Biomechanical Comparison of Four Mandibular Angle Fracture Fixation Techniques

Jose Luis Muñante-Cardenas, DDS, MSc, PhD¹ Luis Augusto Passeri, DDS, MSc, PhD¹

¹ Department of Surgery, School of Medical Sciences, State University of Campinas, Sao Paulo, Brazil

Craniomaxillofac Trauma Reconstruction 2015;8:123–128

Address for correspondence Luis Augusto Passeri, DDS, MSc, PhD, R. Tessália Vieira de Camargo, 126, Cidade Universitária “Zeferino Vaz,” Zip Code 13083-887, Campinas, SP, Brazil (e-mail: passeri@fcm.unicamp.br).

Abstract

The aim of this study was to make a comparison of the biomechanical behavior of four different internal fixation systems for mandibular angle fractures. A total of 40 polyurethane mandible replicas were employed with different fixation methods: group 1SP, one 2.0-mm four-hole miniplate; group 2PPL, two 2.0-mm four-hole parallel miniplates; group 3DP, one 3D 2.0-mm four-hole miniplate; and group 3DPP, one 3D 2.0-mm eight-hole miniplate. Each group was subjected to incisal or homolateral molar region loading. The load resistance values were measured at load application causing tip displacement of 1, 3, and 5 mm, and at the time at which the system achieves its maximum strength (MS). Means and standard deviations were compared among groups using analysis of variance and the Tukey test. Group 2PPL showed higher strength for all the displacements. For incisal loading, no statistically significant differences were found between groups 1SP, 3DP, and 3DPP. For molar loading, group 1SP and 3DPP showed statistically significant differences. For MS testing, group 1SP and 2PPL showed statistically significant differences in incisal loading; group 1SP and 3DP showed no statistically significant differences; and group 3DPP showed lower values of strength. Two parallel miniplates provide the most favorable mechanical behavior under the conditions tested.

Keywords

- mandibular angle fractures
- 3D plates
- compressive strength
- material resistance

The mandible is one of the most affected bones in facial fractures, with a frequency of 36 to 70%.¹ More specifically, the angle is the most frequently fractured region of the mandible.^{2,3}

Ever since Champy et al⁴ adapted the technique of Michelet et al,⁵ surgeons have increasingly used stable internal fixation to treat maxillofacial fractures, achieving highly favorable results. However, despite progress, the treatment of mandibular fractures continues to be associated with multiple complications. In particular, mandibular angle fractures have high rates of postoperative complications.⁶

In this regard, new clinical and biomechanical studies have been used to evaluate and compare the benefits of different fixation techniques used in the reduction of mandibular angle fractures, showing different results.^{7–11} Recently, the use of

three-dimensional (3D) systems has been suggested as an alternative treatment.^{12–14} However, the ideal method for fixation of angle fractures remains controversial.

The purpose of the present study is to make a biomechanical comparison of the most clinically accepted internal fixation systems used to reduce mandibular angle fractures and to compare them with two 3D approaches.

Materials and Methods

This study used 40 replicas of human mandibles made of rigid polyurethane resin (Nacional, Jaú, SP, Brazil) with properly standardized measurements. The fixing material used consisted of 30 straight miniplates (1 mm × 23.5 mm × 5.5 mm) with four holes per miniplate, 10 3D plates

received

April 13, 2014

accepted after revision

April 21, 2014

published online

November 20, 2014

Copyright © 2015 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA. Tel: +1(212) 584-4662.

DOI <http://dx.doi.org/10.1055/s-0034-1393737>. ISSN 1943-3875.

Fig. 1 Prefabricated acrylic resin guides were used to standardize the socket at the bottom of the condyle and coronoid regions (a) as well as the defect-simulating angle fracture (b).

(1 mm × 20 mm × 11.5 mm) with four holes, and 10 3D plates (0.8 mm × 31.5 mm × 10 mm) with eight holes. All screws were part of the 2.0-mm system and included 200 5-mm-long monocortical screws and 40 13-mm-long bicortical screws (Engimplan, Rio Claro-SP, Brazil).

Sample Preparation

All mandible replicas were prepared for testing by drilling a socket at the bottom of the condyle and coronoid regions. The models were uniformly sectioned using a saw. To create defects simulating a typical angle fracture, the following points were marked: point (A) was set in the alveolar process 5 mm posterior to the distal face of the second molar. From this point, a line was traced perpendicular to the mandibular base to point (B), which was located inferior to the mandibular base. A third point (C) was marked 10 mm posterior to point B. The sectioning followed the line from point A to point C. Both sockets and fracture line were standardized for the experiment with the help of a prefabricated acrylic resin guide (→Fig. 1).

Simulated mandibles were passively stabilized. The plates were then applied across the fissure according to the manufacturer's instructions. To standardize the plate position, guides made of acrylic resin were made for each group and applied laterally to polyurethane mandibles during fixation (→Fig. 2).

Group 1SP was fixed with one four-hole miniplate and four 5-mm screws in the region of the oblique line of the mandible,

Fig. 2 A prefabricated acrylic resin guide was used to standardize the position of the plates.

as described by Champy et al. Group 2PPL received two four-hole miniplates arranged in parallel: the miniplate at the top edge was affixed to the mandible with four 5-mm screws; the miniplate at the bottom edge was affixed to the mandible with four 13-mm screws. Group 3DP was fastened in the middle of the buccal surface of the mandible with four 5-mm screws. Group 3DPP was fixed with eight 5-mm monocortical screws installed in the mandibular angle neutral zone (→Fig. 3). Each group was divided into two subgroups of five models. Therefore, each technique was tested with five independent models; each one was used for one testing procedure only.

A single investigator affixed all plates and screws, thus diminishing variation in the fixation techniques. The biomechanical test was performed at the Laboratory of Dental Materials using a universal testing machine (Instron Universal 4411; Instron Corporation, Norwood, MA).

The fixed mandibles were placed in a metal bracket that allowed the samples to be correctly positioned. A 500 Newton (N) load was applied at a fixed point by a device attached to the load cell (→Fig. 4). The machine was programmed to apply a progressive load at a displacement speed of 1 mm/min at the following two points: the first molar or in the central incisors (near and distant point of the system, respectively).

The resistance values were obtained in N when displacement reached 1, 3, and 5 mm and at the time at which the

Fig. 3 Image showing one miniplate on the top edge (1SP), two parallel miniplates (2PPL), 3D miniplate four holes (3DP), and 3D miniplate eight holes (3DPP).

Fig. 4 Sample positioned for mechanical testing in an Instron 4411 machine (Instron Corporation, Norwood, MA).

system achieves its maximum strength for each sample only once. These values were assessed by Tukey test after analysis of variance to detect differences between mean values. SPSS 21 software (IBM Inc., Armonk, NY) was used, with a significance level of 5% for all tests.

Results

The variance analyses showed that group 2PPL had the greatest biomechanical stability with incisal loading. Group 1SP showed the lowest peak load scores compared with other fixation methods, however, no statistically significant differences were found when groups 3DP and 3DPP were compared. No statistically significant difference was found between the groups at 1 mm of displacement while 2PPL plate placement had more favorable biomechanical behavior than the 1SP and 3D groups when displacements were 3 and 5 mm. The results of the statistical analysis are summarized in ►Table 1.

When analyzing the maximum resistance, the group 2PPL showed the best mechanical behavior. Groups 1SP and 3DP

did not show statistically significant differences. Group 3DPP showed the lowest resistance values. The mean and standard deviation of the maximum resistance, as well as the final displacement for each system are shown in ►Figs. 5 and 6, respectively.

In molar loading, no statistically significant differences were found among groups 2PPL, 3DP, and 3DPP at 1 mm displacement. Group 2PPL presented statistically significant higher bending stiffness compared with all the groups when displacements were 3 and 5 mm. Groups 1SP and 3DP showed no statistically significant difference. The results of the statistical analysis are summarized in ►Table 2.

When analyzing the maximum resistance, groups 1SP and 2PPL did not show any statistically significant difference. Similarly, groups 1SP and 3DP showed similar values and without statistical significance. On the other hand, group 3DPP showed lower values of mechanical resistance. The mean and standard deviation of the maximum resistance as well as the final displacement for each system are shown in ►Figs. 5 and 6, respectively.

Table 1 Mean, standard deviation, and statistical comparison of vertical incisal loading in groups analyzed

Group	Vertical incisal loading value		
	1 mm	3 mm	5 mm
1SP	1.62 ± 0.7 ^a	3.88 ± 1.1 ^b	5.79 ± 1.5 ^b
2PPL	2.99 ± 0.4 ^a	7.48 ± 0.9 ^a	11.76 ± 2.6 ^a
3D	1.89 ± 0.7 ^a	4.42 ± 0.6 ^b	6.84 ± 1.8 ^b
3DPP	2.95 ± 1.4 ^a	4.42 ± 1.3 ^b	5.8 ± 0.4 ^b

Note: Different superscript letters in a column indicate statistically significant differences between groups (analysis of variance and Tukey test, $p < 0.05$).

Fig. 5 Mean and standard deviation of the maximum resistance reached for the incisal and molar loading in each group.

Fig. 6 Mean and standard deviation of the vertical displacement upon reaching the maximum resistance for incisal and molar loading in each group.

Discussion

A high percentage of all mandibular fractures involve the angle.^{2,15} Recent epidemiological studies in different regions of the world confirm this marked prevalence.^{3,16} The angle possesses some particular features which differentiates it from other mandibular areas, such as a reduced section area at the fracture line and the presence of impacted teeth, factors that would potentially affect treatment results.² In fact, the treatment of these fractures is associated with high rates of postoperative complications.^{6,15}

Although there are many studies that have analyzed the mechanical behavior of different fixation methods, few have evaluated the 3D systems in the fixation of mandibular angle fractures. To optimize clinical procedures in the treatment of this type of fracture, we studied the mechanical behavior of 3D plates and compared them with conventional fixation techniques.

Although it is true that clinical investigations are most desirable for the study of fixation materials, it is difficult to compare and interpret the majority of clinical results because of differences among study populations.⁹ On the other hand, biomechanical studies can use standardized samples, which eliminate variability seen in populations. This makes such studies a trustable tool in evaluating the resistance of the materials and fixation methods.

Like in other studies^{9,13,17} we chose synthetic polyurethane mandibular replicas a substrate because they are made

of the best material considered the choice material for in vitro studies.¹⁸ Such replicas mimic some of the variables of human mandibular bones, thus representing the anatomy on its real dimensions and proportions.⁹ This standardization eliminates many variables associated with the use of animals and cadaver bones.¹³ In addition, they can be acquired and used quickly, thus avoiding ethical and legal challenges present in the use of other biological substrates.

However, in this study, we observed some difficulties during the preparation of the models, especially during its adaptation to the metal bracket previous to performing the tests. The posterior part of the condyle of many of these mandibles had to be lightly reshaped to correctly position them.

The widely known biocompatibility of titanium, as well as its physical and chemical properties, makes it the material of choice for fixation and osteosynthesis. Titanium plates and screws are easily handled and are adaptable. In addition, they provide excellent primary stability for the surgical reduction of fractures.¹⁹

The fixation methods analyzed in this study were chosen based on the techniques most widely used by maxillofacial surgeons and new treatment proposals for the fixation of mandibular angle fractures. Champy et al⁴ were the first to apply less rigid plates in the treatment of mandibular fractures, recommending the installation of a conventional 2.0-mm plate at the upper edge of the mandibular angle. Clinically, the Champy technique involves a quick and simple intraoral surgical procedure. Subsequent clinical studies have confirmed its effectiveness and, even today, it is the preferred technique of experienced surgeons.^{20,21}

Some authors showed that angle fractures treated using the Champy's technique were particularly vulnerable to torsion forces. To avoid such eventualities, they recommended the use of two plates: one in the tension area and the other in the compression area at the inferior edge of the mandible. In this way, it is possible to achieve a good anatomic repositioning of the fracture, thus avoiding separation and rotation of the segments.^{11,22,23} In accordance with these authors, we found that 2PPL had superior mechanical resistance when compared with 1SP. However, both the groups behaved similarly in the maximum resistance in the molar loading test.

Although fixation of angle mandibular fractures with two plates presents clear biomechanical advantages, it is also linked to a high rate of postoperative complications.^{24,25} In clinical situations, some considerations should be taken in account, such as the use of a trocar to install the second plate. Also, surgical trauma is greater and the procedure time can be longer. In addition, the possibility of bacterial contamination, edema, hematoma, and lesions of the marginal mandibular nerve is also greater.²⁶

Faced with the difficult choice of using one or two plates, new 3D fixation systems have been recently proposed as an alternative treatment of mandibular angle fractures. These plates have a low profile and are strong, but malleable.²⁷ In theory, the 3D design of this plate allows it to stabilize both tension and compression areas that are present in the fractures.¹²⁻¹⁴

Table 2 Mean, standard deviation, and statistical comparison of vertical loading in groups analyzed

Group	Vertical molar loading value		
	1 mm	3 mm	5 mm
1SP	2.56 ± 1.5 ^b	9.66 ± 3.2 ^b	19.19 ± 5.3 ^b
2PPL	6.64 ± 2.5 ^a	17.31 ± 3 ^a	24.93 ± 2.2 ^a
3D	4.06 ± 0.5 ^{a,b}	10.1 ± 0.8 ^b	14.43 ± 0.8 ^{b,c}
3DPP	4.31 ± 1.5 ^{a,b}	8.76 ± 1.6 ^b	11.06 ± 1.9 ^c

Note: Different superscript letters in a column indicate statistically significant differences between groups (analysis of variance and Tukey test, $p < 0.05$).

In an in vitro study, Kalfarentzos et al¹³ evaluated 3D plates of four and eight holes and compared them with fixation methods using one or two plates. The authors reported excellent mechanical behavior of these systems when subjected to flexion and torsion forces. In another study, Alkan et al¹¹ did not find any significant differences when fixations with two plates and the 3D plates with eight holes were compared. In clinical studies, 3D systems demonstrated greater stability and resistance in comparison to one- or two-plate systems.^{12,27,28}

In contrast with these studies, we found that the 2PPL group gave better results. Higher resistance values were obtained by this group for incisal loading, showing a statistically significant difference with all the other groups in displacements of 3 and 5 mm. Similarly, this group also showed the best results for molar loading, with superior resistance values and statistical significance when compared with the groups 3DP and 3DPP.

When we compare groups 3DP and 3DPP we found that both the groups had very close resistance values that were not significantly different for all displacements. Our results support the results reported by Kalfarentzos et al.¹³

In contrast to the results of Alkan et al,¹¹ we found that group 1SP showed better mechanical behavior than 3DPP for displacements of 5 mm with molar loading. This observation could be related to the position and orientation of the plates.²⁹ Thus, 1SP would be installed in a more favorable area, according to the "ideal lines of fixation" described by Champy et al. In contrast, plate 3DPP is much more distant from these lines, installed in a neutral zone. This affirmation can be proven when we analyze the mechanical behavior of 3DP plates. This group, where the plates were installed in a position closer to the "ideal lines of fixation," presented resistance values that were not significantly different from those measured for group 1SP for all displacements, even those greater than 5 mm.

When the maximum resistance of the systems was evaluated, group 3DPP showed the lowest resistance values for both molar and incisal loading; the resistance values were statistically significant when compared with other groups. We believe that the lower profile of the plate (0.8 mm) may be related to the poor performance of the system. For some authors, a lower profile could have been compensated by the bars that interconnect the plates in 3D systems, which are used for strengthening of the structure.²⁸ However, the number of bars present in the evaluated 3DPP plates (four straight and two curved at the edges) apparently did not have a positive influence on the mechanical behavior of them.

Finally, during experimental execution, it was possible to observe a relationship between the lever arm and the mean resistance value found when the force was applied to the molar or incisal region. The greatest resistance was found in the molar area for all the evaluated groups. This can be interpreted as a positive outcome of clinical situations, because the greatest load during mastication are found in this region.³⁰

It is important to note that the laboratory techniques, such as the mechanical assays used in this study, are only auxiliary

methods that determine potential differences among the different fixation systems. Therefore, the results of this study should be prudently extrapolated to clinical situations, where the fracture characteristics, material availability, patient status, surgeon preferences, and other factors should be considered to determine the best treatment method.

In conclusion, the present study demonstrated that two parallel miniplate techniques had statistically greater resistance to compression loads than the Champy technique and 3D fixation systems. In addition, Champy technique and 3DP plates did not show statistically significant differences.

Acknowledgments

This study was supported by FAPESP (Fundação de Amparo a Pesquisa do Estado de São Paulo, Brazil, Grant no. 2011/19737-8). The authors thank Dr. Erika Harth-Chu for her helpful revision of the article.

References

- Hogg NJ, Stewart TC, Armstrong JE, Girotti MJ. Epidemiology of maxillofacial injuries at trauma hospitals in Ontario, Canada, between 1992 and 1997. *J Trauma* 2000;49(3):425-432
- Safdar N, Meechan JG. Relationship between fractures of the mandibular angle and the presence and state of eruption of the lower third molar. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1995;79(6):680-684
- Brasileiro BF, Passeri LA. Epidemiological analysis of maxillofacial fractures in Brazil: a 5-year prospective study. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2006;102(1):28-34
- Champy M, Loddé JP, Schmitt R, Jaeger JH, Muster D. Mandibular osteosynthesis by miniature screwed plates via a buccal approach. *J Maxillofac Surg* 1978;6(1):14-21
- Michelet FX, Deymes J, Dessus B. Osteosynthesis with miniaturized screwed plates in maxillo-facial surgery. *J Maxillofac Surg* 1973;1(2):79-84
- Passeri LA, Ellis E III, Sinn DP. Complications of nonrigid fixation of mandibular angle fractures. *J Oral Maxillofac Surg* 1993;51(4):382-384
- Ellis E III. Treatment of mandibular angle fractures using the AO reconstruction plate. *J Oral Maxillofac Surg* 1993;51(3):250-254, discussion 255
- Schierle HP, Schmelzeisen R, Rahn B, Pytlík C. One- or two-plate fixation of mandibular angle fractures? *J Craniomaxillofac Surg* 1997;25(3):162-168
- Haug RH, Fattahi TT, Goltz M. A biomechanical evaluation of mandibular angle fracture plating techniques. *J Oral Maxillofac Surg* 2001;59(10):1199-1210
- Fox AJ, Kellman RM. Mandibular angle fractures: two-miniplate fixation and complications. *Arch Facial Plast Surg* 2003;5(6):464-469
- Alkan A, Celebi N, Ozden B, Baş B, Inal S. Biomechanical comparison of different plating techniques in repair of mandibular angle fractures. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2007;104(6):752-756
- Feledy J, Caterson EJ, Steger S, Stal S, Hollier L. Treatment of mandibular angle fractures with a matrix miniplate: a preliminary report. *Plast Reconstr Surg* 2004;114(7):1711-1716, discussion 1717-1718
- Kalfarentzos EF, Deligianni D, Mitros G, Tyllianakis M. Biomechanical evaluation of plating techniques for fixing mandibular angle fractures: the introduction of a new 3D plate approach. *Oral Maxillofac Surg* 2009;13(3):139-144

- 14 Hochuli-Vieira E, Ha TK, Pereira-Filho VA, Landes CA. Use of rectangular grid miniplates for fracture fixation at the mandibular angle. *J Oral Maxillofac Surg* 2011;69(5):1436–1441
- 15 Cabrini Gabrielli MA, Real Gabrielli MF, Marcantonio E, Hochuli-Vieira E. Fixation of mandibular fractures with 2.0-mm miniplates: review of 191 cases. *J Oral Maxillofac Surg* 2003;61(4):430–436
- 16 Bormann KH, Wild S, Gellrich NC, et al. Five-year retrospective study of mandibular fractures in Freiburg, Germany: incidence, etiology, treatment, and complications. *J Oral Maxillofac Surg* 2009;67(6):1251–1255
- 17 Vieira e Oliveira TR, Passeri LA. Mechanical evaluation of different techniques for symphysis fracture fixation—an in vitro polyurethane mandible study. *J Oral Maxillofac Surg* 2011;69(6):e141–e146
- 18 Bredbenner TL, Haug RH. Substitutes for human cadaveric bone in maxillofacial rigid fixation research. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000;90(5):574–580
- 19 Bos RR. Treatment of pediatric facial fractures: the case for metallic fixation. *J Oral Maxillofac Surg* 2005;63(3):382–384
- 20 Potter J, Ellis E III. Treatment of mandibular angle fractures with a malleable noncompression miniplate. *J Oral Maxillofac Surg* 1999;57(3):288–292, discussion 292–293
- 21 Gear AJ, Apasova E, Schmitz JP, Schubert W. Treatment modalities for mandibular angle fractures. *J Oral Maxillofac Surg* 2005;63(5):655–663
- 22 Choi BH, Yoo JH, Kim KN, Kang HS. Stability testing of a two miniplate fixation technique for mandibular angle fractures. An in vitro study. *J Craniomaxillofac Surg* 1995;23(2):123–125
- 23 Choi BH, Suh CH. Technique for applying 2 miniplates for treatment of mandibular angle fractures. *J Oral Maxillofac Surg* 2001;59(3):353–354
- 24 Ellis E III, Walker L. Treatment of mandibular angle fractures using two noncompression miniplates. *J Oral Maxillofac Surg* 1994;52(10):1032–1036, discussion 1036–1037
- 25 Ellis E III. A prospective study of 3 treatment methods for isolated fractures of the mandibular angle. *J Oral Maxillofac Surg* 2010;68(11):2743–2754
- 26 Siddiqui A, Markose G, Moos KF, McMahon J, Ayoub AF. One miniplate versus two in the management of mandibular angle fractures: a prospective randomised study. *Br J Oral Maxillofac Surg* 2007;45(3):223–225
- 27 Guimond C, Johnson JV, Marchena JM. Fixation of mandibular angle fractures with a 2.0-mm 3-dimensional curved angle strut plate. *J Oral Maxillofac Surg* 2005;63(2):209–214
- 28 Zix J, Lieger O, Iizuka T. Use of straight and curved 3-dimensional titanium miniplates for fracture fixation at the mandibular angle. *J Oral Maxillofac Surg* 2007;65(9):1758–1763
- 29 Fedok FG, Van Kooten DW, DeJoseph LM, et al. Plating techniques and plate orientation in repair of mandibular angle fractures: an in vitro study. *Laryngoscope* 1998;108(8 Pt 1):1218–1224
- 30 Throckmorton GS, Buschang PH, Ellis E III. Improvement of maximum occlusal forces after orthognathic surgery. *J Oral Maxillofac Surg* 1996;54(9):1080–1086