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Original Article

Comparison of strengths of five internal fixation methods used after bilateral sagittal split ramus osteotomy: An *in vitro* study

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ABSTRACT

Background: Results on the strength and displacement of internal fixation methods for bilateral sagittal split ramus osteotomy are controversial, and some designs have not been adequately studied. Therefore, this study was conducted to compare techniques using bicortical or monocortical screws.
Materials and Methods: In this *in vitro* study, 35 sheep hemi-mandibles were randomly assigned to five groups of seven each: fixation using (1) a 13 × 2 screw, (2) two 13 × 2 screws (arranged vertically), (3) three 13 × 2 screws, (4) 1 plate with 4 holes and four monocortical screws, and (5) a Y-shaped plate and five monocortical screws. Specimens underwent vertical forces until failure. Breakage forces and displacements of groups were recorded and compared statistically. Using one-way analysis of variance (ANOVA) with a Tukey's *post hoc* test and Kruskal–Wallis test. Level of significance was predetermined as 0.05.
Results: Strengths of Groups 1–5 were, respectively, 14.43 ± 4.35, 28.00 ± 8.89, 28.29 ± 8.01, 29.43 ± 8.24, and 61.29 ± 12.38 N, respectively (P = 0.000, analysis of variance). The corresponding displacement extents were 7.98 ± 0.04, 7.85 ± 0.26, 8.00 ± 0.00, 7.35 ± 1.73, and 6.79 ± 2.03 mm (P = 0.298, Kruskal–Wallis test).
Conclusion: Use of a single bicortical screw is the weakest method, while Y-shaped plates might provide the highest strength. Using two or three bicortical screws or 4-hole plates might deliver similar strengths.

Key Words: Bone plates, fracture fixation, internal, sagittal split ramus osteotomy, surgical fixation devices

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INTRODUCTION

Bilateral sagittal split ramus osteotomy (BSSRO) is commonly practiced and benefitted from a broad contact between the osteotomized segments, allowing a sufficient and accurate contact, and enhancing stability and repair.[1] The osteotomized sections should be fixed in order to allow repair to occur; they can be successfully fixed with various techniques and tools such as metal plates and/or screws,[2-5] namely stable internal fixation which is positioned in direct contact with the bone, enabling it to function during repair,[6] which reduces the need for maxillomandibular blocks.[1,6,7] This technique needs varying sizes and types of instruments such as positional or compressive screws, monocortical plates, or their combination.[1,3,8-10]

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However, there are cases in which bicortical screws are not advisable; these include extreme advancements of the mandible, or asymmetrical mandibular motions, which might decrease the bone contact between the osteotomized segments.[1] Although less severe cases can be managed by grafting or compensatory wear and tear, severe extents of mandibular movement might be the cases of using altered designs such as plates and monocortical screws (or a combination of mono- and bi-cortical screws), which might have some advantages; for example, they are easier to install/correction/removal, do not need skin incisions, can exert smaller torques to the proximal segment, and reduce the probability of neurovascular damage.[1,7,11,12]

Various combinations of plates and screws have been compared in *in vitro* studies[13-19] which have shown controversial results. Moreover, some designs have not been studied adequately. Therefore, this *in vitro* study was conducted to comparatively evaluate the strength and displacement of five different designs of internal fixations in BSSRO of sheep mandibles.

MATERIALS AND METHODS

In this experimental *in vitro* study, 35 hemimandibles of sheep (aged between 1 and 2 years old with an average of 1.7 years) were obtained and cleaned off all soft tissues. The sample size was predetermined as five groups of seven specimens each (based on the results of the study of Olivera *et al*.).[1]

Jaws were obtained in frozen and complete form. Their sizes and widths were subjectively checked to be similar. Each jaw was dissected into two left and right hemimandibles from the mandibular symphysis. BSSRO was performed using the standard method in order to move the anterior segment for 5 mm.[1] The specimens were randomly assigned to five fixation groups of seven specimens each: in Group 1, fixation of osteotomy was performed using a 13 × 2 screw placed 20 mm above the mandibular border (taking into account the intra-alveolar canal) and 5 mm posterior to the osteotomy site [Figure 1] and in Group 2, fixation was performed using two 13 × 2 screws (in a vertical linear formation, 10 mm away) positioned 20 and 30 mm above the mandibular border and 5 mm posterior to the osteotomy [Figure 2]. In Group 3, fixation was performed using three 13 × 2 screws at least 5 mm posterior to the osteotomy site, at least 20 mm above the mandibular border, and 10 mm away from each other [Figure 3]. In Group 4, monocortical fixation was performed using 1 plate with 4 holes which was screwed onto the mandible 20 mm above its border, using four 9 × 2 screws [Figure 4]. In Group 5, monocortical fixation was carried out using a Y-shaped plate 20 mm above the border, using five 9 × 2 screws [Figure 5]. Fixations were done with titanium pieces (Behin Ideh Ortoped, Tehran, Iran).

About 7 mm superior to the gonial angle, two 5-mm holes 10 mm away from each other (vertically) were drilled in order to be able to fix the specimens to the testing machine (Zwick Roell, Amsler HCT 25-400, Ulm, Germany). The specimens were attached to

Figure 1: An example from the first group (1 screw).

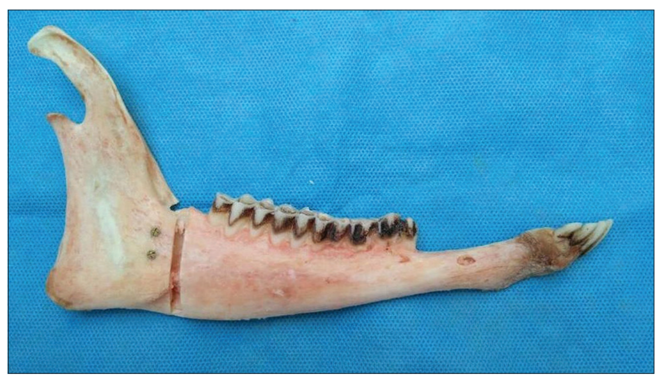

Figure 2: An example from the second group (2 screws).

Figure 3: A specimen from the third group (3 screws).

the machine, using a metal support in a way that the occlusal plane of the hemimandible and the horizontal plane of the machine were aligned parallel. In the area of force application, the hemimandible was supported so that the power cell did not slip and there could be no errors when performing the test. Testing was performed by exerting a progressive vertical force on the second molar [Figure 6] until failure and breakage of the fixation or fractures occur through the mandible [Figure 7]. At the end, the maximum values of the registered forces in the groups as well as their corresponding displacements were measured and reported. In case the specimen did not break, a force equal to 8 mm of displacement would be recorded. The failure threshold was considered as 8 mm displacement.[1] Cases with <8 mm displacement which had fractures were considered unsuccessful as well.

Statistical analysis

Descriptive statistics and 95% confidence intervals (CI) were calculated for force and distribution values of each group. Kolmogorov–Smirnov test was used to check the normality of data. Data regarding force were normally distributed, but displacement data did not follow a normal distribution. Therefore, data force values of five groups were compared using one-way analysis of variance (ANOVA) with a Tukey's *post hoc* test. Displacement values were compared using a Kruskal–Wallis test and a Dunn *post hoc* test (in the case if there is significance of Kruskal–Wallis test). Level of significance was predetermined as 0.05.

RESULTS

The average extents of displacement of all groups except Y-shaped plates were above 7 mm. The average force was similar in the groups "2 screws, 3 screws, and 4-hole plates" around 28 and 29 N. The average force of the group "1 screw" was half of this extent. On the other hand, the average force of Y-shaped plates was about twice larger than the average of the mentioned three groups. Detailed descriptive statistics and 95% CIs are presented in Table 1.

Figure 4: A specimen from the fourth group (4-hole plates).

Figure 5: A specimen from the fifth group (Y-shaped plates).

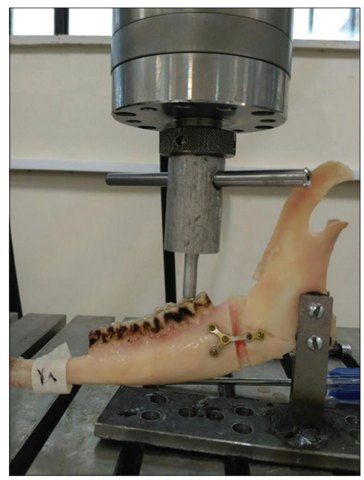

Figure 6: The application of vertical force.

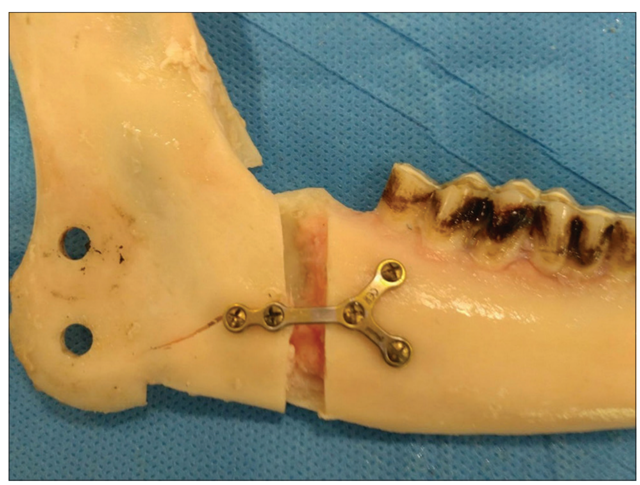

Figure 7: An example of mandible breakage under vertical forces.

Table 1: Descriptive statistics and 95% confidence intervals for breakage force and displacement values

	n	Mean±SD	CV (%)	95% CI	Minimum	Maximum
Displacement (mm)						
1 screw	7	7.98±0.04	0.5	7.95-8.02	7.89	8.00
2 screws	7	7.85±0.26	3.3	7.60-8.09	7.42	8.00
3 screws	7	8.00±0.00	0.0	8.00-8.00	8.00	8.00
4-hole plates	7	7.35±1.73	23.5	5.75-8.94	3.43	8.00
Y-shaped plates	7	6.79±2.03	29.9	4.91-8.67	2.76	8.00
Total	35	7.59±1.22	16.1	7.17-8.01	2.76	8.00
Force (N)						
1 screw	7	14.43±4.35	30.1	10.40-18.45	9.00	21.00
2 screws	7	28.00±8.89	31.8	19.78-36.22	13.00	42.00
3 screws	7	28.29±8.01	28.3	20.87-35.70	17.00	39.00
4-hole plates	7	29.43±8.24	28.0	21.80-37.05	18.00	38.00
Y-shaped plates	7	61.29±12.38	20.2	49.84-72.73	48.00	83.00
Total	35	32.29±17.75	55.0	26.19-38.38	9.00	83.00

SE: Standard error; CV: Coefficient of variation; CI: Confidence interval

ANOVA showed a significant difference between the five force groups (P = 0.000). Tukey's test showed that there were significant differences between all groups, except between specimens fixed with 2 screws versus those fixed with 3 screws, specimens fixed with 2 screws versus those fixed with 4-hole plates, and specimens fixed with 3 screws versus those fixed with 4-hole plates [Table 2 and Figure 8]. Comparison of displacement data using Kruskal–Wallis test did not show a significant difference between the five groups (P = 0.298).

Table 2: Results of Tukey's *post hoc* test comparing force values (*n*)

I	J	Difference (I-J)	*P*	95% CI
1 screw	2 screws	−13.57	0.050	−27.15-0.00
	3 screws	−13.86	0.044	−27.43-−0.28
	4-hole plates	−15.00	0.025	−28.58-−1.42
	Y-shaped plates	−46.86	0.000	−60.43-−33.28
2 screws	1 screw	13.57	0.050	0.00-27.15
	3 screws	−0.29	1.000	−13.86-13.29
	4-hole plates	−1.43	0.998	−15.00-12.15
	Y-shaped plates	−33.29	0.000	−46.86-−19.71
3 screws	1 screw	13.86	0.044	0.28-27.43
	2 screws	0.29	1.000	−13.29-13.86
	4-hole plates	−1.14	0.999	−14.72-12.43
	Y-shaped plates	−33.00	0.000	−46.58-−19.42
4-hole plates	1 screw	15.00	0.025	1.42-28.58
	2 screws	1.43	0.998	−12.15-15.00
	3 screws	1.14	0.999	−12.43-14.72
	Y-shaped plates	−31.86	0.000	−45.43-−18.28
Y-shaped plates	1 screw	46.86	0.000	33.28-60.43
	2 screws	33.29	0.000	19.71-46.86
	3 screws	33.00	0.000	19.42-46.58
	4-hole plates	31.86	0.000	18.28-45.43

CI: Confidence interval

DISCUSSION

In this study, the strengths of five types of mandibular split osteotomy fixation in sheep mandibles were compared *in vitro*. According to the results, all of the fixation techniques succeeded to provide proper stability and strength in the mandible following the application of vertical forces (both in terms of the strengths against the forces and the amount of displacements of fixed parts). However, the highest strength values were found to be in the Y-shaped plate fixation method (mean 61.29 N), which was significantly higher than all the other fixation methods. Furthermore, the least strength values against force application were observed in fixation with 1 screw (mean 14.43 N), which was significantly lower than other fixation methods. On the other hand, fixations with 2 screws, 3 screws, and 4-hole plates had similar breakage strengths. These observations were in line with displacement extents, with the Y-shaped fixation method having the highest strength values, also showing the least displacement (average displacement of 6.79 mm), although no overall significant difference was observed between the methods, probably because of the maximum limit of 8 mm imposed in the measurement of displacement. In order for the fixation or bone to fail, a sudden drop in the biomechanical resistance might be needed. In some specimens, the applied forces increased gradually and the displacement occurred without reaching the maximum force values, hence no failure. In such specimens, the final displacement (at 8 mm) was considered as the point of failure.[1]

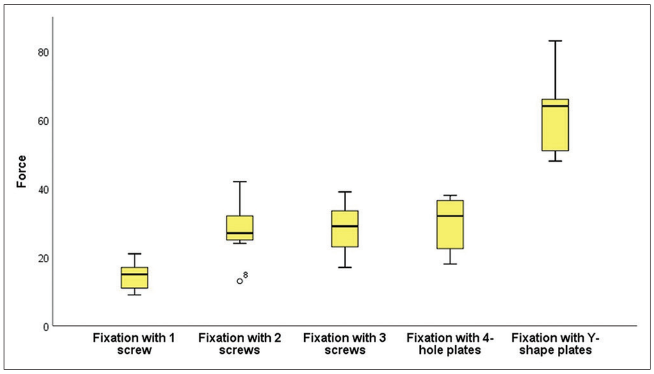

Figure 8: Boxplots presenting nonparametric descriptive statistics for breakage forces (N).

Nonetheless, the 8-mm displacement might not accord with clinical evidence; Ardary *et al*.[20] argued that the range of failure should be considered to be 1 mm, instead of the currently mentioned value of 8 mm.[1] *In vitro* biomechanical tests are a useful tool for evaluating the strength of fixations and the extent of displacement of osteosynthesis materials before their clinical applications. Although the anatomy of sheep or cow mandible differs from that of human mandible, they can provide high reproducibility, they are economic, their resistance might not change by months of freezing, and their use is one of the best options.[1,5,15,16,21,22] To simulate the effects of human osteotomy on the sheep's mandible, changes to the surgical protocol should be made, such as the medial inclination of the incision and the incision under the mandibular foramen. However, it should be taken into account that the data obtained from biomechanical tests combined with the use of bone-like human bones cannot be used directly for clinical applications in humans. Obviously, further clinical studies should be undertaken to verify their results. In addition, in many clinical situations, the surgeon might chose the fixation method based on other factors such as the type of displacement (advance, asymmetry, and rebound) and its extent, as well as the balance between the proximal and distal segments or the type of fracture.

The use of positional screws is the most common method for fixation of sagittal osteotomy. On the other hand, the use of monocortical screws and plates for fixation of sagittal osteotomy has become very common in recent years, and with appropriate results.[3,7,23-25] Furthermore, the use of plates with bicortical screws is also recommended.[2,4,17,26,27] The rigidity and strength of linear systems fixed using bicortical positional screws might be stronger compared to that of miniplate systems with quadruple screws.[4,21] Furthermore, some studies have reported that fixation with bicortical screws has more resistance to displacement.[14,15,28]

The usage of bicortical screws may pose a risk of damage to the lingual nerve, while monocortical systems might least likely damage the nerve.[29] Still, some surgeons prefer bicortical screws because of lower stability, strength, breakage resistance, and rigidity of plates fixed using monocortical screws and their lower resistance to breakage.[30-35] This can be due to the smaller involvement of the bone and/or the smaller surface area of the miniplate exerting a greater pressure.[32] On the other hand, in some studies, the fixation stability of the microplate has been reported as similar to that of bicortical fixation,[36-38] which might be attributed to methodological differences such as the demographics of the samples or techniques of measurements, or the expertise of the surgeons. Recent meta-analyses have shown that skeletal stability obtained by bicortical screws might not differ from miniplate fixation.[39,40] It seems that even the lower strengths of miniplates might suffice to endure clinical stresses because the masticatory forces are much weaker in the recovery period right after the surgery.

A method for increasing the biomechanical strength of fixations is the use of 4-hole miniplates, in which there are two proximal holes fixed with bicortical screws and two distal holes with monocortical screws. Ozden *et al*. showed that the use of this technique has a greater resistance compared to miniplates fixed with monocortical screws.[15] In the present study, fixation with a 4-hole plate yielded breakage strength comparable to those of using 2 or 3 screws, which was a different protocol from that of Ozden *et al*.[15] Our findings were in line with those of Atik *et al*. who showed that 4-hole plates could provide adequate stability compared to other fixation models.[41] On the other hand, findings of Albougha *et al*.[42] do not agree with these research; instead, they indicated that miniplates with T and Y forms had the greatest von Mises stress levels.[42] Sarkarat *et al*. reported that parallel miniplates and 4-hole plates might have the highest stability values, while single screws and 2-hole miniplates had the lowest resistance to posterior forces.[19] This was consistent with the findings of this study. Our results regarding the relative weakness of single-screw fixations were in line with the research of Bohluli *et al*.,[18] Hammer *et al*.,[2] and Sarkarat *et al*.,[19] who demonstrated that single-screw could have the least resistance to breakage. In the present study, breakage forces were similar in fixations using 2 or 3 screws or using 4-hole plates. As well, Olivera *et al*. did not find significant differences between three methods of reverse L pattern with 3 screws, a hybrid of a plate and 4 screws, and two plates fixed using 8 screws.[1]

This study was limited by some factors. In single-screw fixation, the segment should torque or rotate on the axis of screw, which is not a determinant for the strength, while in two or more point fixation, fracture of bone/screw or plate should occur. This was a constraint of all such studies. Although the sample size was predetermined based on a previous study,[1] larger samples could allow detection of more failures and therefore a better estimation of skeletal strength. Moreover, pure vertical forces applied in all *in vitro* studies (like Nieblerova *et al*.[43]) cannot reflect clinical conditions, with mandible movements rapidly changing in magnitude and direction,[44] against which the fixation device should resist.[45] In addition, generalizability of this and similar designs is limited because we have checked the strength under vertical forces only, but BSSO segments are also prone to horizontal and multidirectional stresses in clinical conditions. It should be noted that in clinical conditions, factors such as muscle strength, diet, or demographics as well as surgical protocol and matching the segments can play crucial roles. The distance from the osteotomy site to the area of force application can influence the recorded maximum values of the registered forces. It is better to apply the forces on the occlusal surface instead of a point, if technically possible. The minimum–maximum ranges of the measured forces were very large. However, it was mostly due to outliers because the variations existing in the data were reasonable, as indicated by coefficients of variation.

CONCLUSION

Within the limitations of this study, it was concluded that using a single bicortical screw for fixation of BSSO might be the weakest method, while using the Y-shaped plate attached with monocortical screws could provide the highest strength among the assessed techniques. The use of 2 or 3 bicortical screws or 4-hole plates and monocortical screws might provide similar strengths.

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Conflicts of interest

The authors of this manuscript declared that they have no conflicts of interest, real or perceived, and financial or nonfinancial in this article.

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