Objective. The purpose of this study was to biomechanically evaluate the stability of a T-shaped miniplate fixation of a modified sagittal split ramus osteotomy (MSSRO) with buccal step and to compare it with single or double-parallel straight miniplates fixing a standard sagittal split ramus osteotomy (SSRO).

Study design. Eighteen Synbone mandibular replicas were used in the study and divided into 3 groups. Standard SSRO was applied in the first and second groups, and the third group was cut for MSSRO with buccal step. After 7 mm of advancement, fixation modalities for the 3 groups included a single straight miniplate, double-parallel straight miniplates, and a T-shape miniplate, respectively. Each model was secured in a jig and subjected to vertical load on the anterior teeth.

Results. The T miniplate group showed a significantly higher value for stability than the group with a single straight miniplate. There was no significant difference in stability between the T miniplate and the double-parallel straight miniplate groups.

Conclusion. For mandibular advancement surgery of 7 mm in a laboratory environment, a T-shaped miniplate used with MSSRO and buccal step as a combination significantly optimize the resistance and stability of the fixation compared with a standard SSRO fixed with a single straight miniplate.

(Sagittal split ramus osteotomy (SSRO) of the mandible is the most common mandibular osteotomy performed around the world. The broad area of bone overlap that occurs with this procedure facilitates the application of stable internal fixation devices.

The SSRO is currently stabilized by the use of positional screws and/or miniplates. These fixation schemes have been investigated and reviewed in both clinical and biomechanical studies, which sometimes showed contradictory results.1-4 Although retrospective clinical studies have shown that there are no significant postoperative differences in stability between bicortical screw and miniplate fixation techniques,5,6 biomechanical studies have revealed that miniplates have less mechanical stability compared with bicortical screws.7,8 The latter studies have shown that 3 bicortical screws or hybrid schemes of bicortical screw and miniplate provide greater stability against rotational movement. Though more rigid and stable, it remains unclear whether such amount of fixation is what is needed to confer sufficient stability. There is still no answer of how rigid rigid fixation should be in an environment with reduced occlusal forces and jaw activity for a patient briefly kept on a soft diet after surgery.9.

The miniplate technique, introduced by Michelet et al. in 1973,10 uses miniplates with monocortical screws attached to the buccal cortex of the proximal and distal segments. This technique shows advantages, such as granting intraoral route, minimal torsion on the condyle, and less risk of inferior alveolar nerve injury. It is particularly advantageous in larger advancements where proximal and distal overlap is minimal. For many surgeons, the straight type of miniplates with monocortical screws is a popular choice. Although it has been tested both short- and long-term and showed...
stable results, its usage was often followed by a period of intermaxillary fixation and extended soft diet interval for 6-8 weeks, particularly when attempting large advancements. For such cases, fixation failure, such as bending of the plate, is not a remote possibility and has been recently reported.

In our institution, we are using a combination of a T-shaped miniplate and a modified SSRO (MSSRO) with buccal step laid adjacent to the mandibular second molar area (Fig. 1). The design of the buccal step, which was originated by Gallo et al. and reported by Wolford et al., creates a horizontal bone ledge superior to the condylar segment that gives more control over the condylar segment, preventing its rotation and therefore reducing mechanical resistance. This step is particularly advantageous for patients with retrognathism, because the area of bone contact is increased. The design of the step creates 2 sites for fixation on the mandibular body that are engaged by the 2 arms of a single T-shaped miniplate. Because our early clinical studies and experience with MSSRO and T miniplate has been good with no incidence of failure, we decided to evaluate this model versus the standard bilateral sagittal split with 1 or 2 miniplates with mechanical testing.

MATERIALS AND METHODS

Eighteen polyurethane synthetic mandibular replicas (Synbone, Laudquart, Switzerland) were used in this study. The replicas matched the average norms of the height and thickness of a normal mandible bone. They have been successfully tested in related studies and shown to be good simulators of the human bone, eliminating many of the variables associated with human cadaveric mandibles and bone from animal resources.

The models were divided into 3 groups (6 models/group). Two groups were subjected to uniform osteotomies resembling standard SSRO, and the third group was cut for MSSRO with buccal step. All the osteotomies were performed bilaterally by the same examiner using a reciprocating saw (Aesculap-motor, GA 246) and fixed with 7 mm of advancement. Fixation modalities for the 3 groups included a single straight miniplate, double-parallel straight miniplates, and a single T-shaped miniplate, respectively (Fig. 2). All plates were standard titanium (Synthes MF, compact 1.5 mm) with titanium monocortical screws (Synthes MF, mandible compact 2.0 mm, 6 mm length).

Each model was secured in a jig (Fig. 3) and subjected to vertical load on the anterior teeth edges applied by an Instron 1123 (Canton, MS) mechanical testing unit at a rate of 10 mm/min. Loading was continued until irreversible deformation of the plate occurred. Yield load within a range of 0-500 N was evaluated for all of the groups. This load was the most important factor in the assessment of the mechanical characteristics of fixation devices and is defined as the load at which a system begins to permanently deform. Means and standard deviations were calculated and compared for statistical significance using Tukey test with a confidence level of 99% (P < .01).

RESULTS

After load applications on models, the plates for all of the groups were uneventfully deformed at the bridging area of the osteotomy without screws pulled away from the bone or plates fractured. For the first group, deformation was noticeably the earliest to occur. The mean yield load values for the groups were 12.2 ± 2.31 N for the single straight miniplate group, 34.2 ± 3.30 N for the double-parallel miniplates, and 31.3 ± 4.26 N for the T miniplate group. Statistical analysis using Tukey multiple comparisons test with a confidence level of 99% showed a significantly higher value of stability for the T miniplate group compared with the single straight miniplate group (P < .01). No significant difference was found between the T miniplate and the double-parallel straight miniplate groups (P > .01; Table I; Fig. 4).

DISCUSSION

Various biomechanical studies have been conducted for evaluating different fixation systems following mandibular orthognathic surgery. It is well known that the biomechanical function of rigid fixation systems clinically depends on the interaction between plate, screws, and bone; therefore, it is proposed that an appropriate in vitro testing model should investigate fixation systems acting as a unit rather than testing the plate strength alone. In the present study, we evaluated the stability of the com-
Combination of T miniplate and MSSRO compared with a clinical model resembling standard SSRO fixed with a monocortical plate or double-parallel plates after mandibular advancement. Test loads were applied down on the incisors, because that showed more effect on the osteotomy site than torsional loading on molars.20

Rigid fixation versus semirigid fixation

Bicortical screws are among the most critically evaluated of the rigid internal fixation techniques.19,21 Although relatively simple and stable, their rigid fixation has been associated with risk to the neurovascular apparatus and imprecise condylar position, in addition to the scars that might follow their insertion extraorally. Joss and Vassalli22 mentioned in their systematic review in 2009 that larger skeletal long-term relapse rates after mandibular advancement were more evident in patients treated with bicortical screws instead of miniplates. Although rigid fixation confers short-term stability for initial healing, it is believed that long-term stability is conducted through functional and neuromuscular factors that can be achieved by using less rigid pattern of fixation, so-called semirigid fixation.21,23 By using miniplates, bone fragments are held to heal during function while permitting minimal physiologic movement, which is called functionally stable fixation.23

Table I. Results

<table>
<thead>
<tr>
<th>Yield load</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (single straight plate)</td>
<td>12.2 N</td>
<td>2.31</td>
</tr>
<tr>
<td>Group 2 (double straight plates)</td>
<td>34.2 N</td>
<td>3.30*</td>
</tr>
<tr>
<td>Group 3 (T plate)</td>
<td>31.3 N</td>
<td>4.26*</td>
</tr>
</tbody>
</table>

*Significant difference (P < .01) from group 1, by Tukey test.

Fig. 2. Experimental models. A, Single straight miniplate with sagittal split ramus osteotomy (SSRO). B, Double-parallel straight miniplates with SSRO. C, T miniplate with modified SSRO.

Fig. 3. Experimental jig.
One-point fixation versus 2-point fixation

Because using a single miniplate on an osteotomy site confers a 1-point fixation scheme, this point had been shown to become the area where stresses from occlusion or surrounding musculatures gather; therefore, failure of the fixation is not a remote possibility, particularly with large advancements. A report made by Ellis and Esmail in 2009 introduced 3 cases of fixation failure after a sagittal split advancement fixed using a standard single straight miniplate. For each case, they noticed a malocclusion formed within a 3-month period, and plate deformation was confirmed radiographically. They attributed the failure to the muscle forces that were exerted on the fixation site after advancement.

Bending of the bone plate has not been widely demonstrated. It may be that many surgeons who use a single miniplate for SSRO have had an occasional patient with such findings, but it was not severe or it went unrecognized. The routine use of interarch elastics by many surgeons may maintain a good occlusion while the mandible drifts to a new position.

Adding a new fixation point using double miniplates as a scheme of 2-point fixation has a large effect on conferring greater stability and decreasing latent failure, because stresses are distributed over 2 plates. For the T miniplate, its two arms hold the 2 fixation sites drawn by the buccal step. This allows a double miniplate–like action through a single construct with stresses being distributed over 2 fixation sites. To date, we have had no cases of fixation failure in continuously using this technique since 1991.

Occlusal forces and food biting behaviors

Occlusal forces after jaw surgery have been studied by many researchers, resulting in largely different values. They reported that a reduced amount of bite force for extended periods follows the surgery; however, no definitive values were proposed. With the shortage of information, it appears more valuable and clinically relevant to look at the normal masticatory forces and to see whether the fixation levels of the present groups exceed the levels needed to split usual food items.

A number of studies have reported food biting behaviors and forces applied by teeth during splitting tasks. Trulsson and Johansson chose human objects with normal occlusion and dental status and measured the forces applied by incisors to split half of a peanut and biscuit. They ranged 16-19 N and 7.8-10.3 N, respectively. A study by Moriya on Japanese volunteers reported the splitting forces for selected food items with certain morsel thicknesses: for apple 17 mm,12 N; chocolate 5 mm,14 N; gelatin 7.5 mm, 5.4 N; and cheese 10 mm, 0.6 N.

A quick comparative look at our groups shows that a single straight miniplate has a little to overcome for most of the food biting levels. Transposing this data to a clinical model, a prolonged soft diet or a period of intermaxillary fixation (IMF) should be used to treat a patient. In contrast, a T miniplate used with a MSSRO provided sufficient stability for the osteotomy site for usual food biting levels, negating the need for a period of IMF or a severely restricted diet.

Van Sickels et al. reported fixation levels for SSRO of up to 140 N using 3 bicortical screws and cylinder plate for fixing mandibular models after advancement with loads applied on the anterior teeth. An in vitro study by Ozden et al. compared 10 different fixation schemes and reported that loading levels reached up to 778 N with using bicortical screws in a scheme of inverted backward-L, which was biomechanically the most stable fixation scheme among the examined groups; conversely, from a clinical point of view, such levels of fixation noticeably exceed the actual needs of fixation when considering food biting behaviors and reduced occlusal forces. Therefore, extra stresses generated from such fixation schemes may affect the long-term stability.

One advantage of using a T miniplate with MSSRO and buccal step is that the osteotomy helps prevent condylar segment rotation. Additionally, the surgical movement and osteosynthesis in the region of mandibular body intraorally confers a 2-point fixation effect with a single construct, providing stability for osteotomy site sufficiently over the levels of splitting usual food items during the early postoperative period. There has been no incidence of fixation failure in our practice.

Nevertheless, the technique is more sensitive than the traditional split regarding the design of the osteotomy. The potential of having unfavorable splits of the buccal plates remains and requires additional attention.
From a clinical prospective, it is highly advised to orient the horizontal cut of the buccal step parallel to the designated movement of the distal segment as simulated on paper. This is noticeably helpful in maintaining condylar segment alignment and ultimate fitting at the buccal step, particularly when attempting advancements accompanying clockwise rotations (i.e., class II deep bite) or mild counterclockwise rotations (i.e., mild open bite deformity). On the other hand, the MSSRO can be successfully applied for moderate asymmetry cases requiring ≤7 mm midline correction, and condylar segment flaring on the deviation side can be overcome similarly to SSRO by trimming or developing a green stick fracture or osteotomy on the internal ramus aspect belonging to the distal segment, negating the need for plate bending between segments. However, severe asymmetries can be better managed with different osteotomy modalities, such as using intraoral vertical ramus osteotomy on the deviation side.

In conclusion, for mandibular advancement surgery of 7 mm, a T miniplate used with MSSRO and buccal step significantly optimized the resistance and stability of the fixation compared with a single straight miniplate fixing standard SSRO in a laboratory environment.

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REFERENCES

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