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Summary

Purpose: The aim of this study was to evaluate the distribution of deformation stresses in customized and non-customized plates during simulated advancement genioplasty, using the finite element method.

Methods: A customized plate (Traumec) was developed with 4.75 mm advancement, in ASTM F67 Grade 2 titanium, with four screws. Non-customized (standard) plates with 6 mm advancement (Stryker with six screws and Osteomed with four screws) were used for comparison. All the screws presented the same length (10 mm) and fixation system (2.0). The Traumec and Osteomed plates were fixed with two screws in the mandible, and another two in the segment, whereas the Stryker plate was fixed with three screws in the mandible, and another three in the segment. Six virtual models were generated in a computer-aided design program (Rhinoceros), in which the advancement and insertion of the plates were evaluated. All the plates were submitted to application of perpendicular and oblique forces of 5 N in the chin region.

Results: The Osteomed plate showed the highest stress value (1506 MPa), and the Traumec, the lowest stress value (560.20 MPa). The Stryker plate showed higher stress values for the segment screws than for the mandibular screws, unlike the other plates.

Conclusions: The customized Traumec plate showed better deformation stress distribution and plate/segment stabilization when submitted to advancement genioplasty.

Key words: genioplasty, finite element method, plates

INTRODUCTION

Fixation systems with plates and screws are used in oral maxillofacial surgery for the treatment of mandibular fractures and orthognathic surgery. Although they have been used for decades and have become the standard treatment, the materials used in these systems may fail due to excess loading and other causal factors during the surgical procedure, including failure in plate adaptation and fixation to bone, material design, fabrication, and degree of purity of the plate material (Azevedo and Hippert, 2002; Azevedo, 2003; Azevedo and Marques, 2010).

Internal fixation with steel archwires, widely used in the past, commonly led to maxillo-mandibular blocking, because the steel archwire provided only bone alignment in the correct position, without promoting stability of the fracture during bone healing (Ellis 3rd, 1993; Coskunses et al., 2015). Fixation systems with plates and screws were proposed by Luhr in 1969 (Luhr, 1969) to promote greater stabilization of the fractured segments, by introducing metal plates and screws and placing them in direct contact with the bone structure; it was considered a better stabilizing method because its biomechanical properties were superior to those of other methods (Luhr, 1969; Ellis 3rd and Karas, 1992; Uppada et al., 2014).

Advantages of fixation using plates include: postoperative release from the maxillo-mandibular block, enabling patients to return to their routine activities more quickly; earlier mandibular movement; and almost normal ability to eat (Uppada et al., 2014). However, the high precision required for performing the technique must be borne in mind, as well as the need for meticulous adaptation of the plates to the bone contour, considering that these plates are not customized to enable adaptation to the different bone contours of patients (Vasco et al., 2015). Coskunses et al. concluded that using conventional fixation plates in surgical procedures for advancements of over 5 mm, or for making changes in the vertical position, is a controversial issue (Coskunses et al., 2015). Material fixation fatigue may occur during the heavy bending needed to adjust the plate to the mandibular morphology, during the surgical procedure (Lindquist, 2001), and may cause fracture of the fixation material, making it necessary to remove and replace the osteosynthesis fixation material if there is instability. Katakura et al. demonstrated that reconstruction plates did not fracture due exclusively to excessive bending from the use of force, but that these fractures occurred because there were regions of stress concentration, suggesting that changes and adjustment could be made in the morphology of the reconstruction plates to promote a more individual result (Katakura et al., 2004). In the fixation system, non-customized plates of standard size were used, and were bent to adapt them to the distances required for planning orthognathic surgeries. Therefore, mandatory use of larger plates than those programmed for use in surgeries is required so that they can be bent to enable insertion. Moreover, there are variations in the number of screws required to retain the plates to enable better fixation.

The folds of non-customized plates generate stresses that are minimized when using customized plates, because these plates are fabricated individually, with predetermined sizes for each patient. In addition to obtaining the ideal plate design and size, the number of screws can also be customized. The possibility of reducing stresses and fractures in non-customized plates for osteosynthesis is dependent on this screw-related aspect, especially when the plates are used in chin advancement surgeries in the mandible, in which a large number of screws may create areas of higher stress. In customized plates, fewer screws may be sufficient for fixation and stabilization of the sectioned bone. Thus, the aim of this study was to evaluate the distribution of deformation stresses in customized and non-customized plates during simulated advancement genioplasty, using the finite element method.

MATERIALS AND METHODS

A computed tomography image of a mandible was obtained from the database of the Dental Simulation Laboratory of the São Leopoldo Mandic Dental Research Center, and used to evaluate customized and non-customized plates. The tomography was of a young adult male patient who presented a skeletal class II malocclusion, with severe mandibular retrusion, indicating mandibular and chin advancement. The tomography was digitized to perform the virtual orthognathic surgery plan in the software (Software Dolphin v.11.7, Chatsworth, CA, USA). In this simulation, chin advancement of 4.75 mm was indicated and performed without vertical changes and parallel to the horizontal Frankfort plane.

The mandible image was processed for the Patran program (MSC software, São Paulo, SP, Brazil), for digital reconstruction into a 3D model. After virtual reconstruction, the model was exported to Marc software (MSC software, São Paulo, SP, Brazil) for editing of the virtual models. Post-processing was performed by a computer-aided design program (Rhinoceros, São Paulo, SP, Brazil).

Analysis using the finite element method called for delimiting only the chin region in the models. A surgical treatment plan was simulated with 4.75 mm advancement in the chin region. The mentoplasty technique simulated in the experiment was a horizontal osteotomy of the chin (Ellis 3rd, 1993), sectioned 2 mm above the point of greatest prominence of the mandibular symphysis, and approximately 5 mm below the inferior margin of the mental foramen. After adequate mobilization of the osteotomized segment, fixation was simulated with the plates evaluated in this study.

The customized plate (Traumec) (Figure 1A) was designed by its manufacturer, Traumec Health Technology (Rio Claro, SP, Brazil), in CAD Solid Edge software (Siemens, Munich, Germany), according to the measurements obtained from the virtual orthognathic surgery plan (Software Dolphin v.11.7, Chatsworth, CA, USA). The advancement distance of 4.75 mm was reported to the manufacturer directly. The geometry and design of the plate followed the manufacturer's standard models. Then, the 'blank' design that corresponded to the preform of the plate was defined using the software. After corrections and adjustments to the form, the machining planning and programming were defined using CAM ESPRIT software (ESPRIT, Camarillo, CA, USA). The plate was completely machined using computer numerical control (CNC) (Haas Automation Inc, Oxnard, CA, USA), followed by finishing, polishing, and cleaning in an ultrasound bath (Brasmedical, Ribeirão Preto, SP, Brazil). The manufacturer was responsible for surface anodizing, laser engraving of the plate size, inspection, packaging, and final delivery.

The customized plate models were selected according to the simulated surgical treatment plan, with 4.75 mm advancement in the chin region. The available Osteomed brand (Figure 1B) and Stryker brand (Figure 1C) plate model catalogs were consulted to choose the closest size to achieve the advancement distance. The closest standard size selected was 6 mm, available from both brands.

The customized and non-customized plates were acquired and analyzed using a digital caliper (Litz Professional, Germany) and digital microscope

(B008, Supereyes, Shenxhen D&F, Ltd, Bantian Village, China), with 10× to 500× magnification, and with its own software to perform the measurements. The plates had the same thickness (0.7 mm), but their designs were patterned after their manufacturers' models. The plates also had the same composition (ASTM F67 Grade 2 titanium). The screws were of the same length (10 mm) and could be used in the same fixation system (2.0). They also had the same head design so that they could be submitted to finite element analysis. This information was used to virtually reconstruct the plates and screws. The models were exported to Marc software (MSC software, São Paulo, SP, Brazil) to edit the virtual models. Post-processing was performed with a computer-aided design program (Rhinoceros, São Paulo, SP, Brazil). The process provided elements and knots in the finite element mesh, thus affording greater accuracy (Table 1).

Next, the non-customized and customized plates were placed in position, according to each model. The Traumec and Osteomed plates were fixed with two screws in the mental region and another two in the mandible (Figures 2A and 2B), whereas the Stryker plate was fixed with three screws in the chin and three in the mandible (Figure 2C). The non-customized plates were 6 mm – the standard size provided by the manufacturer – so bends were simulated to adapt the plates to the 4.75 mm advancement performed in this study. The number of screws and the distance between them were predetermined by the manufacturers.

Two different forces were applied to each model, totaling six simulations. Restriction of movement was evidenced in the region of mandible delimitation, and the loads applied were in the chin segment, representing the muscle forces to which the segment could be subjected in a clinical situation. These simulations referred to two routine positions that patients adopt in supporting their hand on their chin, and that may occur in the postoperative stage (period of bone healing), associated with suprahyoid muscle activity. A 5 N load was applied to the chin equally in an oblique (45°) and a perpendicular (90°) direction in relation to the vertical plane (Figure 3), and distributed on the entire chin bone surface. This load distribution was necessary to avoid stress concentration in only a few knots, otherwise leading to the concentration of high stresses, according to the simplified stress analysis that describes stress as the ratio of force to area. The modeling software calculated the stresses on the plate and bone structures according to the data obtained from Poisson's ratio and modulus of elasticity, as shown in Table 2.

All the materials were considered homogeneous, isotropic, and linearly elastic. All contacts between the structures were considered perfectly matched. The distribution of stresses in the bone tissue around the bone/plate surfaces, and on all the screws of all the plates (Figure 4), was verified from the models submitted to activation stresses, analyzed by graphic stress images using the Von Mises criterion, and by tensile and compressive stress types (X and Y). Quantitative analysis was obtained when the color gradients of the images were associated with a numerical scale. This allowed determination of the minimum and maximum values for each color, and, in turn, indicated the level of stress occurring in a certain region, expressed in megapascals (MPa). All the analyses were performed with the ANSYS Workbench 15.0 software package (Ansys Inc., Canonsburg, PA, USA).

RESULTS

Table 3 shows the stresses on the plates of the different commercial brands, and on their respective screws, following the application of oblique and perpendicular loads. Lower oblique and perpendicular stress values were observed for the Traumec customized plate, in comparison with the other non-customized plates. The customized plate showed higher stress when an oblique load was applied, whereas the non-customized plates had higher stress values when an oblique force was applied. The stresses on the customized plate screws were also lower than those on the Osteomed non-customized plate screws, with both plates having four screws. Moreover, when a perpendicular load was applied, higher stress values were observed for all the plates, and all the screws of all the plates, except for screws P1 and P3 of the Stryker non-customized plate.

A comparison of the non-customized plates showed that the Osteomed four-screw plate presented higher stress values for the screws in the mandible (P1 and P3) than the six-screw Stryker plate screw values in the mandible (P1, P2, and P3). The lowest stress values for the Traumec customized plate were also observed for the screws in the mandible (P1 and P3). In relation to the six-screw Stryker plate, higher oblique and perpendicular stress values were observed for the central screws, in both the mandible (P2) and the segment (P5). The stress values for the mandible screws (P2) were significantly higher than the values for the lateral screws.

Table 4 presents the stress ratios among the screws positioned in the mandible in comparison with those positioned in the segment. The application of an oblique load promoted a better stress distribution relationship on the screws of both the four-screw customized and the four-screw non-customized plates, whereas significant, proportionally higher values were observed for the six-screw non-customized plate (up to 27.26 times higher for the relationship between P6 and P3). When a perpendicular load was applied, proportionally higher values were also verified for the six-screw non-customized plate, with intermediate values for the Traumec customized plate, followed by lower values for the Osteomed non-customized plate. In relation to the Stryker plate, a higher stress ratio was observed on the left side than on the right, especially when applying an oblique load, indicating lower stress ratios for the central screws.

DISCUSSION

The characteristics of each plate evaluated in our study influenced the stress values observed for the plates and screws. These results may be related to the plate designs, and the number and location of the screws.

The simulations for load application indicated lower stress values for the Traumec customized plate, in comparison with the non-customized types. The Traumec customized plate had a design that may have favored lower stress values because it was fabricated with the exact shape and size planned in the surgical procedure, thus providing better adaptation to the mandible and bone segment. Stress areas could be minimized substantially, because no bends were made previously in the plate to adapt it to the anatomical shape of the mandible and bone segment. Conversely, the non-customized plates did not conform exactly to the anatomy of the mandibular bone or the bone segment, thereby increasing the stress areas. Straight plates positioned in tension zones have been reported to present better results than curved plates (Pereira-Filho et al., 2016). Moreover, the plates were made of titanium, which has been found to absorb the forces of stress and transfer this stress to the adjacent bone, leading to possible fracture of the plates (Zachariades et al.,1993; Uckan et al., 2009). However, since the adaptation was not perfect, the bone segment suffered from the direct action of the muscles, which led to a change in its position. This reinforces the notion that customized plates should be well fixated, especially in the bone segment, which is constantly impacted by muscle action during bone repair. Although the possibility of fracture is low, these fractures may occur especially in patients with parafunctional habits, in which the normal mastication load may double or triple, representing a significant risk of permanent deformation, depending on the quality of the titanium used by the manufacturer. Although irreversible plastic deformation does not necessarily lead to fracture of the plate, because mastication is cyclic, this deformation may lead to growing levels of mobility between the segments of the mandible, thereby impairing bone repair (Prein and Rahn, 1998; Zachariades et al., 2011). Furthermore, the bone segment suffers from direct and constant activity of the suprahyoid muscle, and so could change position during bone repair following chin advancement surgery.

In relation to the Traumec customized plate, perpendicular loading showed higher stress values than oblique loading. This may be attributed to better adaptation of the plate to the mandible/segment when the force is applied in this direction. The soft tissue response and the stability were found to depend on the stability of the surgical procedure, the material used, the postoperative period, and the hard tissue remodeling (Uppada et al., 2014). During postsurgical bone remodeling, both the mastication forces and any other incidental forces acting on the operated segment bear directly on their final location; therefore, the better adapted the plate is to the segment, the lower the chances of undesirable movements (Uppada et al., 2014).

In regard to the non-customized plates, the highest stress was found when the oblique force was applied; this may be explained by the lack of perfect plate/segment adaptation in this direction of force. Comparing the two non-customized plates, the Stryker plate presented lower stress than the Osteomed plate, because it dissipated the stresses better; this could be attributed to a higher number of screws, enabling better adaptation.

In respect to the screw results, those positioned in the segment showed a higher level of accumulated stress than those positioned in the mandible. This probably occurred because the segment was more vulnerable to movement, and the screws enabled better fixation and stabilization of the segment, thereby avoiding displacements during the bone repair period. Thus, the stresses on the segment screws were higher than those on the mandible screws, which joined the plate to the mandible. Another consideration is that the screw placement angle and pattern have greater influence on stability than the screw size (Zizelmann et al., 2011). However, no studies have been found that evaluated the variation in the number of screws involved in the fixation plates being tested.

When the screws of the Traumec customized plate segment were submitted to oblique and perpendicular loads, they showed lower stress values, followed by the non-customized Stryker and Osteomed plates. These results may also be attributed to the plate design, the more anatomically adaptable fixation between the mandible and the segment, and, in particular, the absence of bends. Even when a plate had four screws, the stress values ranged from 2.06 to 11.47 times lower than those for the Osteomed non-customized plate that also had four screws. In this regard, Atieh et al. considered that an important factor for the performance of a titanium plate was the space existing between the points of fixation of the plates, in that this space should be inversely proportional to the flexural strength of the plate, and to plate and bone rigidity (Atieh et al., 2012).

Although titanium has a modulus of elasticity eight times greater than that of cortical bone (Azevedo and Marques, 2010), cortical bone is much thicker than the plate (Luhr, 1969; Ellis 3rd and Karas, 1992; Ellis 3rd, 1993; Uppada et al., 2014; Coskunses et al., 2015), and so the authors suggested that thicker plates could be more effective. Moreover, shorter or less extensive plates have been found to be more rigid (Murakami et al., 2014). However, the increase in the number of screws for fixation of the segment appears to increase its fragility (Zizelmann et al., 2011). In this respect, the Stryker plate, which was longer than the others, showed great stress differences between the screws of the mandible and those of the segment, unlike the other plates. This result could be attributed to the Stryker plate having two screws more than the other plates, and, consequently, being designed with a double tape shape in the central body. Although the Traumec and Osteomed plates are designed similarly, and each has four screws, they vary in length and thickness. This difference could have also contributed to generating a higher stress level in the Osteomed non-customized plate. This indicates that customization of the plate provided better effects and more benefits when analyzed in regard to stress distribution. However, further studies are necessary to evaluate the mechanism that promotes better stress distribution among all the screws.

Mazzoni et al. developed a computer-aided project (CAD/CAM) for developing completely guided orthognathic surgery that can be planned for individual patients. They assert that virtual surgical planning and customized plates represent a promising future for orthognathic surgery (Mazzoni et al., 2015), by making the virtual surgery plan more reliable, and by allowing customized plates to be indicated, especially in patients with asymmetric deformities (Hsu et al., 2013), in which cases the tridimensional position planned during advancement chin surgeries can be maintained (Hsu et al., 2013).

Since the force applied to the chin is variable, no plastic deformation analysis was performed in this study; therefore, the flow limit of plates was not considered, and the plate presenting the greatest degree of deformation could not be determined. The plastic deformation of the plate may induce a different clinical result from that of the immediate postsurgical period, because it alters the spatial position of the segment in relation to the mandible.

Although customized and non-customized plates may have similar indications and performances regarding stabilization of the bone segment after a surgical procedure, both are subject to load application and the possibility of fracture. However, the Traumec customized plate showed better deformation stress distribution when submitted to advancement genioplasty.

CONCLUSION

The Traumec customized plate showed better deformation stress distribution and plate/segment stabilization when submitted to advancement genioplasty.

CONFLICT OF INTERESTS STATEMENT

The authors declare that there are no financial, economic, or professional interests that may influence positions expressed in the article.

REFERENCES

Atieh MA, Zadch H, Stanford CM, Cooper LF: Survival of short dental implants for treatment of posterior partial edentulism: a systematic review. *Int J Oral Maxillo Fac Implants* 27: 1323–1331, 2012.

Azevedo CRF, Hippert Jr E: Failure analysis of surgical implants in Brazil. *J Eng*

Failure Analys 9: 621–633, 2002.

Azevedo CRF, Marques ER: Three-dimensional analysis of fracture, corrosion and wear surfaces. *J Eng Failure Analys* 17: 286–300, 2010.

Azevedo CRF: Failure analysis of commercially pure titanium plate for osteosynthesis. *J Eng Failure Analys* 10: 153–164, 2003.

Carneiro BA, de Brito RB Jr, França FM: Finite element analysis of the provisional structures of implant-supported complete prostheses. *J Oral Implantol* 40: 161–168, 2014.

Coskunses FM, Kan B, Mutlu I, Cilasun U, Celik T: Evaluation of prebent miniplates in fixation of Le Fort I advancement osteotomy with the finite element method. *J Craniomaxillofac Surg* 43: 1505–1510, 2015.

Ellis E 3rd, Karas N: Treatment of mandibular angle fractures using two mini dynamic compression plates. *J Oral Maxillofac Surg* 50: 958–963, 1992.

Ellis E 3rd: Rigid skeletal fixation of fractures. *J Oral Maxillofac Surg* 51: 163–173, 1993.

Hsu SS, Gateno J, Bell RB, Hirsch DL, Markiewicz MR, Teichgraeber JF, Zhou X, Xia JJ: Accuracy of a computer aided surgical simulation protocol for orthognathic surgery: a prospective multicenter study. *J Oral Maxillofac Surg* 71: 128–142, 2013.

Katakura A, Shibahara T, Noma H, Yoshinari M: Material analysis of AO plate fracture cases. *J Oral Maxillofac Surg* 62: 348–352, 2004.

Lindquist C: A comparative study on four screw-plate locking systems in sheep: a clinical and radiological study. *Int J Oral Maxillofac Surg* 30: 160–166, 2001.

Luhr HG: The compression osteosynthesis of mandibular fractures in dog. A histologic contribution to primary bone healing. *Eur Surg Res* 1: 3–10, 1969.

Mazzoni S, Bianchi A, Schiariti G, Badiali G, Marchetti C: Computer-aided design and computer-aided manufacturing cutting guides and customized titanium plates are useful in upper maxilla waferless repositioning. *J Oral Maxillofac Surg* 73: 701–707, 2015.

Murakami K, Yamamoto K, Tsuyuki M, Sugiura T, Tsutsumi S, Kirita T: Theoretical efficacy of preventive measures for pathologic fracture after surgical removal of mandibular lesions based on a three-dimensional finite element analysis. *J Oral Maxillofac Surg* 72: 1–18, 2014.

Pereira-Filho VA, Oliveira LF, Reis JM, Gabrielli MA, Neto RS, Monnazzi MS: Evaluation of three different osteosynthesis methods for mandibular angle fractures: vertical load test. *J Craniofac Surg* 27: 1770–1773, 2016.

Prein J, Rahn BA: Scientific and technical background. In: Prein J, *Manual of Internal Fixation of the Cranio-facial Skeleton*. Berlin: Springer-Verlag, 1–49, 1998.

Uckan S, Veziroglu F, Soydan SS: Comparison of stability of resorbable and titanium fixation systems by element analysis after maxillary advancement surgery. *J Craniofac Surg* 20: 775–759, 2009.

Uppada UK, Sinha R, Reddy DS, Paul D: Soft tissue changes and its stability as a sequlae to mandibular advancement. *Ann Maxillofac Surg* 4: 132–137, 2014.

Vasco MAA, Souza JTA, Casas EB, Silva ALRC, Hecke M: A method for constructing teeth and maxillary bone parametric model from clinical CT scans. *Comput Methods Biomech Biomed Eng Imaging* Vis 3: 117–122, 2015.

Zachariades N, Papademetriou I, Rallis G: Complications associated with rigid internal fixation of facial bone fractures. *J Oral Maxillofac Surg* 51: 275–278, 1993.

Zizelmann C, Hammer B, Gellrich NC, Kokemüller H, Bormann KH, Rohner D: In vitro biomechanical comparison of the effect of pattern, inclination, and size of positional screws on load resistance for bilateral sagittal split osteotomy. *J Oral Maxillofac Surg* 69: 1458–1463, 2011.

TABLES

Table 1. Customized and non-customized plates evaluated in the study, and the respective quantitative descriptions of number of elements in the mesh.

Type of plate	Manufacturer (City, State, Country)	Characteristic	Number of elements in the mesh	Number of knots in the mesh
Customized	Traumec Health Technology (Rio Claro, SP, Brazil)	CHIN type Size: 4.75 mm Manufactured from titanium ASTMF 67 Grade 2 4 screws 10 mm long 0.9 mm thick	7,693,127	5,591,463
Non-customized	Osteomed (Dallas, TX, USA)	CHIN type Size: 6 mm Manufactured from titanium 4 screws 10 mm long 0.7 mm thick	7,961,909	5,893,245
Non-customized	Stryker (Kalamazoo, MI USA)	CHIN type Size: 6 mm Manufactured from titanium 6 screws 10 mm long 0.6 mm thick	8,469,419	5,312,622

Table 2. Mechanical properties of the materials.

Structure	Modulus of elasticity (MPa)	Poisson ratio
Cortical bone[12]	13,700	0.3
Medullary bone[12]	1,370	0.3
Titanium[12]	110,000	0.35

Table 3. Stresses on the customized and non-customized plates, and on their respective screws (in MPa), with application of oblique and perpendicular loads and the O/P (oblique/perpendicular) ratio.

Plate	Plate / Screw	Load		O/P ratio
		Oblique	Perpendicular	
Traumec	Plate	144.76	334.16	0.43
	P1	50.21	153.43	0.33
	P3	21.43	133.06	0.16
	P4	108.88	195.36	0.56
	P6	88.45	217.81	0.41
Osteomed	Plate	3893.50	1506.00	2.59
	P1	205.62	373.53	0.55
	P3	245.90	325.66	0.76
	P4	225.02	579.13	0.39
	P6	263.18	571.90	0.46
Stryker	Plate	1506	560.21	2.69
	P1	37.39	24.69	1.51
	P2	82.11	97.17	0.84
	P3	34.05	14.33	2.38
	P4	289.18	402.95	0.72
	P5	321.16	391.55	0.82
	P6	298.05	390.68	0.76

Table 4. Stress ratio between the screws positioned in the segment and in the mandible, with oblique and perpendicular loads for the different types of plate.

Relationship between screws	Traumec		Osteomed		Stryker	
Type of loading	Oblique	Perpendicular	Oblique	Perpendicular	Oblique	Perpendicular
P4/P1	1.27	2.17	1.55	1.09	16.32	7.73
P5/P2	–	–	–	–	4.03	3.91
P6/P3	1.64	4.13	1.76	1.07	27.26	8.75

CAPTIONS TO THE ILLUSTRATIONS

Figure 1. Customized and non-customized plates evaluated in the study: A) Traumec Health Technology; B) Osteomed; C) Stryker.

Figure 2. Positioning of the plates in the chin: A) customized Traumec Health Technology 4.75 mm size plate; B) non-customized Osteomed plate with 6 mm advancement and four screws placed at predetermined distances; C) non-customized Stryker plate with 6 mm advancement and six screws placed at predetermined distances. Bends were simulated in the non-customized B and C plates to obtain the ideal size and adaptations.

Figure 3. Directions of the forces applied: A) oblique force; B) perpendicular force.

Figure 4. Distribution of screws in the mandible/segment and identification of the screws for customized and non-customized plates with A) six or B) four screws.


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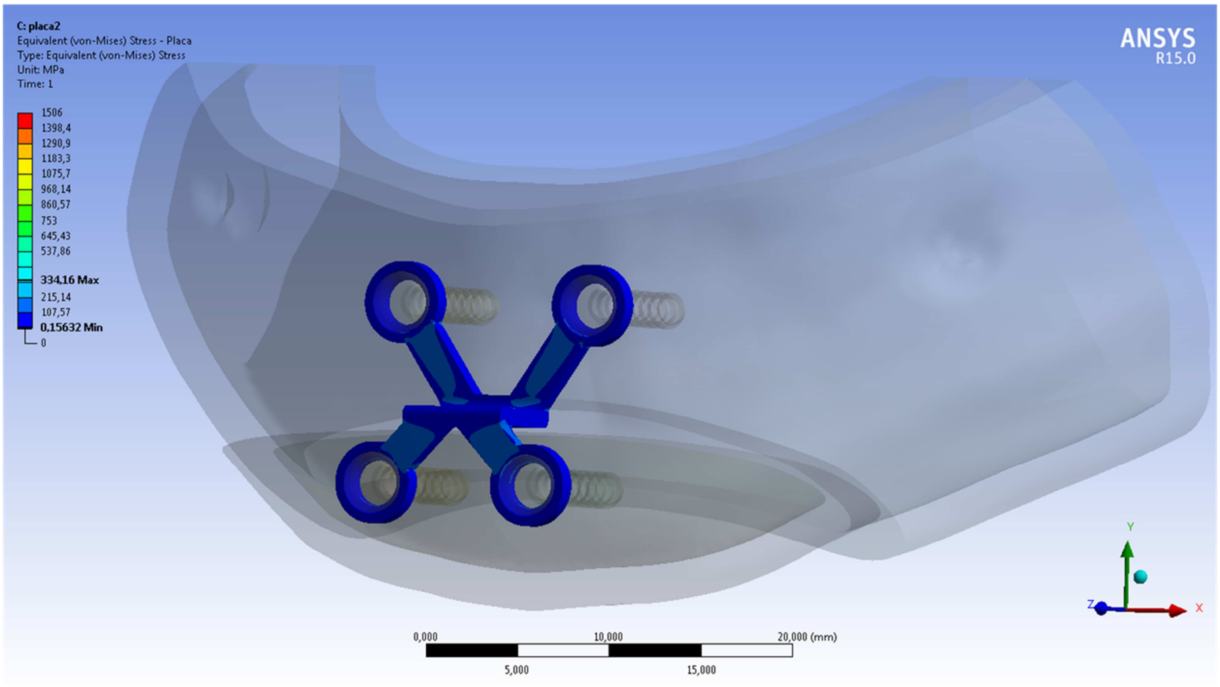
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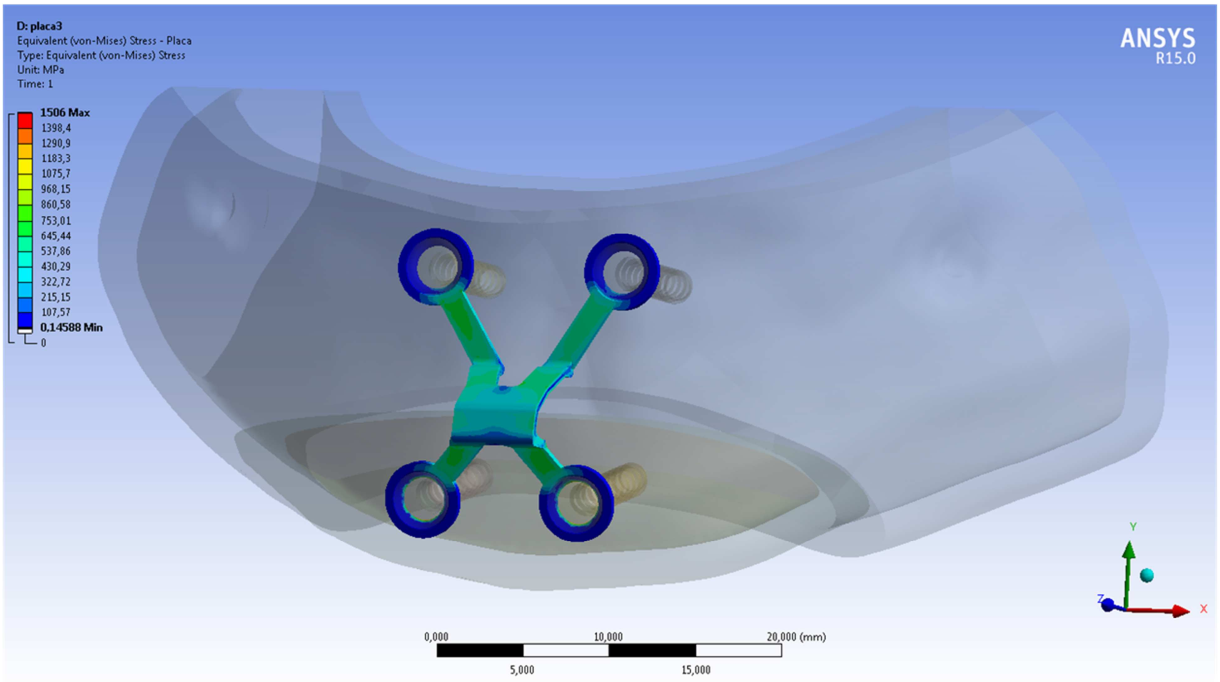
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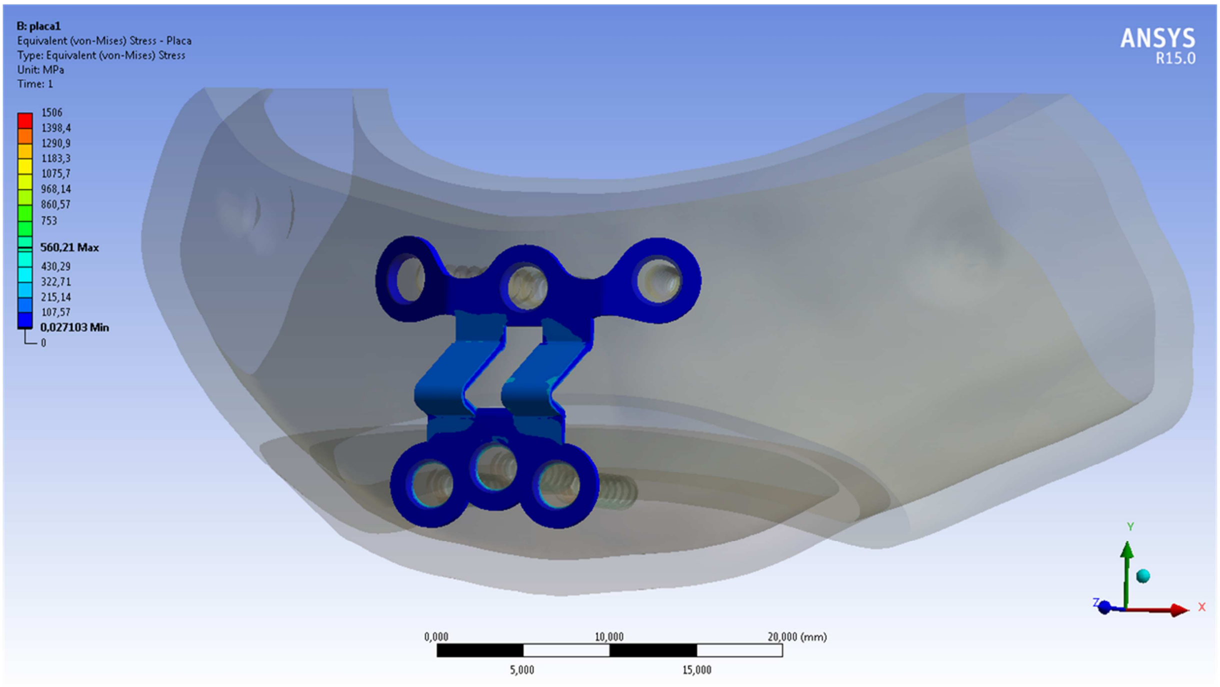
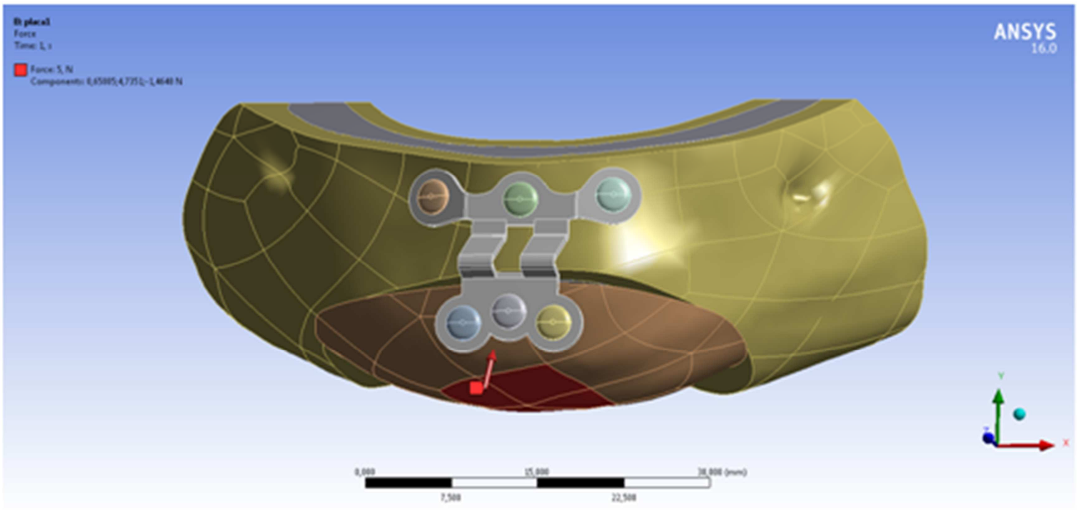
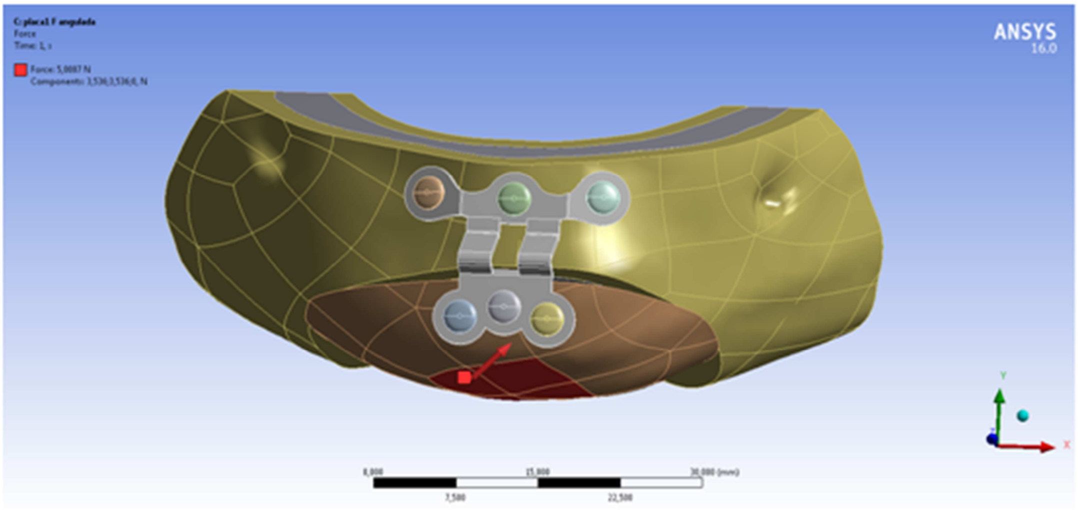
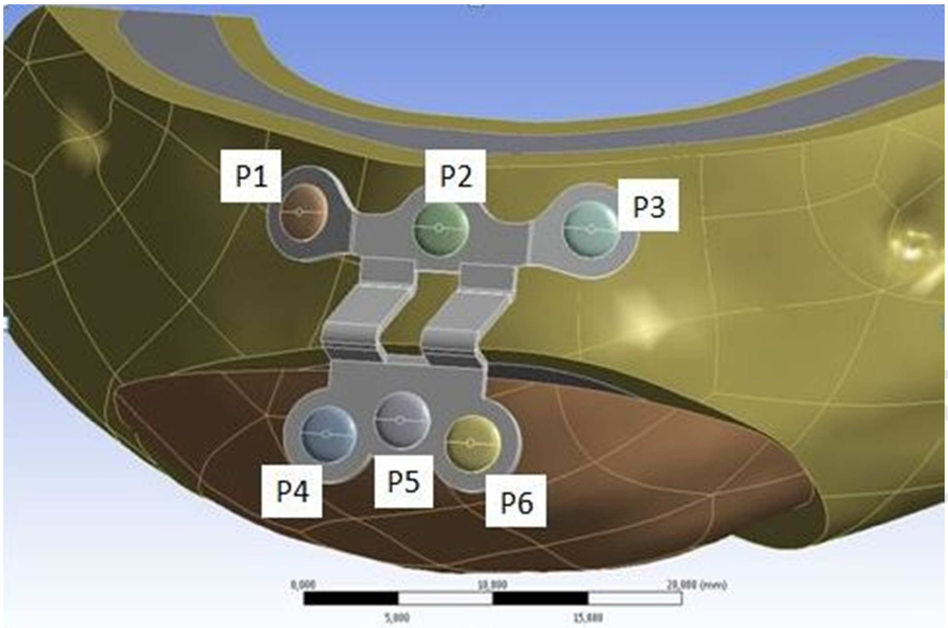
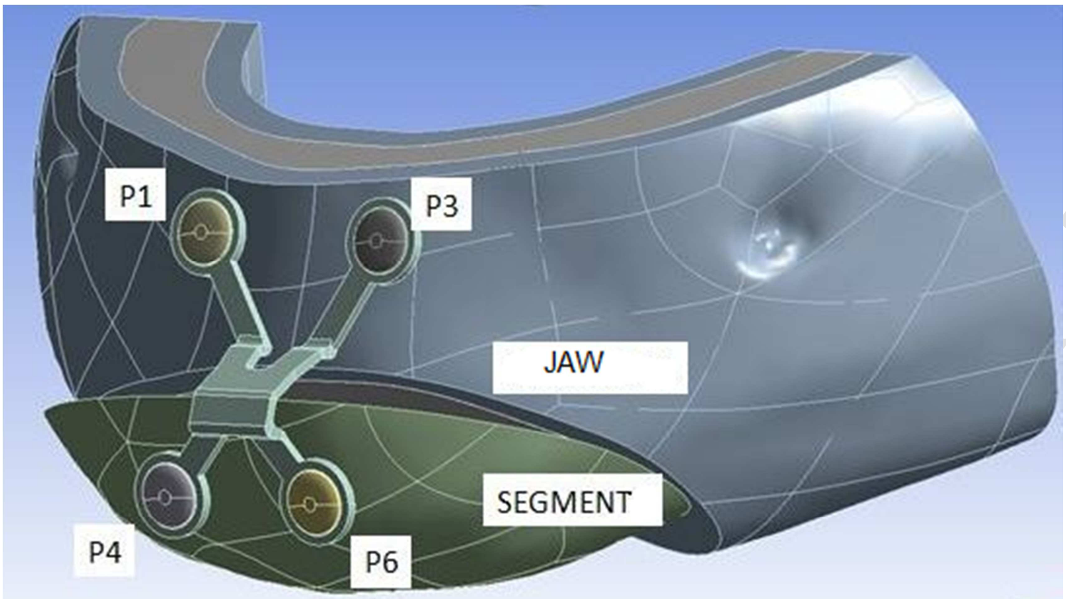
Z
X


B: placa1
Equivalent (von-Mises) Stress - Placa
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
1506
1398,4
1290,9
1183,3
1075,7
968,14
860,57
753
560,21 Max
430,29
322,71
215,14
107,57
0,027103 Min
0
ANSYS
R15.0
0,000
10,000
20,000 (mm)
5,000
15,000
Y
Z
X


Force
Force: 5, N
ANSYS
16.0


Force
Time: 1, s
Force: 5,0007 N
Components: 3,536;3,536;0, N
ANSYS
16.0
0,000
15,000
30,000 (mm)
7,500
22,500
Y
X


P1
P2
P3
P4
P5
P6


P1
P3
JAW
SEGMENT
P4
P6

Highlights

- For the customized plate, perpendicular load provided higher stress values than for oblique load;
- For the non-customized plates, highest stress was found when oblique force was applied;
- Screws positioned in the segment showed higher stress accumulation than those in the mandible;
- Customized plate showed better deformation stress distribution than the non-customized plates.