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Biomechanical Evaluation of Sagittal Split Ramus Osteotomy Fixation Techniques in Mandibular Setback

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Abstract: The objective of this study was to evaluate and compare the biomechanical behavior of internal fixation techniques in bilateral sagittal split ramus osteotomies (BSSROs) for mandibular setback. Artificial polyurethane mandibles were used in this study. The distal segment of the mandible was repositioned in an 8-mm setback position. All mandibles were divided into three groups: Group 1 had a straight plate with a four-hole monocortical fixation, Group 2 had a curved plate with a four-hole monocortical fixation, and Group 3 had a three–inverted L-type bicortical screw fixation. Vertical loads were applied on the incisal edge by a material testing system. The resistance force at 1, 3, 5, and 10 mm of displacement was analyzed. From the experimental results, Group 1 showed significantly lower results than Groups 2 and 3. No significant difference was observed between Groups 2 and 3 at 1, 3, and 5 mm of displacement. However, at 10 mm of displacement, the resistance force of Group 3 was greater than that of Group 2. For BSSROs, this study concluded that curved plate fixation exhibited the same rigidity as the inverted-L bicortical screw fixation did at ≤5 mm displacement.

Keywords: sagittal split ramus osteotomy; fixation; bone plate; screw

1. Introduction

Severe skeletal dentofacial deformities have led several patients to undergo surgical orthodontic treatment, as they cause chewing difficulties and esthetic problems [1,2]. Dr. Angle provided the first simple definition of normal human occlusion and described three classes of malocclusion based on the occlusal relationships of the first molars [3]. Bilateral sagittal split ramus osteotomies (BSSROs) or vertical ramus osteotomies for mandibular setback with orthodontics are effective for treating skeletal Class III malocclusion [4]. Most surgeons prefer BSSROs because its rigid fixation permits early mandibular function [2,5].

Many modifications of fixation methods for BSSROs have been proposed. Fixation methods, including bicortical screws, plates with monocortical screws, and a combination of these two techniques (hybrid technique), have been reported for bilateral sagittal split ramus osteotomies [2,4]. Instability at the osteotomy site contributes to early relapses in BSSROs [6,7]. Adequate fixation can provide sufficient resistance to displacing forces that cause micromovements across the osteotomy site. Spiessl et al. introduced rigid fixation in BSSROs by using three bicortical screws through the transcutaneous approach [8]. Many studies have reported that the three-bicortical screw fixation method offers the strongest resistance force against displacement [8–11]. However, temporomandibular disorders due to the displacement of the mandibular condyle and the risk of nerve damage due to excessive compression force can occur [2].

Various in vitro experimental studies have been reported; however, the most ideal fixation method remains to be established. Biomechanically, the curved plate, which conforms to the native curvature or trajectory of the mandibular external oblique ridge much more, appears to offer more rigidity than regular straight plates. Few studies on curved plates have been reported. This study compared the in vitro mechanical stability from the fixation method, which involves fixation using a straight plate with four monocortical screws, a curved plate with four monocortical screws, and three–inverted L-type bicortical screws applied to an artificial mandibular model simulating a BSSRO.

2. Materials and Methods

2.1. Specimen Preparation

Artificial polyurethane whole mandibular models (model No. 8596; Synbone, Malans, Switzerland) were used in this study. The titanium fixation system (Depuy Synthes, West Chester, PA, USA) was used in this study. Each experimental mandible underwent bilateral sagittal split osteotomies conducted by a single researcher, Dr. Yi-Fan Wu. Bone cuts were made using a Stryker Total Performance System reciprocating saw and fissure bur. After this, an 8-mm setback was performed after interference was removed. The mandibular models were divided into three groups (Figure 1), and each group included eight specimens. (1) Group 1 was the straight plate with a monocortical fixation group (titanium straight plate with four monocortical screws, plate thickness of 1.0 mm, screws 2.0 mm in diameter and 6 mm in length). (2) Group 2 was the curved plate with a monocortical fixation group (titanium curved plate with four monocortical screws, plate thickness of 1.25 mm, screws 2.0 mm in diameter and 6 mm in length). (3) Group 3 was the three–inverted L-type bicortical screw fixation group (three–inverted L-type titanium bicortical screws, screws 2.0 mm in diameter and 12 mm in length; Figure 1).

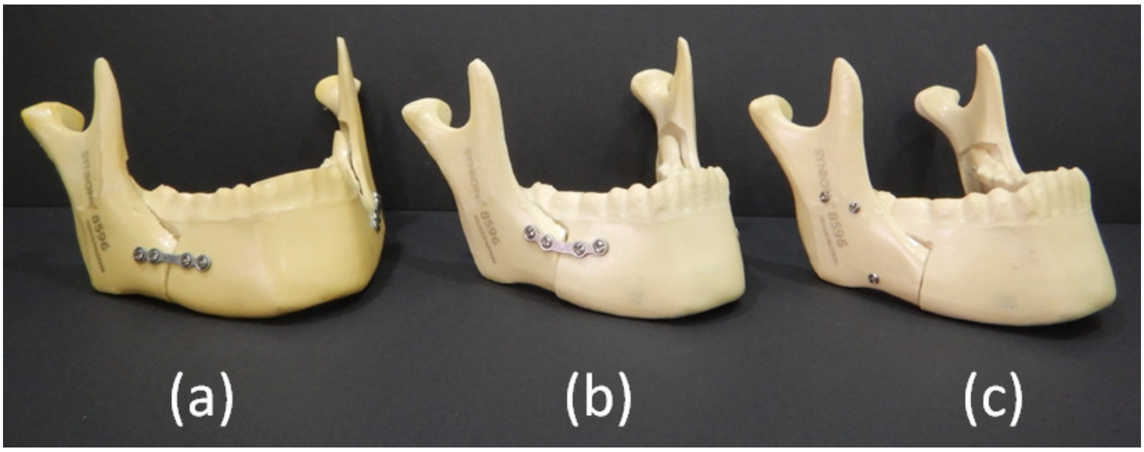

Figure 1. Fixation methods for bilateral sagittal split ramus osteotomies (BSSRO) used in this study: (**a**) Group 1: straight plate with four monocortical screw fixation. (**b**) Group 2: curved plate with four monocortical screw fixation. (**c**) Group 3: three–inverted L-type bicortical screw fixation group.

2.2. Measurement of Fixation Ability

The mandibular models were fixed in a custom-fabricated supporting apparatus (Figure 2). We used the embedding cassette to fully hold the bilateral mandibular condyle head and coronoid process. All loading tests were conducted using the material testing machine (JSV-H1000, Japan Instrumentation System Co., Nara, Japan). The loading machine developed a linear displacement over the incisal edge at a speed of 1 mm/min, and the force necessary to deflect distal segments at 1, 3, 5, and 10 mm was recorded in newtons (N).

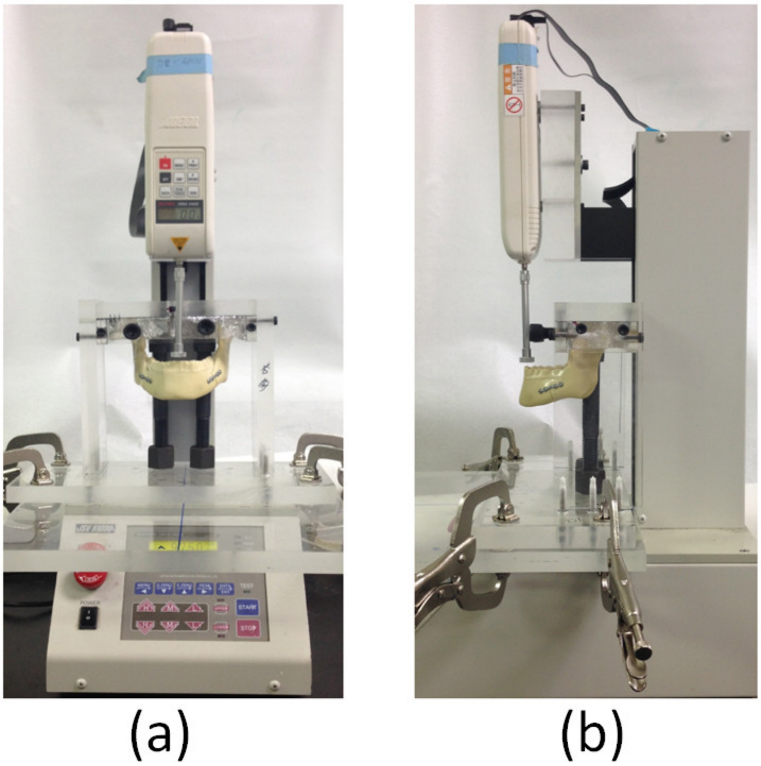

Figure 2. Artificial mandibular bone fixed to a supporting base for the biomechanical test: (**a**) frontal view; (**b**) side view.

2.3. Statistical Analysis

The experimental results of the three fixation methods were summarized and are expressed as median and interquartile range (IQR). The Kruskal–Wallis test was used to compare the fixation ability among the three groups. Post hoc pairwise comparisons were conducted precisely using the Wilcoxon rank sum test with the Bonferroni adjustment, and the significance level was 0.0167 (0.05/3). SPSS v19 (IBM Corporation, Armonk, NY, USA) was used for statistical analysis.

3. Results

The experimental results are listed in Tables 1 and 2. Group 1 presented significantly lower values for stability than Groups 2 and 3 at all measured displacement points. Group 3 was the most rigid, whereas Group 1 had the lowest mechanical resistance. At 1, 3, and 5 mm of displacement, the results from Group 1 were lower significantly than those from Groups 2 and 3. In addition, no significant differences were observed between Groups 2 and 3. However, at 10 mm of displacement, the outcomes of Groups 1 and 2 were less significant than those of Group 3.

Table 1. Resistance force (N) at the three displacements sites during raw experimental measurement.

Type of Fixation	Model No.	Resistance Force			
		1 mm	3 mm	5 mm	10 mm
Group 1 (Straight plate)	1	15	29.4	40.2	57.1
	2	5.1	18.5	36.6	91.2
	3	11.0	27.2	41.2	66.3
	4	10.2	19.0	41.7	67.0
	5	11.3	19.2	40	59.2
	6	16.0	21.0	39.2	61.0
	7	12.1	20.2	38	63.2
	8	9.1	17.3	38	71.1
Group 2 (Curved plate)	1	22.6	44.5	63.1	105.0
	2	9.7	43.5	78.2	125.9
	3	18.1	51.0	71.3	110.0
	4	20.2	55.2	69	108.2
	5	21.0	49.6	77.1	113.0
	6	23.2	50.0	76.1	103.0
	7	27.1	52.6	75.8	102.2
	8	25.2	57.1	68.2	109.3
Group 3 (Inverted-L bicortical screw)	1	18.2	49.3	78.7	145.0
	2	19.1	52.3	74.3	139.1
	3	22.0	56.2	77.4	141.2
	4	24.1	61.1	80.1	148.2
	5	21.2	59.3	81.0	150.0
	6	19.8	55.8	77.9	139.2
	7	21.5	58.0	78.2	147.7
	8	21.9	59.2	72.0	148.0
Unit: N					

Table 2. Resistance force of the three groups (median ± interquartile range (IQR)).

Amount of Displacement	Group 1 (Straight Plate)	Group 2 (Curved Plate)	Group 3 (Inverted-L Bicortical Screw)
1 mm	11.15 ± 4.90	21.80 ± 6.08	21.35 ± 2.70
3 mm	19.70 ± 7.03	50.50 ± 8.78	57.10 ± 6.10
5 mm	39.60 ± 2.95	73.55 ± 8.45	78.05 ± 4.68
10 mm	64.75 ± 10.43	108.75 ± 8.75	146.35 ± 8.45
Unit: N			

4. Discussion

Numerous studies have discussed fixation techniques for BSSROs, but few have explored the use of curved plates for fixation. In addition, biomechanical experiments using cadavers or artificial bones have predominantly focused on half (one side) of the mandible. The present study used a complete mandibular model and used a curved plate for fixation in BSSROs. The experimental results revealed that fixation using the curved plate created a resistance force similar to that obtained using three bicortical bone screw fixation, and stable occlusion was maintained. Therefore, curved plate fixation is a reliable method in clinical settings.

Few studies have used allografts in various fixation methods for BSSRO. Tharanon et al. [8] tested the resistance force of bone screws and bone plates in cadaver jaws and observed a nonsignificant difference between the resistance provided by three-bicortical screw fixation and one four-hole plate fixation. Given the low availability of fresh frozen human cadaver mandibles, in vitro tests for orthognathic surgery have mostly used animal jaws [12–15] or artificial bones [10,16–21]. However, the shapes of animal mandibles, regardless whether they are derived from goats or pigs, are different from the human mandible. Therefore, individual differences in animal jaw properties may affect experimental results. Given the ease of specimen standardization and material availability, the present study employed artificial mandibles as the experimental specimens. Artificial bones are uniform and consistent in terms of dimensions and material properties [22]. The American Society for Testing and Materials F-1839-08 "Standard Specification for rigid Polyurethane Foam for Use as a Standard material for testing Orthopaedic devices and instruments" states that "the uniformity and consistent properties of rigid polyurethane foam make it an ideal material for comparative testing of bone screws and other medical devices and instruments" [23]. In addition, Bredenner et al. [24] suggested that artificial bones can replace fresh frozen cadaver bones in research evaluating jaw biomechanics [25].

Most research employing artificial bones to examine fixation techniques in sagittal split ramus osteotomy have used artificial semimandibular bone models, such as in the studies by Brasileiro et al. [17], Ribeiro-Junior et al. [25], Brasileiro et al. [16], Sato et al. [21], Pereira Filho et al. [18], Oh et al. [26], and Oguz et al. [20]. Peterson et al. [10] and Sener et al. [19] are among the few using complete mandibular models to conduct in vitro mechanical tests. Peterson et al. [10] divided mandibular models into five groups, apart from the control group, with all other models categorized into four groups according to screw and plate fixation techniques applied on them. Subsequently, they performed a BSSRO to advance the mandible by 7 mm and conducted a mechanical test by applying force on the incisal and molar regions. The same study revealed that, regardless of whether in the incisal or molar region, the four experimental groups were all significantly different from the control group regarding their yield loading performance. Among the four experimental groups, only the group with the inverted L-type bicortical screw fixation met the clinical demand for occlusal loading. Furthermore, the force applied in the incisal region exerted a larger influence on the screws and plates at the bone cut site than the force applied in the molar region did. Accordingly, the present study applied force in the incisal region to compare the performance of the three fixation techniques.

According to previous studies using either complete mandibular models for tests [10] or models of only one side of the mandible [16], the resistance facilitated by the straight plate fixation approach was lower than that facilitated by the inverted L-type three-bicortical screw fixation approach. In the present study, the results for Groups 1 and 3 were consistent with those in these studies.

The resistance force of Group 2 differed non-significantly from that of Group 3 in displacing the mandibular incisal region by 1, 3, and 5 mm. The two groups yielded significantly different data at a displacement of 10 mm, and both groups had a resistance force of more than 100 N. In clinical practice, the muscles at the surgical site are temporarily shortened, and are in a traumatized state during the initial postoperative phase after orthognathic surgery; hence, the occlusal force in this phase is considerably lower than that before surgery. Such a temporary change in occlusal force facilitates natural protection against osteosynthesis segment displacement for overall stability in patients in the postoperative recovery phase after orthognathic surgery.

Orthognathic surgery is an elective operation and surgeons should always be alert enough to avoid the risk of unnecessary complications, such as the neurosensory disturbance of lingual nerves. The rates of lingual nerve injury varies; 9%~19% according to literature by Al-Bishri et al. [27] and Jacks et al. [28]. The placement of excessively long bicortical screws on the superior border of mandibular angle might damage lingual nerve, however, the use of monocorical plate and screw fixation prevents this complication. There are always pros and cons regarding all surgical techniques or procedures. Regardless of fixation protocols, either rigid or non-rigid; with or without positioning devices, the displacement of mandibular condyle during ramus osteotomies is inevitable and must be kept as minimal as possible to prevent TMJ arthropathy, thereby leading to immediate or delayed relapse. To enable the passive adaptation of bone segments and proper seating of the condyle heads into glenoid fossa during mandibular surgery, the full mobilization of the distal segment and meticulous removal of all bony interferences are the most crucial parts that should never be overlooked by clinicians [29].

The limitations of this study must be acknowledged. In vitro biomechanical tests were conducted on artificial bones in this study; artificial bones fail to comprehensively simulate the complex movements of the human mandible. Furthermore, as in previous studies, this study used artificial bones for testing and thus overlooked the effect of the mandibular trabecular bone structure on fixation performance.

5. Conclusions

Based on the experimental setup and limitations, the conclusions regarding the fixation ability of BSSROs are as follows:

(1) The resistance force of Groups 2 and 3 indicated better bone fixation than Group 1.
(2) The resistance force at 1, 3, and 5 mm displacement was significantly the same for Groups 2 and 3.

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