A comparative evaluation of the hybrid technique for fixation of the sagittal split ramus osteotomy in mandibular advancement by mechanical, photoelastic, and finite element analysis

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Objective. This study evaluated the mechanical characteristics and stress distribution of the hybrid technique fixation of the sagittal split ramus osteotomy.

Study Design. In the mechanical test, 10 polyurethane replicas of human hemimandibles of each group were submitted to linear loading test. For the photoelastic evaluation, 3 hemimandible replicas of photoelastic resin were subjected to photoelastic analysis. In the finite element analysis, 3 computer models simulated the displacement and the results of maximum principal stress were analyzed.

Results. The results of this study demonstrated that the fixation technique with 3 bicortical screws presented better mechanical resistance and stress distribution pattern when compared with the hybrid technique that, on the other hand, presents better results in comparison with a miniplate and monocortical screws.

Conclusions. The results suggest that the hybrid technique increased the resistance and improved stress distribution of miniplate/monocortical screw fixation, maintaining most of the advantages of this technique. (Oral Surg Oral Med Oral Pathol Oral Radiol 2012;114(suppl 5):S60-S68)

Rigid internal fixation (RIF) methods have been widely used by surgeons in both maxillofacial trauma and orthognathic surgery because of countless advantages in comparison with wire osteosynthesis. These advantages include no rigid intermaxillary fixation (IMF) with internal fixation, which contributes to the comfort of the patient and does not allow the bone fragments to displace, resulting in long-term treatment stability.

As the benefits of RIF are obvious, the questions raised today are how rigid should the RIF be and what is the best technique to apply this fixation. The most widely used techniques for the fixation of the sagittal split ramus osteotomy (SSRO) are bicortical screws (both in lag and positional techniques, with different dispositions, like the inverted L and the linear arrangements) and miniplates with monocortical screws.

More recently, many surgeons have been using the so-called hybrid technique, which was initially proposed by Schwartz and Relle,1 aiming to associate the advantages of the fixation with bicortical screws and miniplates with monocortical screws. Before being considered a form of SSRO fixation, the use of screws associated with miniplates was primarily used for the management of unfavorable splits, lingual or buccal plate fracture, or bone gaps owing to third molar sockets.2,3

Clinically, a miniplate is first applied across the anterior vertical osteotomy using 4 monocortical screws. Then, a bicortical positional screw is placed just posteriorly to the last tooth and above the inferior alveolar nerve,1 aiming to give more mechanical resistance to the fixation system. Some surgeons prefer to first install the bicortical screw to establish the segments, however, and the miniplate with monocortical screws afterward.

Very few studies have analyzed the mechanical characteristics and stress distribution of the hybrid fixation technique in comparison with the traditional fixation with bicortical screws and miniplates with monocortical screws.
cal screws. Based on this fact, the aim of the present study was to evaluate the hybrid technique of fixation of the sagittal split osteotomy in comparison with bicortical screws and miniplates with monocortical screws by means of 3 in vitro tests: mechanical, photoelastic, and finite element analysis.

MATERIAL AND METHODS

Mechanical test
To reach standardization in SSROs, an osteotomy was performed on a polyurethane hemimandible replica according to what was proposed by Epker.4 Then, 30 two-piece polyurethane samples were produced from this SSRO mandible for mechanical tests.

The experimental samples were equally divided into 3 groups. Each group was reconstructed simulating a 5-mm advancement, as described by other studies,5,6 with 3 different techniques using 2-mm system plates and screws (Neoortho—JJGC Ind. e Com. de Mat. Dent Ltda., Curitiba, Paraná, Brazil). Group 1 was fixed with the hybrid technique, using a single 13-mm bicortical screw and a miniplate with 4 monocortical screws; group 2 was fixed with three 13-mm bicortical screws in the inverted L arrangement; and group 3 was fixed with a 4-hole miniplate with four 5-mm monocortical screws (Figures 1-3).

To reach standardization in relation to the hemimandible segments with a 5-mm advance fixation placement, the methodology proposed by Asprino et al.7 was used, which suggests the use of a guide made of acrylic resin for the advancement and attachment of the miniplates and screws.

The sample groups were submitted to a linear loading test from the upper part to the lower part, in the first molar region, by means of the Instron 4411 servohydraulic material-testing unit (Instron Corp., Norwood, MA). The material-testing unit produced linear displacement at a rate of 1 mm per minute and the loading was continued up to failure. Peak and ending load data (kgf) were obtained, as well as peak and ending displacement information (mm). Peak load is the load at which the system begins to permanently deform. Peak displacement is when permanent deformation begins. Mean and SD values were derived and compared for statistical significance within the attachment categories and tested using analysis of variance. A P value less than .05 was considered significant and mean values were compared using the Tukey test.

Photoelastic test
The samples for the photoelastic tests were produced by the impression of the 2 pieces of the polyurethane mandible replica with SSRO in a silicone impression material (Clássico Artigos Odontológicos Ltda., São Paulo, Brazil). A total of 3 identical photoelastic models were made from the resin GY-279 mixed with the catalyzer HY-2963...
(Araltec Produtos Químicos Ltda., Guarulhos, SP, Brazil), 1 for each of the 3 tested groups.

The photoelastic models were taken to a plane polariscope (Eikonal Instrumentos Ópticos Comércio e Serviço Ltda., São Paulo, Brazil) attached to the Instron 4411 test machine (Figure 4), and submitted to load at the first molar region up to a 3-mm displacement, at 1 mm per minute speed, which presented the best distribution of isochromatic fringes during the pilot tests for stress distribution evaluation. The photoelastic models were photographed before load input to check the absence of residual stress over the models. They were also filmed and photographed after the desired displacement (3 mm) was reached. For this task, the qualitative method of analysis was applied.

Finite element analysis

A human hemimandible similar to the one used in the mechanical and photoelastic tests was constructed based on a DICOM format mandible from the CTI (The Renato Archer Center for Information Technology, Campinas, SP, Brazil) databank, which was previously obtained from a dry mandible subjected to a helical computed tomography scan. The miniplate and screws were computer-simulated based on the physical specimens from Neoortho, presenting the same fixation used in the mechanical and photoelastic tests. The images of the DICOM format hemimandible and of the miniplates/screws were transferred to a Rhinoceros 4.0 (McNeel North America, Seattle, WA), and 3-dimensional hemimandible geometries of the 3 groups were created bearing only the first molar to simplify the model.

The hemimandible geometry was exported to the software Femap version 10.1 (Siemens PLM Software Inc., Plano, TX) for the preprocessing of the finite element (FE) model for the 3 rigid internal fixation techniques studied.

Table I. Characteristics of the 3-dimensional finite element models

<table>
<thead>
<tr>
<th>Model</th>
<th>Elements</th>
<th>Nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid</td>
<td>145,698</td>
<td>219,928</td>
</tr>
<tr>
<td>Inverted L</td>
<td>129,548</td>
<td>194,667</td>
</tr>
<tr>
<td>Miniplate</td>
<td>65,550</td>
<td>100,446</td>
</tr>
</tbody>
</table>

Table II. Mean, standard deviation, and Tukey test—peak load and displacement

<table>
<thead>
<tr>
<th>Sample category</th>
<th>Peak load (kgf)</th>
<th>Peak displacement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid</td>
<td>19.21 (1.91)</td>
<td>B 18.34 (4.62)</td>
</tr>
<tr>
<td>Inverted L Screws</td>
<td>28.30 (4.33)</td>
<td>A 9.20 (2.54)</td>
</tr>
<tr>
<td>Miniplates and screws</td>
<td>4.27 (0.93)</td>
<td>C 5.36 (1.45)</td>
</tr>
</tbody>
</table>

Note: Matching letters (A, B, C) indicate no significant statistical difference.

The tetrahedral elements and 10 nodes of each of the models tested are listed in Table I.

The FE models must have some mechanical properties of the materials that are being simulated. These mechanical properties that regarded them as homogeneous, isotropic, and linear elastic are the Young modulus and the Poisson ratio. The properties from mandibular polyurethane substratum were obtained from a compression test of a specimen in the Instron 4411 and the properties from the titanium alloy provided by the manufacturers. The Young modulus for the mandibular substratum was 624.42 MPa and the Poisson ratio was 0.28. For the titanium alloy, the Young modulus and the Poisson ratio were, respectively, 116,000 MPa and 0.34.

The mandible was constrained in the region of the temporomandibular joint and posterior ramus, as in the other tests, and the load applied to the region of the central fossa of the first molar until a 3-mm displacement was reached. The models were evaluated according to maximum principal stress, whose stress scale measures, in MPa (N/mm²), the general effective stress on a material. For the qualitative analysis, a color scale with 16 stress values was used, varying between −3 and 20 MPa for the hemimandible and −3 to 500 MPa for the miniplates/screws.

RESULTS

Mechanical tests

The hemimandibles were submitted to a linear loading test and the results of peak and final load and displacement were recorded. These values and a summary of the statistical analyses are presented in Tables II and III.

In accordance with the results of mechanical tests, fixation with bicortical screws in an inverted L arrangement has the highest mechanical resistance, both for the peak and the final load values. The hybrid technique
was less resistant than the bicortical screws, and the fixation with miniplate and monocortical screws was the least resistant group.

Regarding peak and final displacements, the highest displacement occurred with the hybrid technique, and for both bicortical screws in the inverted L arrangement and for the miniplates with monocortical screws, there was no statistically significant difference and the displacement value was lower than the one presented when the hybrid technique was applied.

### Photoelastic test

For the hybrid fixation technique (Figure 5), in the photoelastic analysis, the highest stress concentration was found around the bicortical screw, and the fringes dissipate especially toward the distal direction through the mandibular ramus.

In the case of the inverted L arrangement (Figure 6), the highest stress concentration was found in the screws located superiorly and near the osteotomy, with less stress concentration in the screw located inferiorly. The stress distribution in this group presented the highest homogeneity when comparing the 3 groups studied.

In the case of the fixation with miniplates and monocortical screws (Figure 7), the stress concentration was mainly around the screws near the osteotomy, in the proximal and distal segments. In comparison with the

### Table III. Mean, standard deviation, and Tukey test—ending load and displacement

<table>
<thead>
<tr>
<th>Sample category</th>
<th>Ending load (kgf)</th>
<th>Ending displacement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid technique</td>
<td>18.44 (3.74)</td>
<td>19.20 (5.28)</td>
</tr>
<tr>
<td>Inverted L Screws</td>
<td>27.93 (4.18)</td>
<td>9.41 (2.92)</td>
</tr>
<tr>
<td>Miniplates and screws</td>
<td>4.27 (0.93)</td>
<td>5.36 (1.45)</td>
</tr>
</tbody>
</table>

Note: Matching letters (A, B, C) indicate no significant statistical difference.

Fig. 5. Photoelastic test of the Hybrid fixation technique. Image is available in color at www.ooooe.net.

Fig. 6. Photoelastic test of the inverted L arrangement fixation. Image is available in color at www.ooooe.net.

Fig. 7. Photoelastic test of the miniplates and screws fixation. Image is available in color at www.ooooe.net.
hybrid fixation technique, the stress was of higher intensity.

**Finite element analysis**

In the case of the hybrid fixation technique, according to finite element analysis, the area of highest stress concentration was around the screws close to the osteotomy, and for the screw near the osteotomy in the proximal segment, the stress dissipation was mainly from the anterior to the posterior region, in an area of less bone thickness (Figure 8). Intriguingly, in an internal view of the osteotomy, an important area of stress concentration was formed around the bicortical screw, which was the highest stress concentration of the entire fixation system (Figure 9). In relation to the stress generated in the fixation system, an important amount of stress was created in the bicortical screw and in the miniplate close to the screw near the osteotomy in the distal segment (Figure 10).

Regarding the fixation technique with bicortical screws, the stress distribution around the screws was the most homogeneous of the 3 tested groups, mainly when analyzing the finite element model in the buccal view of the distal segment (Figure 11). In the internal view of the proximal segment (Figure 12), an important quantity of stress generated in the simulation was concentrated near the upper screw (Figure 13), with dissipation through the oblique line of the mandible, with little stress around the screw closest to the osteotomy that was the region of the segment with less bone thickness.

The fixation group with a miniplate and 4 monocortical screws had high stress concentration around the screws near the osteotomy, mainly in the screw in the
proximal segment (Figure 14). The stress near this screw in the proximal segment was dissipated in the direction of the osteotomy, which is a region with little bone thickness (Figure 15). When analyzing the stress in the fixation system, the concentration in the miniplate was higher near the region of the osteotomy in the distal segment; however, when evaluating the screws, the stress was concentrated over the screw near the osteotomy in the proximal segment (Figure 16).

**DISCUSSION**

Oral surgeons have adopted the so-called hybrid technique throughout the past few years. Such use has been based on 2 main arguments: improvement of the mechanical resistance of the fixation with miniplates and monocortical screws and facilitated fixation technique, maintaining some of the advantages of the conventional miniplate/monocortical screws fixation technique and combining with the advantages of the bicortical screws technique.

Fixation with bicortical screws was introduced by Spiessl\(^8\) and later made popular by Paulus and Steinhauser.\(^9\) Almost simultaneously, Michelet et al.\(^10\) proposed the fixation of sagittal split osteotomy segments with miniplates and monocortical screws.

The SSRO advancement procedure has a very particular biomechanical feature. As with the advancement of the segments, a gap is produced in the osteotomy area, which requires that load transfer between segments occur mainly through their fixation systems,\(^11\) requesting maximum stability from the fixation system that acts as a compound beam with broad cross sections of bone on the proximal and distal aspects and a thin cross section in which the hardware is attached to the middle (miniplate group), at a few points across the osteotomy site (bicortical screws group) and a combination of both.\(^12\)

The literature has demonstrated that fixation using bicortical screws is more mechanically resistant than fixation with miniplates in in vitro studies. Anucul et al.\(^13\) described that the bicortical screws fixation is 3 times more resistant than miniplates. This result is similar to the one obtained by Hammer et al.\(^14\) Peterson et al.,\(^15\) in a study comparing the different fixation methods of the SSRO advancement, demonstrated that both straight and curved miniplates were less resistant than bicortical screws. Other studies in the literature also found similar results,\(^6,12,16\) which is in accordance with the results of this research.
The advantages of the use of the bicortical screws technique include better mechanical resistance provided mainly by the great contact area between the bone segments, in comparison with the fixation technique with a miniplate and monocortical screws. This type of fixation has disadvantages, however, like the necessity of bone contact between the segments that could be reached only in small advancement cases, the higher risk of nerve injury owing to compression and during drilling, and also condylar flaring in cases of severe mandibular advancement and asymmetries. By adding a bicortical screw to an SSRO fixed with a miniplate/monocortical screws set, the mechanical resistance was improved with statistical significance in this study, although not as much as in the case of 3 bicortical screws. This result is in accordance with other studies, such as Ozden et al. and Shetty et al. From a mechanical perspective, a screw applied bicortically in this retromolar region inhibits the trend toward segment displacement through its resistance to axial and shear stresses. Relative displacements between the mandible segments can be further reduced by widening the separation between the miniplate and retromolar screw, thereby increasing the length of the moment arm.

The decision on placing a screw in the superior border of the mandibular ramus in the hybrid technique is based on research (Obeid and Lindquist, for instance) that demonstrated, in an anatomic study of human cadaveric mandibles, that the superior border of the ramus was the one with the thickest buccal and lingual cortical bone. The retromolar region, moreover, also has excellent accessibility through an intraoral approach.

The hybrid technique proposed by Schwartz and Relle tried to combine the advantages of fixation with bicortical screws with the advantage of fixation with miniplates and monocortical screws. The bicortical screws added to fixation with a miniplate and monocortical screws increases the mechanical properties of the fixation system; however, in some cases, such as in large advancement, asymmetric movements, and in cases with teeth in the area of the osteotomy, the bicortical screws could or should not be placed because of lack of sufficient bone thickness, mainly in the lingual area of the distal segment of the osteotomy, or by a chance of condylar displacement by mandibular flaring. The resistance and mechanical stability of fixation with 3 bicortical screws can be explained by the photoelastic and finite element analysis owing to good uniformity of stress distribution, that was not concentrated in specific areas of fragility as in other modalities of fixation. The stress areas in the 3 bicortical screws fixation were in areas of greater thickness and bone strength. Also, stress in the fixation system is not as intense as in other groups.

In the case of fixation with miniplates and monocortical screws, as demonstrated in other studies, stress concentration is always higher around the screws near the osteotomy, especially in the proximal segment that has thin bone thickness, which increases the fragility of the fixation system. The evaluation of the stress in the fixation system, which is possible only in the finite element analysis, showed that an important amount of stress is located on the miniplate in the region of the osteotomy, exactly where this hardware works with load-bearing function, which is usually an area of a high risk of fixation failure near the osteotomy.

With less mechanical resistance, the use of miniplates with monocortical screws is widely used by oral surgeons because of its indications and advantages. Advantages include no need for a stab incision, eliminating the possibility of a nerve or vascular injury, the plate bending that passively accommodates the step and positional changes of the bone segments, with little torsion at the level of the condyles, and decreases the possibility of an injury to the inferior alveolar nerve, as the screws are placed monocortically with no compression between the bone segments that could squeeze the nerve.

The stress behavior in the so-called hybrid technique is very interesting, as following the addition of a bicortical screw, a decrease in the stress around the miniplates was detected and an important concentration of stress was created around the bicortical screw. This screw, though, is located in an area where the bone is thicker and more cortical, which provides more stability to the fixation system. Regarding the stress in the fixation system, it was less intense when compared with traditional fixation with miniplate/monocortical screws, which minimizes the possibility of fixation failure because of material fatigue. The stress generated in the bicortical screws was similar to that created in the inverted L arrangement, so the risk of overloading in the bicortical screws was similar to the ones in fixation with 3 bicortical screws.

Important information is related to displacement, which was always higher for the hybrid technique when compared with the other tested groups. This mechanical feature is because the bicortical screw provides higher resistance; in addition, it served as a fulcrum point for the system, and an additional screw does not change the mechanical resistance of the system.

Ochs listed some factors that may influence the use of the RIF, as follows: bone anatomy, osteotomy design, surgical movement, third molars, unfavorable splits, inferior alveolar nerve position, and proximal segment positioning.
For example, in the case of a patient with a high mandibular plane angle and a short ramus, there may not be enough bone between the second molars and the posterior extent of the lingual plate of the distal segment for 3 superior border screws.22,23 Rarely the lingual cortex just below the superior border is very thin, and does not engage well, not providing adequate stability for a bicortical screw fixation. In those cases, a miniplate fixation must be used and can be associated with a bicortical screw to increase stability.

Another case suitable for a hybrid fixation technique is when an advancement beyond 10 mm is present, when inherent increased instability begins to appear, and bone overlap for bicortical screw fixation24,25 is less available. A similar situation occurs in significantly asymmetric SSRO advancement. The side toward which the midline moves normally fits quite nicely with flat, even contacts and it is possible to apply any kind of fixation. The contralateral side is farther advanced, however, and owing to the distal segment’s lingual plate rotating toward that side, considerable flaring of the proximal segment with a sizable anterior gap will be caused. Once the proper proximal segment and condylar position have been determined, then bone reductions should be done to eliminate contact points and interference on the lingual plate of the distal segment. In those cases when the contact between the segments is not so good and presents large movement, the use of a positional screw in the region of minimal gapping and a miniplate with monocortical screw below is indicated, in an attempt to avoid a re-creation of the preexisting asymmetry or intercondylar widening.26

Most surgeons prefer to remove wisdom teeth, impacted or erupted, at least 6 months before orthognathic surgery.27 The presence of the third molar does not impede the procedure, however, and the surgeon should ignore the tooth and guide the osteotomy through whatever portion of the tooth structure is in the way. After completing the osteotomy, the tooth is removed. The problem is that the third molar leaves a significant bone void with thin cortical, and in those cases, the hybrid technique is used with a miniplate/monocortical screws with an additional bicortical screw in an area with adequate bone stock.

Although the hybrid technique has many advantages and indications, as described previously, some surgeons still prefer the original techniques (bicortical screws or miniplate with monocortical screws), as some of the advantages of fixation with miniplates could be lost with the insertion of a bicortical screw. For example, with the use of a bicortical screw, even in the positional technique, there is torsion at the level of the condyles and a risk of compression of the inferior alveolar nerve, although more evident in the lag screw technique.

Sometimes the bicortical screw is not so easily inserted intrabucally, and a stab incision is needed, and another advantage of the miniplates is lost. Also, the removal of the fixation, in case of infection, for example, becomes difficult, and in some cases, cannot be done under local anesthesia.28

**CONCLUSIONS**

According to mechanical tests, the insertion of a bicortical screw associated with a miniplate/monocortical screws system, in a hybrid technique, increases the resistance of the fixation. It is still less resistant than fixation with bicortical screws, however. The improvement in mechanical resistance is also followed by better stress distribution around and through the fixation. Besides the better in vitro results of the fixation techniques that use bicortical screws, oral surgeons should always consider the clinical characteristics of each case, as discussed in this article, to choose the better fixation technique.

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**REFERENCES**


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