemann bur rather than a reciprocating saw for the corticotomy and opting for a wide approach to the medullary bone to easily introduce the osteotome, thereby reducing the risk of a poor split. Therefore, correct 3D presurgical planning is required to avoid damage to the mandibular canal.

During SSRO, McLeod and Bowe [15] concluded that the inferior alveolar nerve may be damaged by traction during stripping of the soft tissue of the medial ramus, incorrect medial bone cut, unfavorable split, improper retraction or advancement of the distal segment, misjudged placement of a miniscrew, and compression from the proximal segment and distal segment fixation. Zaroni et al. [16] explored the postoperative complications of orthognathic surgery and reported a 19.2% complication rate, including postoperative malocclusion, hemorrhage, inferior alveolar nerve injury, bad split, and infection. Gennaro et al. [17] investigated the intraoperative frequency of nerve exposure and reported a high incidence of neurosensory disturbance in the lower lip and chin after SSRO. Politis et al. [18] stated that postoperative changes in lower lip sensation were 15.1% after SSRO.

Steenen and Becking [19] reviewed unfavorable and unanticipated splits during SSRO and reported a 2.3% incidence of poor split. They also observed that the buccal plate of the proximal segment and the lingual plate of the distal segment were frequently encountered fracture patterns. Studies have indicated that the buccal plate is more prone to result in bad split than the lingual plate. In the process of splitting the mandible into the mesial and distal portions using SSRO, an excessively small mandibular SBM may cause the inferior alveolar nerve to be injured when operating surgical instruments and increase the probability of unexpected bone fracture. Therefore, SBM is the most critical risk factor leading to inferior alveolar nerve injury and bad split during SSRO.

Although the mean values between skeletal pattern groups are essential in determining whether anatomical structures increase the likelihood of postoperative complications, the probability for the value to be minimal is more strongly correlated with the occurrence of postoperative complications (nerve paresthesia or bad split) than the mean values are. Huang et al. [20] reported that the measurement

Table 2: The shortest distance of buccal bone marrow and thickness of the mandible from slice 0 (0 mm) to slice 15 (30 mm) with their skeletal patterns in the one-way ANOVA with the post hoc Tukey HSD test.

Variables	SBM (mean ± SD, mm)	*p* value	M (mean ± SD, mm)	*p* value
0 mm				
Class I	1.71 ± 1.46	0.710	9.79 ± 1.61	0.641
Class II	1.81 ± 1.33		9.55 ± 1.37	
Class III	1.61 ± 1.11		9.65 ± 1.31	
2 mm				
Class I	1.59 ± 1.42	0.149	9.96 ± 1.50	0.735
Class II	1.70 ± 1.30		9.79 ± 1.38	
Class III	1.26 ± 1.07		9.78 ± 1.30	
4 mm				
Class I	1.37 ± 1.35	0.179	10.08 ± 1.60	0.480
Class II	1.75 ± 1.22		10.21 ± 1.44	
Class III	1.37 ± 1.22		9.89 ± 1.27	
6 mm				
Class I	1.25 ± 1.29	0.013*	10.25 ± 1.66	0.116
Class II	1.53 ± 1.11	Class II > III	10.38 ± 1.47	
Class III	0.91 ± 1.02		9.84 ± 1.29	
8 mm				
Class I	1.26 ± 1.31	0.001*	11.09 ± 1.68	0.364
Class II	2.08 ± 1.30	Class II > I	11.25 ± 1.70	
Class III	1.30 ± 1.28	Class II > III	10.84 ± 1.44	
10 mm				
Class I	1.43 ± 1.30	0.001*	11.19 ± 1.78	0.140
Class II	1.92 ± 1.92	Class II > III	11.42 ± 1.64	
Class III	1.07 ± 1.19		10.81 ± 1.65	
12 mm				
Class I	1.65 ± 1.45	<0.001*	12.11 ± 1.90	0.515
Class II	2.68 ± 1.59	Class II > I	12.28 ± 1.80	
Class III	1.45 ± 1.44	Class II > III	11.90 ± 1.75	
14 mm				
Class I	1.82 ± 1.49	0.001*	12.12 ± 1.84	0.392
Class II	2.54 ± 1.40	Class II > I	12.15 ± 1.64	
Class III	1.50 ± 1.58	Class II > III	11.74 ± 1.89	
16 mm				
Class I	2.32 ± 1.79	0.001*	12.64 ± 1.73	0.879
Class II	3.17 ± 1.48	Class II > I	12.79 ± 1.64	
Class III	2.11 ± 1.62	Class II > III	12.76 ± 1.79	
18 mm				
Class I	2.26 ± 1.55	0.088	12.61 ± 1.72	0.905
Class II	2.77 ± 1.36		12.66 ± 1.59	
Class III	2.13 ± 2.00		12.52 ± 1.99	
20 mm				
Class I	2.79 ± 1.41	0.066	13.05 ± 1.72	0.370
Class II	3.25 ± 1.29		12.86 ± 1.57	
Class III	2.6 ± 1.89		13.33 ± 2.11	

Table 2: Continued.

Variables	SBM (mean ± SD, mm)	p value	M (mean ± SD, mm)	p value
22 mm				
Class I	2.59 ± 1.45	0.429	12.68 ± 1.71	0.424
Class II	2.83 ± 1.29		12.51 ± 1.65	
Class III	2.47 ± 1.83		12.95 ± 2.12	
24 mm				
Class I	3.09 ± 1.49	0.780	13.00 ± 1.77	0.084
Class II	3.08 ± 1.39		12.63 ± 1.55	
Class III	2.92 ± 1.68		13.39 ± 2.20	
26 mm				
Class I	2.54 ± 1.34	0.995	12.49 ± 1.78	0.267
Class II	2.57 ± 1.25		12.31 ± 1.52	
Class III	2.55 ± 1.64		12.84 ± 2.07	
28 mm				
Class I	2.69 ± 1.25	0.329	12.69 ± 1.91	0.173
Class II	2.52 ± 1.28		12.46 ± 1.43	
Class III	2.90 ± 1.59		13.09 ± 2.13	
30 mm				
Class I	2.47 ± 1.20	0.018*	12.23 ± 1.78	0.909
Class II	1.98 ± 1.29	Class III > II	12.32 ± 1.46	
Class III	2.61 ± 1.28		12.37 ± 1.95	

SBM: shortest distance of buccal bone marrow; M: thickness of the mandible. ∗: significant, $p < 0.05$.

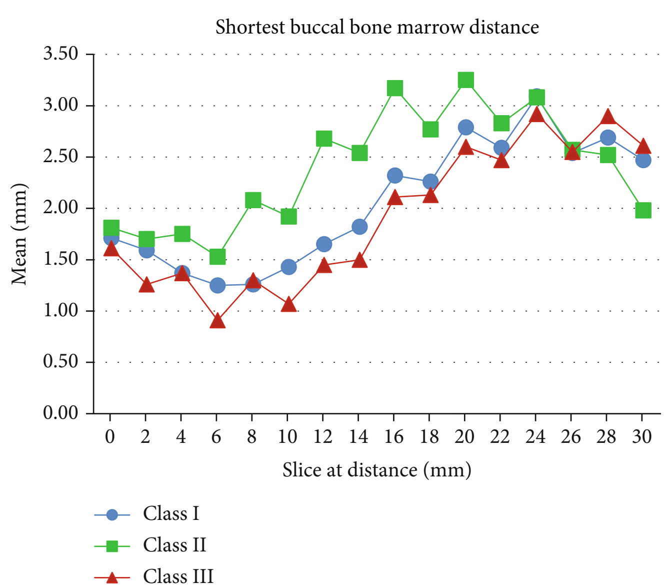

Figure 3: The shortest buccal bone marrow (SBM) distances in the three skeletal patterns.

values were significantly smaller for participants with nerve paresthesia than for those without at the 16, 18, 20, or 24 mm slices anterior to the mandibular foramen. Many studies [21–25] on SBM values have been conducted. Yamamoto et al. [21] noted a significant difference among skeletal class III participants who had undergone SSRO surgery and found that nerve paresthesia occurred in 0% of participants with SBM ≥ 1 mm and in 61.5% of participants with SBM < 1 mm. Yamauchi et al. [23] observed significant postoperative nerve paresthesia in 57.1% of participants with

Table 3: From slice 0 (0 mm) to slice 15 (30 mm), the shortest buccal bone marrow distances of skeletal patterns with hemiarch comparisons.

Variables	Right (mean, mm)	Left (mean, mm)	p value	Significant
0 mm				
Class I	1.75	1.68	0.931	
Class II	1.84	1.77	0.861	
Class III	1.4	1.82	0.107	
2 mm				
Class I	1.75	1.43	0.270	
Class II	1.84	1.56	0.317	
Class III	1.4	1.12	0.107	
4 mm				
Class I	1.37	1.38	0.648	
Class II	1.74	1.76	0.855	
Class III	1.17	1.58	0.065	
6 mm				
Class I	1.37	1.13	0.254	
Class II	1.46	1.61	0.409	
Class III	0.83	0.98	0.414	
8 mm				
Class I	1.31	1.21	0.626	
Class II	1.97	2.2	0.289	
Class III	1.17	1.42	0.276	
10 mm				
Class I	1.42	1.43	0.571	
Class II	1.92	1.92	0.838	
Class III	0.98	1.17	0.493	
12 mm				
Class I	1.67	1.63	0.577	
Class II	2.70	2.65	0.904	
Class III	1.41	1.48	0.511	
14 mm				
Class I	1.86	1.78	0.449	
Class II	2.42	2.67	0.358	
Class III	1.43	1.56	0.861	
16 mm				
Class I	2.51	2.14	0.156	
Class II	3.18	3.15	0.733	
Class III	2.05	2.16	0.675	
18 mm				
Class I	2.15	2.37	0.374	
Class II	2.69	2.84	0.495	
Class III	2.1	2.17	0.568	
20 mm				
Class I	2.97	2.61	0.044^*	$R > L$
Class II	3.42	3.08	0.175	
Class III	2.68	2.53	0.517	
22 mm				
Class I	2.55	2.64	0.556	
Class II	2.85	2.8	0.845	
Class III	2.40	2.54	0.750	

Table 3: Continued.

Variables	Right (mean, mm)	Left (mean, mm)	p value	Significant
24 mm				
Class I	3.21	2.98	0.294	
Class II	3.23	2.92	0.414	
Class III	3.03	2.81	0.304	
26 mm				
Class I	2.28	2.8	0.056	
Class II	2.72	2.43	0.581	
Class III	2.57	2.53	0.665	
28 mm				
Class I	2.86	2.52	0.302	
Class II	2.83	2.27	0.017*	$R > L$
Class III	3.06	2.74	0.116	
30 mm				
Class I	2.55	2.39	0.585	
Class II	2.05	2.03	0.962	
Class III	2.55	2.67	0.914	

*: significant ($p < 0.05$) in the Wilcoxon signed-rank test.

Table 4: From slice 0 (0 mm) to slice 15 (30 mm), the percentage in the shortest buccal bone marrow distance (SBM < 1 mm) with their skeletal patterns.

Variables	Class I	Class II	Class III	Total	p value	Significant
0 mm	40.00%	25.00%	33.30%	32.80%	0.215	
2 mm	40.00%	28.30%	41.70%	36.70%	0.256	
4 mm	41.70%	26.70%	45.00%	37.80%	0.088	
6 mm	50.00%	28.30%	55.00%	44.40%	0.008*	Class I > II, class III > II
8 mm	51.70%	20.00%	45.00%	38.90%	0.001*	Class I > II, class III > II
10 mm	41.70%	21.70%	53.30%	38.90%	0.002*	Class III > II
12 mm	41.70%	16.70%	41.70%	33.30%	0.004*	Class I > II, class III > II
14 mm	33.30%	11.70%	38.30%	27.80%	0.002*	Class I > II, class III > II
16 mm	21.70%	5.00%	23.30%	16.70%	0.012*	Class I > II, class III > II
18 mm	23.30%	8.30%	30.00%	20.60%	0.011*	Class III > II
20 mm	6.70%	5.00%	21.70%	11.10%	0.006*	Class III > II
22 mm	11.70%	8.30%	21.70%	13.90%	0.089	
24 mm	3.30%	5.00%	10.00%	6.10%	0.284	
26 mm	8.30%	8.50%	20.00%	12.30%	0.083	
28 mm	5.00%	10.20%	11.70%	8.90%	0.406	
30 mm	5.00%	24.10%	8.30%	12.40%	0.003*	Class II > I

*: significant ($p < 0.05$) in the Bonferroni post hoc test for chi-square tests.

SBM < 1 mm and in 7.7% of participants with SBM > 2 mm. However, whether the SBM value is significantly different between classes II and III remains unclear. Our findings indicate that in sections 3–8 (6–16 mm anterior to the mandibular foramen), the mean SBM values were significantly larger in class II patients (1.53–3.17 mm) than in class III patients (0.91–2.11 mm). This indicates that the occurrence of postoperative complications differs between class II and class III patients after SSRO.

Concerning postoperative complications, the occurrence probability rate of SBM was as essential as the size of SBM. We used a chi-square test to examine the probability of having minimal SBM values and demonstrated that for many of the sections within the region where SSRO is conducted, the probability rate of having a minimal SBM value was larger for class III participants than for class II participants. For the eight sections (sections 3–10) that were 6–20 mm anterior to the mandibular foramen, this probability was significantly larger for the class III group than for the class II group, with the differences in probability between the two groups being 16.70% to 26.60% for all sections.

Taking our findings and the results of Yamamoto et al. [21] and Yamauchi et al. [23] together, we conclude that class III participants are more likely to have post-SSRO nerve paresthesia than skeletal class II participants are. In this study, we examined SBM minimum values by combining the left- and right-side values to eliminate the possibility of existing differences between the left and right sides affecting the study results. Only two sections had significant differences between the left and right sides. Therefore, we conclude that the left and right sides do not significantly differ, and the left- and right-side values can be combined when conducting a statistical analysis.

5. Conclusion

Our data indicate that skeletal class III participants had a significantly smaller SBM than skeletal class II participants did. Furthermore, the probability of having a minimum SBM (<1 mm) was significantly higher for class III participants than for class I and II participants. Therefore, class III participants are more likely to have post-SSRO nerve paresthesia than class II participants are. Further research is required to directly determine whether the probability of having nerve paresthesia after SSRO significantly differs between class II and III participants.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Han-Jen Hsu and Chun-Ming Chen equally contributed to this work.

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