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ORIGINAL ARTICLE

Evaluation of different stable internal fixation in unfavorable mandible fractures under finite element analysis

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Abstract

Introduction The mandibular angle fracture is the most common fracture between this type of injury in jaw bone and also is the type of fracture treatment that presents a larger number of complications, and a series different osteosynthesis types have been studied over the years by the world literature. The finite element method is a form of mathematical analysis, which is based on dividing a structure into a finite number of small areas. It has the ability tomathematically model structures, making it possible to apply forces anywhere.

Material and Methods For this study, a three-dimensional mandible with an unfavorable angle fracture was simulated. Five different types of fixations were evaluated: group 1, Champy technique with one 4-holes miniplate, 2.0 system; group 2, technique with two parallel 4-holes conventional miniplates, 2.0 system; group 3, technique with two parallel 4-holes locking miniplates, 2.0 system; group 4, technique with one reconstruction 6-holes plate, 2.8 system in base jaw; and group 5, technique with one reconstruction 6-holes plates, 2.8 system in jaw body + one parallel 4-holes conventional miniplate, 2.0 system.

Results The results showed that strains are better distributed through the locking miniplate and screws system and presented less stress concentration when compared with the conventional ones. The Champy technique had the worst results about of all groups. The use of the locking system shows less stress compared to the non-locking system, and the presence of a reconstruction plate associated with a mini plate does not lead to increased stability compared with an isolated reconstruction plate.

Keywords Finite element method · Angle fracture · Stable internal fixation

Introduction

Fractures of the mandibular angle are one of the most problematic in the facial region due to the high frequency of complications after treatment. These complications mainly involve infections and non-union of the fragments [1, 2]. This injury is the most common in mandible fractures, which account for 23–97% of all facial fractures. Common causes of mandible fracture include physical assault, sports activities, motor vehicle accidents, industrial accidents, warfare, and falls [3, 4].

The angle of the mandible commonly associated with fractures because of the presence of third molars; a thinner cross-sectional area than the tooth-bearing region; and biomechanically, the angle can be considered a "lever" area [5].

Some studies have shown that the region of the mandibular angle is thinner than both the bone of the body region located more anteriorly, and the bone of the ramus located more posteriorly. Thus, a given force applied to the lateral aspect of the mandible might be expected to fracture at the region with the smallest cross-sectional area, the angle of the mandible. Combine this with the fact that the angle of the mandible is where there is an abrupt change in shape from horizontal to vertical rami, which would imply that this region might be subjected to more complex forces than a more linear geometric shape, one can begin to understand why fractures occur in this location [5, 6].

Over the years, various methods of treatment for fractures of the angle of the mandible have been studied at the word literature, various with large acceptance for the surgical professionals and some that lead a bigger discussion about their

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efficacy. These techniques have ranged from closed reduction with maxillomandibular fixation (MMF), to open reduction with wire osteosynthesis, and to open reduction with either rigid internal fixation or adaptive miniplate fixation [5, 7, 8].

The complex mechanical problem of identifying the response to loading of mandible can be investigated by means of finite element analysis (FEA). Finite element analysis (FEA) is a computational technique originally developed by engineers to model the mechanical behavior of structures such as buildings, aircraft, and engine parts and is also applicable to dentistry. When a structure is loaded, its response can be described in terms of stress and strains within the structure. In a simple geometric structure created from homogeneous man-made materials, stress and strain can be predicted with reasonable accuracy from analytical mathematical equations [9, 10].

Finite element analysis (FEA) is a suitable tool to conduct comparative stress analyses in the field of maxillofacial surgery and to make inferences that will enable more efficient designs of osteosynthesis systems. FEA can provide insight to the complex mechanical behavior of natural and restored craniofacial structures affected by three-dimensional stress fields, which are still very difficult to assess otherwise, as such as sinuses and their reconstructions, alveolar bone and dental implants, teeth and restorations, and osteosynthesis system as in the study [11–13].

Biomechanical behavior of different rigid fixation methods and the stresses arising in the region of mandibular angular fractures has not yet been definitively discussed in the literature. Therefore, the aim of this study is to compare five different rigid fixation methods of osteosynthesis in unfavorable mandibular angle fractures and evaluate the complex mechanical behavior by means of FEA.

Material and methods

For the simulation through finite element analysis, it was obtained a tridimensional solid from computed tomography in 1-mm-thick slices of a mandible of a 27-year-old man who showed no craniofacial abnormalities. The mandibular mask was manipulated to approximate a typical angular fracture with proximal and distal parts fully separated (Fig. 1).

The three-dimensional geometry of the mandible, mini- plates, and screws was created with Rhinoceros 4.0 (McNeel-North America, Seattle, WA). The geometry data were imported into Ansys Workbench 14.5 (Ansys, Inc., Canonsburg, PA) for preprocessing before FEA.

The files containing the tridimensional images of titanium miniplates and screws were provided by the NEORTHO enterprises and been used to five different types of osteosynthesis (Fig. 2).

- Type 1. Champy technique with one 4-holes conventional miniplate, 2.0 system.
- Type 2. Technique with two parallel 4-holes conventional miniplates, 2.0 system.
- Type 3. Technique with two parallel 4-holes *locking*, 2.0 system.
- Type 4. Technique with one reconstruction 6-holes plate, system 2.8 in base jaw.
- Type 5. Technique with one parallel 4-holes conventional miniplates, 2.0 system + one reconstruction 6-holes plate, system in jaw bases.

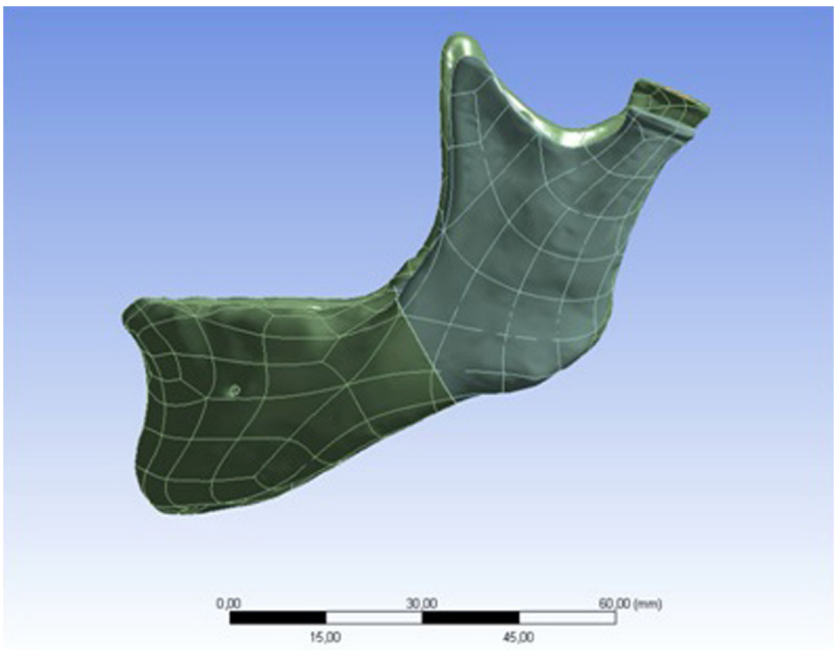

Fig. 1 Computed tomography in 1-mm-thick slices of a mandible of a 27-year-old man

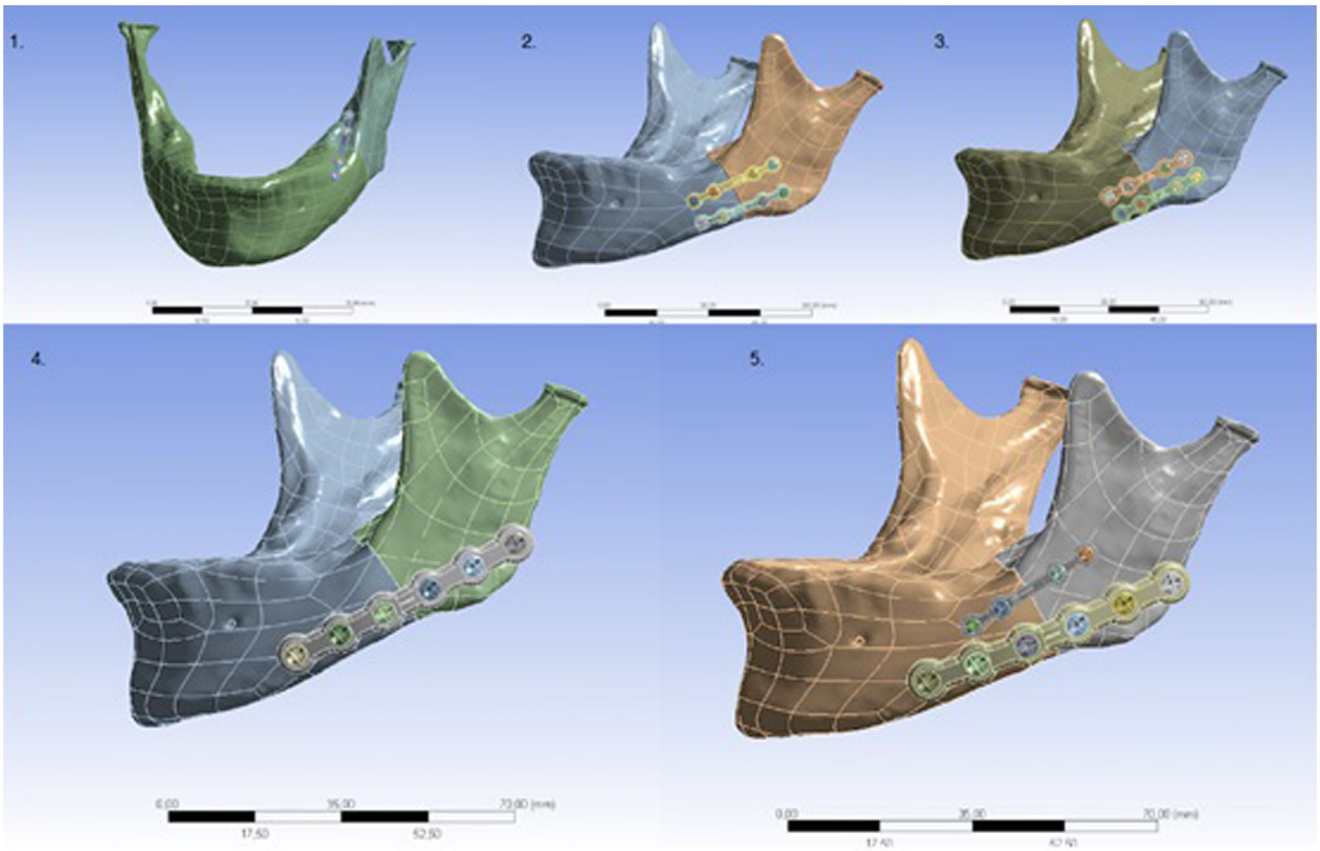

Fig. 2 Five different types of osteosynthesis

For the FEM analysis, the models were considered homogeneous, isotropic, and linear elastic: homogeneous, due to the same mechanical properties in all their points; isotropic, because in all points, the mechanical properties do not change with direction; and linear elastic, because they return to the original shape when tensions are removed. The structures were divided into trabecular bone and cortical bone, being considered with a homogeneous, isotropic, and linear elastic behavior. Forces were applied in the region of the insertion of the temporal muscle (lateral margin of the coronoid process of the mandible) of 235N, medial pterygoid muscle (pterygoid tuberosity) of 145N, and the masseter muscle (lateral side of the mandible) of 151N, which are involved in the lifting of the mandible during the masticatory act. The bulkhead was applied on the occlusal surfaces of the teeth. (Fig. 3).

After this simulation, the stress of the plates were evaluated in mega pascal and the displacement resistance was verified in millimeters. The dislodgment resistance was checked at the proximal segment once the distal segment was stable because the screen at the oclusal tooth was measured by the region with the lower displacement and the region with the higher displacement. So, the longer or higher were the values, the greater was the stress and displacement of the miniplates. The screws were evaluated in separately, and it was just evaluated the stress once to verify the displacement to many vectors that will be present. At the stress simulations, the green colors demonstrate a less stress and the red colors are related with higher stress values [14, 15].

The techniques related to the number and the authors chose types of plates. Just as the choice of unfavorable angle fracture in jaw because they suffer greater muscle strength and have the largest and most relevant discussions in the literature.

Results

Output measures from all analyses are shown in Tables 1 and 2.

In the simulation analysis, the Champy technique was the group that had highest values of mini plates and screws tension, and the item displacement was intermediate between all. In relation to the spread of stress to the bone tissue, this technique showed that there is a great amount of stress in the bone compared to other techniques.

If analyzed the data separately, it is possible to observe that systems with *locking* plates have less strain and stress on the

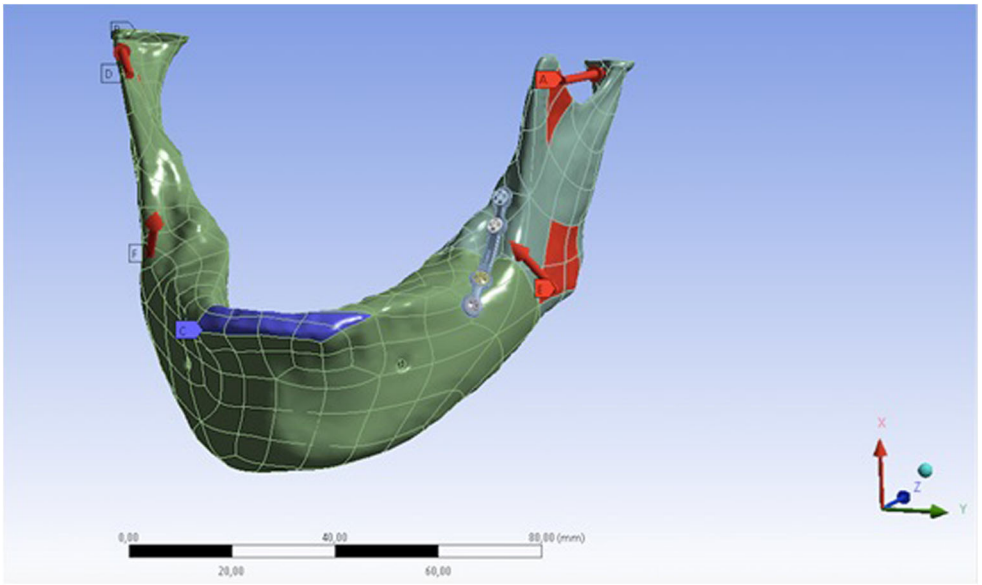

Fig. 3 Occlusal surfaces of the teeth

plates and screws compared to the techniques which conventional plates are used (in the conventional plates, the tension in plates and screws were more homogeneous if compared to the other group).

It is observed that the group 3 that has two parallel *locking* plates performed better role in relation to non-tension propagation to the bone if compared to group 2 technique that has the same spatial configuration but with different types of plates.

It was observed that the technique of group 4, technique that uses an isolated reconstruction plate, the displacement showed lower if compared to the other groups, but it is the group with one of the highest values of stress spread to the bone.

It can be seen that the group 5 showed the lowest propagation tension forces to the bone tissue compared to the other groups.

Discussion

The primary goals for the treatment of mandibular fractures are the restoration of occlusion and healing of the fracture. The use of fixation applied transorally to meet these goals in the management of mandibular angle fractures is not new [16]. When the decision is made to treat these fractures with internal fixation, discussion may arise over the type and number of plate(s) to use and the configuration of plates to provide the fixation [5, 7, 8]. Various biomechanical and epidemiological studies have been conducted for evaluating different fixation systems following mandibular fracture [2] but no consensus exists in which technique is better and the gold patter to be followed, probably, because an enormous numbers of plates' configuration exist and more those configurations are arising every day, and also the opinion and experience of the surgeon are always taken into account in deciding which technique will be used.

Choi et al. proposed that the intraoral approach was more efficient than using a trans facial approach because the surgery was shorter with less chance of facial nerve damage and less expensive because of less hardware and allowed the patient to return to normal function sooner—describing the Champy technic [17]. Another study indicates that the use of one miniplate on the lateral cortex placed with trans buccal instrumentation decreased the risk of postoperative complications by 110% compared with using transorally placed miniplates along the external oblique ridge. There is a data that patients with MAFs who were treated with a transorally placed miniplate along the external oblique ridge were 2.10 times more likely to

Table 1 Output measures

Type of fixation	Miniplate tension (MPA) min./máx.	Displacement (mm)	Screws tension (MPA) min./máx.
1. Champy technique	3.509/6.247	19.695	0.0032/21.422
2. 2 4 h conv. miniplate	0.227/37.037	24.963	0/32.310
3. 2 4 h lock. miniplate	0.011/22.512	21.229	0.0014/9.143
4. 6 h lock rec. miniplate	0.215/2.371,2	9.8738	0.05/2.904
5. 6 h lock rec miniplate + 14 h conv. miniplate	0.325/2.173,8	10.988	0.117/3.263

Table 2 Output measures

Type of fixation	Bone tension Min./máx.
1. Champy technique	0.02/5.6
2. 2 4 h conv. miniplate	0.0064/4.25
3. 2 4 h lock. miniplate	0.02/2.9
4. 6H lock rec. miniplate	0.029/5.8
5. 6 h lock rec. m,iniplate + 14 h conv. miniplate	0.029/1.5

develop a postoperative complication than were patients with MAFs treated by a miniplate on the superior aspect of the lateral cortex placed with trans buccal instrumentation [18].

In this work, it was possible to observe that the Champy technique showed the greatest tension on the plate and screws and also further spread of tension and forces to the bone. Fact that brings discussion related to the use of the technique since even presenting clinical features with great success rates, their performance in the simulation was the worst compared to other groups. But the decision to use a surgical technique should not be taken only through an isolated data, and this analysis does not dismiss or makes a contraindication of using this technique, which logically, it could be expected more tension in the synthesis material by the position of the plate and description of the Champy technique (Fig. 4).

The major discussion and the largest quantity of studies about this subject is a comparative observation between *locking* systems against conventional plates. It is possible to observe clinical studies that there were no significant differences in the postoperative complications between the conventional and the *locking* plate/screw mandibular systems. *Locking* plate/screw system was more rigid than conventional plate/screw system, thereby reducing the need and duration of IMF [19]. Prospective randomized studies have been done about these types of miniplates, and the authors concluded that *locking* miniplates give the advantage of greater stability and early restoration of function with almost similar results as seen in non-*locking* miniplate osteosynthesis. The author also found that less precision was required in plate adaptation, suggesting that complication rates are more likely to be related to bone quality and surgical technique rather than to the fixation system [20]. And a meta-analysis that confirms that mandible fractures treated with 2.0-mm *locking* miniplates and 2.0-mm non-*locking* miniplates present similar short-term complication rates, which suggests that the complication rate is more likely related to bone quality and surgical technique rather than the fixation system. In addition, the low postoperative MMF rate of using 2.0-mm *locking* miniplates also indicates that the 2.0-mm *locking* miniplate is a prospective fixation system in the treatment of maxillofacial fractures [21].

In this study, it was possible to observe that the *locking* plates positioned in parallel showed greater stability and stress distributed on the plate and screws with little force of propagating to the bone compared to the group of conventional plates with the same spatial arrangement. In this way, can be evaluated in a biomechanical test what is observed in clinical practice, in relation to superior stability of this type of system compared to the conventional system (Fig. 5).

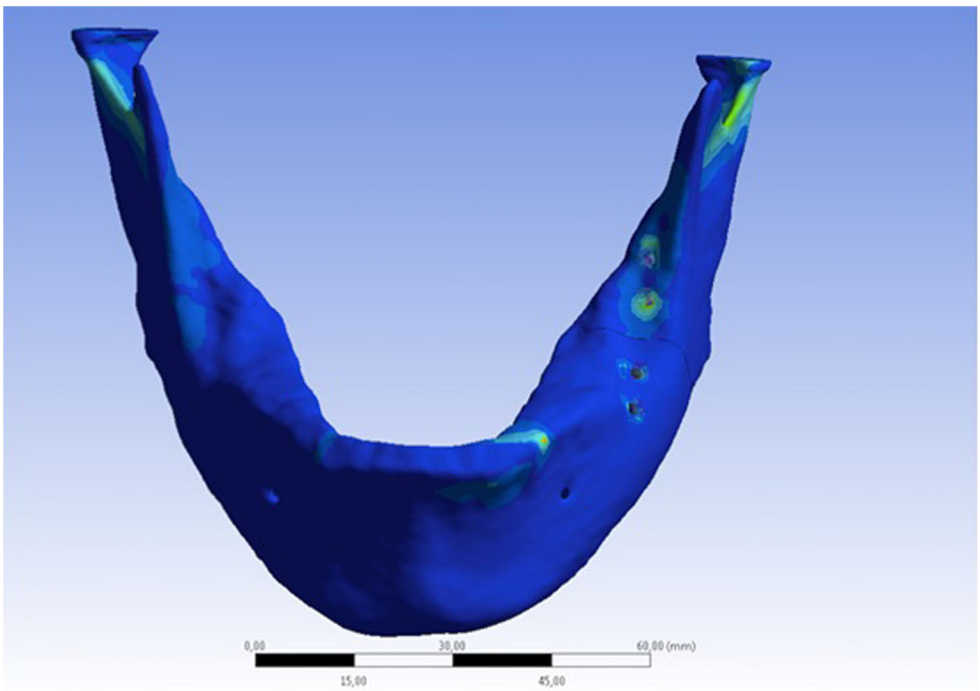

Fig. 4 Champy technique showing the greatest tension on the plate and screws and spread of tension and forces to the bone

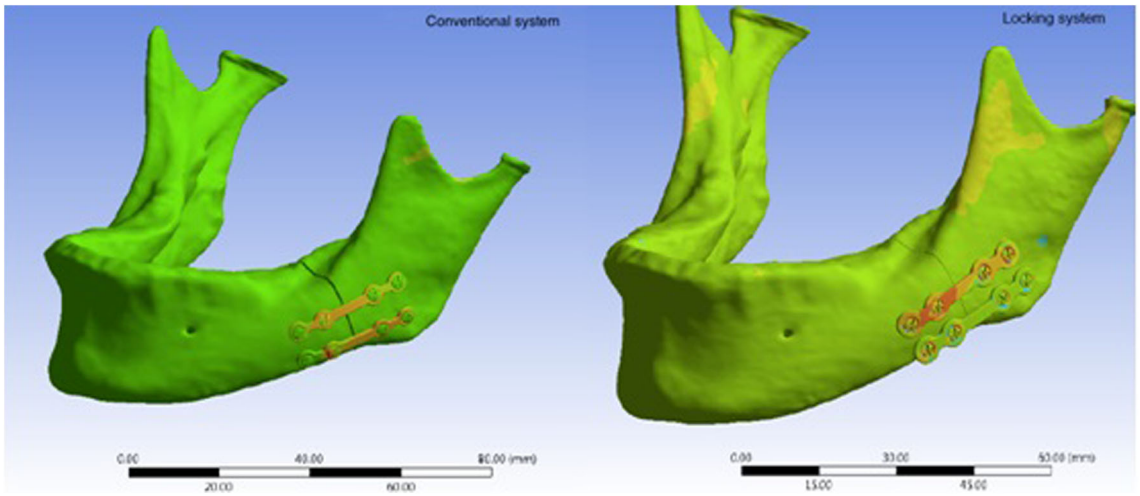

Fig. 5 Conventional system versus locking system

The use of reconstruction plates in mandibular fractures without major loss of continuity or without major bone comminuted injuries is not widely used, but are plates systems which the surgeon can resort to at the time of reduction and fixation of mandibular segments in simple mandibular angle fracture. Some authors have classified this technique as the technique of the AO (Arbeitsgemeinschaft für Osteosynthesefragen) [1] which represents the fourth group in this study and modified AO technique with the use of two plates representing the group six of the methodology. According to (AO)/ Association for the Study of Internal Fixation principles, the main objective of open reduction and internal fixation in the management of mandibular fractures is to achieve undisturbed healing and immediate restoration of form and function without the adjunctive use of MMF [22].

Some studies show that the use of this type of fixation system in angle fractures is very satisfactory with low number of post-operatory complications. Other authors indicate this technique when there is a great loss of the bone, when the first technique used failure (with other systems of fixation) or when there is tooth missing in the trauma, because the technique provides more stability if compared with the more slender systems and can provide high rate of success [23–25].

It was observed that the stability of the two plates is not added or is higher compared to the group with only one reconstruction plate. It is noted that the behavior of the variables studied (tension in plate, tension in screws, and displacement) is similar between the two groups, but with a discreet and increased stress in the group with two plates. In analysis of the tension transmitted to the bone, the configuration which

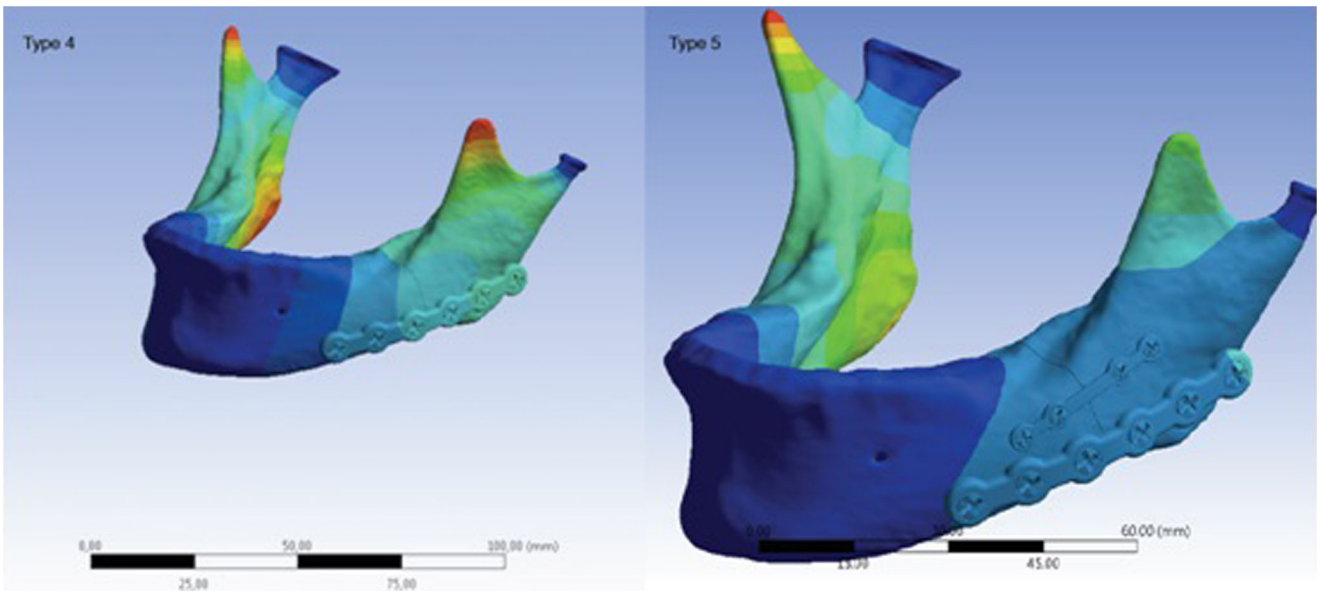

Fig. 6 AO technique with the use of two plates

has two plates (one reconstruction plate and conventional plate system 2.0) showed the lowest stress in the bone compared with the group with only one reconstruction plate and also with the other groups of the study. One possible explanation of the fact that occurred greater, discreet but slightly accentuated, tension in plates and screws in group 5 is that this technique has a protection in the bone tissue, transmitting less stress to the region. A favorable argument for this group related to the tension in bone structure but unfavorable about the fixation system itself since there is greater chance of fracture or dislocation of the synthesis material. Since there is no clear and widespread data about how much tension the fixation system supports or how much strain the bone can suffer for no postoperative problems, the related discussion about the choice between the two techniques should be clinically or even by logistic and financial analysis from cost of using larger amount of this material, but more important than all is the correct indication of the these techniques that may be used in greater fractures with more bone injuries that need more stability (Fig. 6).

The authors note that comparing studies on finite elements in the area of traumatology and maxillofacial surgery is difficult and can often bring comparative counterfeit interpretations since each study is done in a way and developed by a researcher. There are numerous factors that can affect the comparison of data between different studies such as the geometry of the plate may vary from company to company that supplies this material, forces used which may vary at the time of simulation and at the time the methodology of choice,; operator's computer systems which make the calculations not the same and there is no calibration for this bias be reduced, different software which can lead to discrete but not measurable comparisons, and even the limitation of the type of study which is strictly mathematical without capability of a logic analysis at the time of simulation. In that way, the authors restrict this study to compare the data obtained with the clinical and epidemiological papers in synthesis material in the jaw angle fracture; it is what seems to be a data more faithful and more relevant to the scientific community.

Conclusions

It is possible to conclude that the Champy technique was the one that shows more tension in plate and screws and also brings more stresses to the bone tissue. The use of *locking* system has less stress compared to the conventional plate system. The presence of a reconstruction plate associated with a conventional miniplate does not lead to increased stability when compared with an isolated reconstruction plate. The finite element analysis in a large and varied group of studies confines itself to clinical researches comparison, and the data found in the work is unique and not replicable with easily.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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