



# **Evaluation of the Different Methods for Fixation of Sagittal Ramus Split Osteotomy of the Mandibular Ramus in Relation to Stability for Mandibular Advancement: A Systematic Review**

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## **Authors' contributions**

*This work was carried out in collaboration among all authors. Author NME designed the study and managed the literature searches. Authors LRB and LN performed the literature searches as well the literature evaluation and wrote the first draft of the manuscript. Authors EAGJ, GG and RC reviewed the draft and edited it to improve the quality of the paper. All authors read and approved the final manuscript.*

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## **ABSTRACT**

**Aims:** The purpose of this study was to perform a systematic review of the literature on the different fixation methods available for sagittal ramus split osteotomy associated with mandibular advancement tested *in vitro* to evaluate stability of each method.

**Study Design:** Systematic review.

**Methodology:** Following the PRISMA model for systematic reviews, a query was made in the PubMed, Bireme and Cochrane Library databases, identifying articles that reported the different fixation methods for sagittal ramus split osteotomy for mandibular advancement.

**Results:** A total of 352 articles were identified, 11 papers of which, after evaluation in relation to the inclusion and exclusion criteria, were systematically reviewed.

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**Conclusion:** Sagittal ramus split osteotomy is a technique performed for the treatment of mandibular discrepancies in which the methods for fixation of the segments are quite varied. In view of the biomechanical studies, the hybrid technique is the most indicated method, while miniplates with monocortical screws present less stability.

*Keywords: Orthognathic surgery; sagittal split ramus osteotomy; mandibular advancement; fixation.*

## 1. INTRODUCTION

Bilateral sagittal split osteotomy (BSSO) was developed in the early 1950s, on an experimental basis, with poor results and high rates of surgical complications, being described for the first time by Obwegeser in 1955 [1]. This procedure consists of a common and successful technique performed in oral and maxillofacial surgery for the treatment of mandibular discrepancies [2-4].

The methods for the fixation of the proximal and distal segments in the sagittal ramus split osteotomy are quite varied [3]. These range from techniques employing steel-wire osteosynthesis, referred to as non-rigid internal fixation, to the progression towards more modern and current methods, which are classified as rigid internal fixation (RIF), such as miniplate systems and conventional, compressive or locking screws [5].

The development of studies regarding the type of fixation in the mandible has been put in practice by a number of researchers, who use different methodologies for their analyses [2,5,6]. When performing biomechanical tests, the main challenge consists of simulating the facial bones with muscle forces and movements [5].

Thus, because there is no unanimous consensus in the literature to support the claim that an ideal

fixation method has been found for sagittal ramus split osteotomy, the purpose of this study was to conduct a systematic review of the different fixation methods available for sagittal ramus split osteotomy in mandibular advancement subjected to in vitro testing.

## 2. METHODOLOGY

Following the PRISMA model for systematic reviews, the literature search was performed using the PubMed, Bireme and Cochrane Library databases, identifying articles that provided reports on the different fixation methods of the sagittal split osteotomy for mandibular advancement. The terms used for the research were "orthognathic surgery," "sagittal split osteotomy," "sagittal split ramus osteotomy" and "fixation method" (Table 1).

Inclusion criteria were complete articles in the English language, published until August 2017, presenting in vitro research with Class II patients submitted to BSSO, mandibular advance and RIF, excluding case reports or series of cases. Additionally, among the articles initially selected, those that did not present other surgical interventions were maintained. The exclusion criteria included all (1<sup>o</sup>) duplicate articles; (2<sup>o</sup>) articles present on two or in the three database platforms used; (3<sup>o</sup>) articles published in a

**Table 1. Terms used in the search for articles in the respective databases**

Database	MeSH terms
PubMed	((("orthognathic surgery"[MeSH Terms] OR ("orthognathic"[All Fields] AND "surgery"[All Fields]) OR "orthognathic surgery"[All Fields]) AND (sagittal[All Fields] AND split[All Fields] AND ("osteotomy"[MeSH Terms] OR "osteotomy"[All Fields]))) OR ("osteotomy, sagittal split ramus"[MeSH Terms] OR ("osteotomy"[All Fields] AND "sagittal"[All Fields] AND "split"[All Fields] AND "ramus"[All Fields]) OR "sagittal split ramus osteotomy"[All Fields] OR ("sagittal"[All Fields] AND "split"[All Fields] AND "ramus"[All Fields] AND "osteotomy"[All Fields])) AND (fixation[All Fields] AND ("methods"[MeSH Terms] OR "methods"[All Fields] OR "method"[All Fields]))
Bireme	(tw:(orthognathic surgery)) AND (tw:(sagittal split osteotomy)) OR (tw:(sagittal split ramus osteotomy)) AND (tw:(fixation method))
Cochrane	("orthognathic":ti,ab,kw and "sagittal split osteotomy":ti,ab,kw and "sagittal split ramus osteotomy":ti,ab,kw and "fixation":ti,ab,kw (Word variations have been searched)

language other than English; (4<sup>o</sup>) articles that mentioned treatment for class III patients; (5<sup>o</sup>) articles that consisted a literature review or case report; (6<sup>o</sup>) articles that had a focus other than fixation in the mandible (trauma, osteotomy, pathology, others); (7<sup>o</sup>) articles presenting in vivo human or animal research and (8<sup>o</sup>) articles with finite element analysis. The in vivo human studies are going to be evaluated in another study according to the registration number CRD 42018099683 in Prospero, the International prospective register of systematic reviews.

### 3. RESULTS

With the terms defined for the research, 352 articles were identified, of which 11 papers, after evaluation in relation to the inclusion and

exclusion criteria, were systematically reviewed, as shown in the Prism diagram for systematic reviews (Fig. 1), the specific characteristics of each research developed being obtained.

In order to mimic the mandible, 9 papers used mandible replicas in polyurethane, 1 used a dissected mandible, and 1 used only two resin plates. Most studies, i.e., 7 studies, presented a mandibular advancement of 5 mm, as well as 1 with 4 mm, 1 with 6 mm, 1 with 7 mm and 1 with 8 mm. In 5 surveys, the test machine used was Isotron (model 4411, 4202 or 4465), while 1 used MTS, 1 used Autograph, 1 used EMIC, and 3 did not specify the test machine. An in-depth description of the fixations used and the results of each survey are given in Table 2.

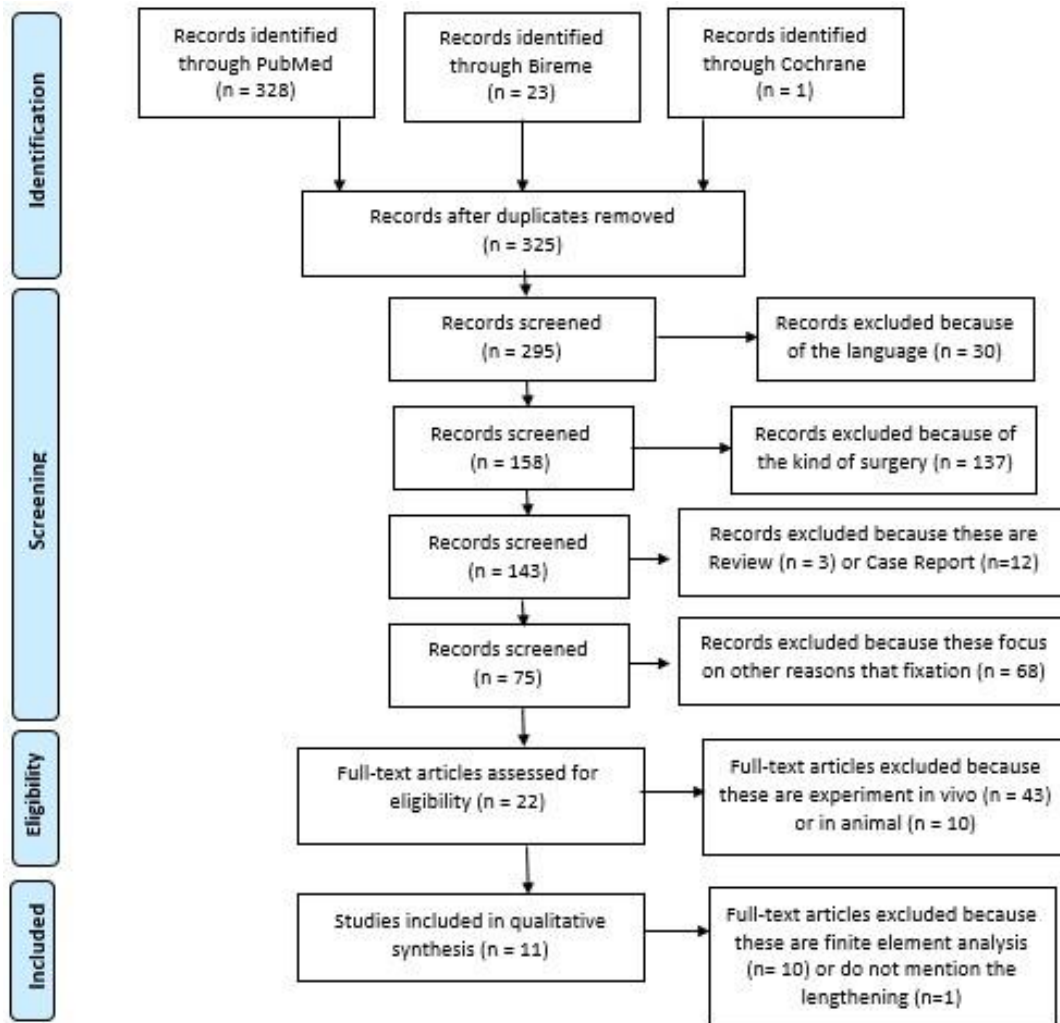


Fig. 1. Prism flow diagram

**Table 2. Detailed description of the variables evaluated in the papers included in this study**

Author	Year	Skull	Study model	Mandibular advancement	Applied force (N)	Machine	Results
Obeid et al. [7]	1991	Six dry human mandibles	6 mandibles received 3 screws at the upper edge and 3 at the lower edge, with each mandible receiving an equal amount of 2.0 or 2.7 screws. Half of the perforations received countersinking.	5 mm	No force applied	NE	Screws in perforations without countersinking showed satisfactory retention, with thread involvement in the vestibular cortical bone, for both 2.0 mm and 2.7 mm. Good lingual cortical retention was observed in both screw sizes, although 2.0 showed better performance. The location with best retention was in the anterosuperior perforation. Alteration in intercondylar distance was found in all mandibles, and there was decrease in one and increase in others.
Shetty et al. [8]	1996	Human mandible as model for 9 replicates	Replica 1: three 2.4 mm bicortical screws (Synthes Maxillofacial, Paoli, PA) in a straight line at the top edge; Replica 2: TiMesh Plate (TiMesh Inc., Las Vegas, NV); Replica 3: TiMesh Plate (TiMesh Inc., Las Vegas, NV), with one bicortical screw at the top edge; Replica 4: one eight-hole Leibinger 3D plate (Leibinger& Fischer LP, Irving, TX); Replica 5: eight-hole 3D Leibinger plate (Leibinger& Fischer LP, Irving, TX) with one bicortical screw at the top edge; Replica 6: four-hole Leibinger 3D plate (Leibinger& Fischer LP, Irving, TX) with one bicortical screw at the top edge; Replica 7: Two Stortz miniplates (Maxillofacial Stortz, St. Louis, MO), with four holes each; Replica 8: Two Stortz miniplates (Stortz Maxillofacial, St. Louis, MO), four holes each, with one screw at the top edge; Replica 9: one Stortz miniplate (Stortz Maxillofacial, St. Louis, MO), four holes, with one bicortical screw at the top edge.	7 mm	22 kgf	NE	Osteosynthesis with miniplates and a bicortical screw was more stable than with the miniplate alone. Comparisons of the instability factor showed that the models with a miniplate and one bicortical screw were more stable than with 3 2.4 mm bicortical screws (gold standard used). Mini-plate systems alone presented less stable test results, with different failure rates between systems. Thus, the exclusive use of miniplate fixation may not provide the stability required for functional restoration shortly after the BSSO. The addition of the bicortical screw in the retromolar region increases the stability of the fixation with miniplates. The use of bicortical screw miniplates offers technical advantages and stability over conventional fixation. The stability of the bicortical screw attachment is independent of the miniplate system used.

Author	Year	Skull	Study model	Mandibular advancement	Applied force (N)	Machine	Results
Brasileiro et al. [9]	2009	60 replicates of human hemimandibles in polyurethane	Group 1: one straight plate with four 6 mm 2.0 monocortical screws; Group 2: one plate with four 6 mm 2.0 screws and one 16 mm bicortical screw; Group 3: three 16 mm 2.0 bicortical screws positioned in an inverted-L pattern.	5 mm	Individual forces to move segments 1 mm, 3 mm, 5 mm and 10 mm	Instron 4411 (Instron Corp, Norwood, MA)	Group 1 showed lower strength values when compared to other fixation techniques ( $p < 0.01$ ), irrespective of force direction. Group 3 showed greater resistance than group 2, with $p < 0.01$ . For molar loading, groups 2 and 3 showed no significant difference. For a 5 mm mandibular advancement, RIF with 3 inverted-L bicortical screws is the most stable in the laboratory. It is suggested that the installation of a bicortical screw in the retromolar region can optimize the resistance of the miniplate with monocortical screws.
Ribeiro Jr et al. [5]	2010	45 replicates of human hemimandibles in polyurethane	Group A: one four-hole straight miniplate; Group B: one four-hole straight locking miniplate; Group C: one four-hole straight miniplate and one bicortical screws; Group D: one four-hole straight locking plate one bicortical screw; Group E: one six-hole straight miniplate; Group F: one six-hole straight locking miniplate; Group G: two four-hole straight miniplates; Group H: two four-hole locking miniplates; Group I: three bicortical screws in an inverted-L pattern. All 2.0.	4 mm	Individual forces to move segments 3 mm	Universal testing machine (model 4202; Instron, Norwood, MA)	There was a statistically significant difference between the groups that used 2 miniplates (Groups G and H) and those that used one miniplate and one bicortical screw (Group C and D) and only bicortical screws (Group I) when compared to those that used 1 miniplate with 2 screws per segment (Group A and B) and a miniplate with 3 screws per segment (Group E and F). The use of a bicortical screw in the retromolar region increases the horizontal and vertical resistance to displacement. Thus, the installation of screws in the retromolar region, with or without monocortical screws, promote better stabilization of the bone segments. Although there was no statistically significant difference between the conventional and locking fixings, the locking miniplates presented better performance in bone fixation in all groups.

Author	Year	Skull	Study model	Mandibular advancement	Applied force (N)	Machine	Results
Sato et al. [10]	2010	50 replicates of human hemimandibles in polyurethane	Group 1: three screws at 90° in a straight line; Group 2: three screws at 60° in a straight line; Group 3: three screws in an inverted-L pattern; Group 4: one titanium miniplate. All 2.0.	5 mm	Forces to move up to 3 mm (1 mm/min)	Instron 4411 (Instron, Norwood, MA)	Groups 1 and 3 showed greater resistance to forces, followed by Groups 2 and 4. Regarding the stress distribution under photoelastic analysis, the most fragile areas were found near the osteotomy and in the lower mandible region in Groups 1 and 3. In the case of Group 2, it occurred around and between the screws. In the case of Group 4, it occurred around the screws near the osteotomy and more distally. Thus, under the conditions tested, Groups 1 and 3 offered a more favorable behavior.
Matsushita et al. [14]	2011	Two polyoxymethylene resin plates	Model 1: four-hole PLLA straight plate; Model 2: four-hole PLLA square plate; Model 3: four-hole PLLA straight plate and an L-plate; Model 4: four-hole PLLA square plate and one L-plate.	6 mm	50-150 N	Mechanical testing machine (Autograph; Shimadzu Co., Ltd., Kyoto, Japan)	There was some level of deformation in model 1, according to the increase in the applied force, with plate fracture, but without fracture of the screws. In model 3, almost the same deformation as in model 1 was observed. In model 2, the plate and screw were ruptured. There were no significant effects on model 4. The increase in the L-plate significantly improved the rigidity of the four-hole PLLA straight plate.
Molon et al. [11]	2011	20 replicates of human hemimandibles in polyurethane	Group 1: three titanium bicortical screws, system 1.5, in an inverted-L pattern; Group 2: three titanium bicortical screws, system 2.0, in an inverted-L pattern.	5 mm	1 kN	MTS servo hydraulic testing machine (MTS Systems Inc., Minneapolis, MN)	None of the variables were statistically significant in the effects of force, although the time to fracture was higher for 2.0 screws. In all cases, there was failure of the synthetic bone before evidence of screw failure. There was no significant difference between 1.5 and 2.0 screws in the applied force until failure. There was no fracture of the 1.5 screws. The 1.5 mm diameter inverted-L screws have as much stability and mechanical strength as the 2.0 screws and can be safe for this procedure.

Author	Year	Skull	Study model	Mandibular advancement	Applied force (N)	Machine	Results
Hwang et al. [12]	2012	Replicates of human hemimandibles in polyurethane	Group 1: one titanium miniplate with four titanium screws (2 mm in diameter); Group 2: three resorbable screws in a straight line in the retromolar region; Group 3: two resorbable screws in the retromolar region and one resorbable screw in the body of the mandible; Group 4: two resorbable screws in the retromolar region and one resorbable screw in the angle of the mandible; Group 5: three resorbable screws in the retromolar region and one resorbable screw in the body of the mandible; Group 6: three resorbable screws in the retromolar region and one resorbable screw in the angle of the mandible; Group 7: three resorbable screws in the retromolar region, one resorbable screw in the angle of the mandible, and one resorbable screw in the body of the mandible.	5 mm	Loading cells 50-kN	Instron universal testing machine (model 4465; Instron Corp, Norwood, MA)	All groups with more than 3 resorbable screws were more rigid than Group 1. Group 7 showed greater biomechanical stability than Group 1, 2, and 3. Groups 4 and 6 exhibited a trend of greater stability than the fixation of Group 5 and 7. Fixation with Group 4 may offer greater biomechanical stability than Group 1 and may offer similar rigidity as that of 7.
Lima et al. [13]	2014	20 replicates of human hemimandibles in polyurethane	Group 1: three cannulated bicortical titanium screws (2.3 mm in diameter) in an inverted-L pattern; Group 2: three solid titanium bicortical screws (2.3 mm in diameter) in an inverted-L pattern.	5 mm	Individual forces to move segments 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 7 mm and 10 mm	NE	The highest value of stress in the proximal segment was found around the upper and lower anterior screws, with minimal stress distribution in the upper posterior screw. In both groups, the screws that exhibited the highest crack concentrations were those close to the anterior region of the fracture. Group 2 showed cracks in the mandibular branch, showing dissipative forces in the mandibular condyle, which may be a clinically a factor that increases the risk of fracture in this region. Group 1 presented better results than Group 2 in mechanical test of 1mm of displacement and in photoelastic test and a viable option for fixation of BSSO may be considerable.

Author	Year	Skull	Study model	Mandibular advancement	Applied force (N)	Machine	Results
Oguz et al. [2]	2015	60 replicates of human hemimandibles in polyurethane	Group 1: two four-hole titanium miniplates parallel to each other, with monocortical screws (6 mm), 2.0 mm in diameter; Group 2: one four-hole titanium plate and monocortical screws (6 mm), 2 mm in diameter. Group 3: one four-hole titanium plate with four monocortical screws (6 mm), 2 mm in diameter, and one additional bicortical (10 mm) 2.0 screw positioned posteriorly to the plate. Group 4: one eight-hole titanium plate with eight monocortical screws (6 mm), 2 mm in diameter. Group 5: one four-hole titanium locking plate (6 mm), 2 mm diameter. Group 6: on six-hole titanium miniplate with 6 monocortical screws (6.0 mm), 2 mm in diameter.	5 mm	5N until the moment of weakening (moving 1, 3 and 5 mm)	Universal testing machine (Instron Universal 4411; Instron Corporation, Norwood, MA)	For mandibular advancements of 5 mm, the resistance forces measured in displacements of 1, 3 and 5 mm were significantly higher for Group -3 and Group 4.
Oliveira et al. [3]	2016	60 replicates of human hemimandibles in polyurethane	Group 1: one four-hole miniplate with 2.0x6.0 mm screws; Group 2: one six-hole miniplate with 2.0x6.0 mm screws; Group 3: two four-hole miniplates with 2.0x6.0 mm screws; Group 4: one eight-hole mini-plate with 2.0x6.0 mm screws; Group 5: hybrid technique with one four-hole miniplate with 2.0x6.0 mm screws and one 12 mm bicortical screw in the proximal segment, 5 mm distally from the second molar and above the edge of the mandible. Group 6: one locking miniplate with 2.0x6.0 mm screws.	8 mm	Loading cell of 10 KN	Mechanical test machine (EMIC model DL2000 – Brazil)	When comparing the types of fixation, according to the amount of displacement 1 and 3 mm, Group 1 X Group 2, Group 3 X Group 4, Group 5 X Group 6, all of them with statistically significant difference. With a 5 mm displacement, Group 6 X Group 3 was not significant, and comparisons between all the other groups were significant. For these three degrees of displacement, fixation with Group 3 and Group 4 showed higher resistance values.



The lack of compatibility between the research methodologies included in this study made it impossible to perform a meta-analysis.

#### 4. DISCUSSION

With this systematic review, it was found that, as well as the fixation methods available, the methodologies of the analyzed studies are quite varied, for example the type of machine used to evaluate the stability of osteosynthesis material, often making it impossible to establish parameters of comparison between them. Nevertheless, it was possible to discuss some topics in order to help elucidate the most effective methods, providing a basis for their choice.

In this review, we included only *in vitro* studies because it is a part of series study of fixation in sagittal ramus split osteotomy. In order to better represent the stomatognathic system, generating conditions closer to the real and more accurate results, the most current studies were performed on polyurethane mandibles [2,3,5,8-13]. Only one was performed with 6 dissected mandibles [7]. It can be said that the use of artificial mandibles made with a material whose features are similar to human mandibles allows researchers to have no worries about ethical issues.

The combination of the conventional plate and screw may not be sufficient to provide the required stability in BSSO [8-10]; however, a bicortical screw in the retromolar region (hybrid system) improves this stability and would have better clinical indication according to *in vitro* results, as presented by Shetty et al. [8], Brasileiro et al. [9] and Ribeiro-Júnior et al. [5].

In the comparison between conventional and locking plates, Ribeiro-Júnior et al. [5] tested the two isolated systems with one plate only, one plate and one bicortical screw, two plates, and two plates and one bicortical screw and found that the locking system improves the performance of the fixation, irrespective of the number of plates or whether there was the addition of the bicortical screw in the retromolar region. According to Oguz et al. [2] and Oliveira et al. [3], the locking system was evaluated as the best fixation system when compared to conventional four- or six-hole straight plate.

Although the use of the plate is already consolidated as a fixation option, the use of

screws alone has been discussed in the literature focusing in an inverted-L pattern. Brasileiro et al. [9] used, in one of the experimental groups, bicortical screws distributed in an inverted-L pattern, which comprised the group of greatest stability. Ribeiro-Júnior et al. [5] also evaluated bicortical screws distributed in an inverted-L pattern, finding that this fixation was more stable than a conventional straight plate or that a four- or six-hole locking plate. Lima et al. [13] compared fixation with 2.3 screws arranged in an inverted-L pattern with channeled screws arranged in an inverted L pattern. Between the two types, the conventional type has smaller biomechanical test values and photoelastic test results than the channeled type, despite being stable. It can then be said that the use of inverted-L 2.0 screws is a plausible option.

As for the comparison between screw diameter, Molon et al. [11] verified 1.5 and 2.0 mm, both distributed in an inverted-L pattern. After the application of forces, they observed that both fixations are resistant and that the synthetic bone failed before any failure of the screws. They claimed, therefore, that the 1.5 mm diameter has stability and resistance similar to the 2.0 mm, being suitable for sagittal split osteotomy osteosynthesis. The 2.0 mm diameter was also compared to 2.7 mm [7] regarding the involvement of the lingual cortical plate, showing that 55% of the 2.7 and 27% of the 2.0 involved this, becoming, therefore, compression screws. Shetty et al. [8] used screws 2.4 mm, and Lima et al. [13] used 2.3 mm screws, both evaluating the position and quantity of screws, as well as the researchers who used 2.00 mm [2,5,9,10,12]. This confirms the fact that the diameter of the screw is not a questionable point, and the ideal diameter of 2.0 mm is already established for fixation of osteotomy in the mandible.

As for the resorbable system, Matsushita et al. [14] used two plates of polyoxymethylene resin to mimic the mandible and observed a 6 mm advance, applying four methods of fixation, namely: (I) four-hole bioabsorbable poly-L-lactic acid (PLLA) straight plate; (II) four-hole PLLA square plate; (III) four-hole PLLA straight plate and one L-plate; and (IV) four-hole PLLA square plate and one L-plate. They showed that after application of force, there was deformation of the plate without change in screws in I and III, deformation of the plate and screw in III, and no significant changes in IV, suggesting that, in a resorbable system, the addition of the L-plate improves the rigidity of the straight plate.

Hawngnet al. [12] compared the resorbable system with that of titanium and found that the use of three or more resorbable screws provided greater rigidity than a titanium miniplate with four 2.0 screws. Using three screws in the retromolar region, one at the angle and the other at the body of the mandible, greater biomechanical stability was observed, and by placing two screws in the retromolar region and one at the mandibular angle, greater biomechanical stability was obtained than with the titanium system, as well as rigidity similar to the use of the five resorbable screws. Then, according to the few papers, the resorbable plates and screws could be an option for fixation with limitations.

In light of the fixation methods addressed and considering the *in vitro* studies, the hybrid system involving a four-hole locking or conventional miniplate with four locking or conventional monocortical screws associated with a conventional bicortical screw presented greater stability to the sagittal split osteotomy *in vitro* studies for the advancement movement. Another fairly stable method using miniplates to the detriment of the three bicortical screws is that of two conventional four-hole straight miniplates and four conventional monocortical screws. Nevertheless, surgical access to their placement would be much more invasive and unnecessary since other methods of fixation as efficient as this one or more are available. If a choice is made to use only a miniplate, the surgeon may choose to use a six-hole conventional or locking sagittal plate or a four-hole locking plate. In our experience team, some surgeons who have used the option of one 4-hole straight plate 2.0 alone, others have chosen two parallel 4-hole straight plate 2.0, and others have taken the hybrid technique. All the alternatives have given satisfactory stability, depending on the surgeon experience.

## 5. CONCLUSION

Based on the data found in the literature review on the fixation methods for BSSO and mandibular advancement, it was possible to conclude that, in relation to stability:

- The hybrid technique, composed of the conventional or locking system, was found as the most stable method and presented better performance in the fixation of the segments, based on biomechanical studies.

- The fixation by means of three bicortical lag screws or otherwise, in an inverted-L pattern, presented excellent results in the *in vitro* / biomechanical tests.
- The osteosynthesis technique using only a miniplate with monocortical screws, irrespective of size, shape, type of plate and number of screws, presented the lowest stability based on biomechanical studies.

## CONSENT

Informed consent was not needed for this paper as it did not involve patient.

## ETHICAL APPROVAL

Ethical approval was not needed for this paper as it did not involve patient or animal.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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