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RESEARCH ARTICLE

The Evaluation of The Treatment Options With Intermaxillary Fixation Screws and Miniplates in Bilateral Mandibular Fractures By Finite Element Analysis

İki Taraflı Mandibüler Kırıklarda Intermaksiller Fiksasyon Vidaları ve Miniplaklarla Tedavi Seçeneklerinin Sonlu Elemanlar Analizi ile Değerlendirilmesi

Aytaç Gürsel[1], M. Ercüment Önder[2], Mine Cambazoğlu[3]

[1]DDS, Ankara University, Faculty of Dentistry, Department of Oral and Maxillofacial Surgery, Ankara, Turkey.

[2] PhD, Lokman Hekim University, Faculty of Dentistry, Department of Oral and Maxillofacial Surgery, Ankara, Turkey

[3] DDS, Ankara University, Faculty of Dentistry, Department of Oral and Maxillofacial Surgery, Ankara, Turkey.

ABSTRACT

Objective: The aim of this study is to assess the stress values and the amount of displacement (D) that occurs on the fracture line during the application of various numbers and ligation methods of intermaxillary fixation screws (IMFS) by using finite element analysis and to perform a comparison to the internal fixation technique with miniplates.

Material and Method: A three-dimensional model of the maxilla, mandible, and temporomandibular joint was created using the DICOM data obtained from Cone Beam Computed Tomography (CBCT). The nonhomogeneous bone structure was transferred to the model based on the Hounsfield Unit (HU) values obtained from DVCT. In the scenario created, a mandible having parasymphysis and corpus fractures together was modeled. IMFS and internal fixation methods were analyzed in eight different scenarios.

Results: Results of the analysis showed that the most successful fracture fixation models were the standard method of IMFS which is 4-point fixation (D:0,068 mm) or horizontal ligation (D:0,066 mm). It is observed that the increase in the number of IMFS has no effect on fracture displacement or the reduction of the stress formed in the bone surrounding the screws. The analysis of internal fixation shows that increasing the number of plates and screws does not change the amount of displacement, but it is influential on the distribution of stresses.

Conclusion: It has been observed that the number of IMFS has no effect on fracture fixation and stress distribution. It is observed that the amount of displacement is less in parasyphysis fractures than it is in corpus fractures.

Keywords: mandibular fracture, intermaxillary fixation, intermaxillary fixation screw, finite element analysis

ÖZET

Amaç: Bu çalışmanın amacı, sonlu eleman analizi kullanılarak intermaksiller fiksasyon vidası (IMFV) uygulamalarında farklı sayı ve bağlama yöntemlerinin kırık hattında oluşturduğu gerilme değerlerini ve yer değiştirme miktarını (D) değerlendirmek ve miniplaklarla yapılan internal fiksasyon tekniği ile karşılaştırma yapmaktır.

Materyal ve Metod: Maksilla, mandibula ve temporomandibular eklemin üç boyutlu modeli, Konik Işınlı Bilgisayarlı Tomografi (KIBT) verilerinden elde edilen DICOM verileri kullanılarak oluşturulmuştur. Homojen olmayan kemik yapısı, KIBT'dan elde edilen Hounsfield Birimi (HB) değerlerine dayanarak modele aktarılmıştır. Oluşturulan senaryoda, parasimfizis ile korpus kırıklarının birlikte bulunduğu bir mandibula modellenmiştir. IMFV ve internal fiksasyon yöntemleri sekiz farklı senaryoda analiz edilmiştir.

Sonuçlar: Analiz sonuçları, en başarılı kırık fiksasyon modellerinin, 4 noktalı fiksasyon (D: 0,068 mm) veya yatay bağlama (D: 0,066 mm) olan standart IMFV yöntemi olduğunu göstermiştir. IMFV sayısının artışının, kırık deplasman miktarının veya vida etrafındaki kemikte oluşan gerilmenin azalması üzerinde bir etkisi olmadığı gözlemlenmiştir. Internal fiksasyon analizinde, plak ve vida sayısının artırılmasının deplasman miktarını değiştirmediği, ancak gerilmelerin dağılımı üzerinde etkili olduğu görülmüştür.

Sonuç: IMFV sayısının, kırığın fikse edilmesi ve gerilme dağılımı üzerinde bir etkisi olmadığı görülmüştür. Ayrıca anterior kırıklarda deplasman miktarının, posterior kırıklara göre daha az olduğu gözlemlenmiştir.

Anahtar Kelimeler: Mandibular kırık, İntermaksiller fiksasyon, İntermaksiller fiksasyon vidaları, sonlu eleman analizi

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Corresponding author: Aytaç Gürsel
Address: Department of Oral and Maxillofacial Surgery, Ankara University Oral and Dental Health Hospital, Ministry of Health, 06560 Yenimahalle, Ankara, Turkey
Phone: +905355941330
Email: taytacgursel@gmail.com

Aytaç Gürsel 0009-0006-3331-2707
M. Ercüment Önder 0000-0002-1488-616X
Mine Cambazoğlu 0000-0002-7886-0532

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INTRODUCTION

The conventional treatment methods for maxillofacial fractures are closed reduction and extraoral-intraoral maxillomandibular fixation (MMF). With the emergence of miniplate and screw systems, open reduction and internal fixation (ORIF) techniques have also been added to the treatment options of mandibular fractures.[1]

The fundamental principle of fracture treatment is bringing the occlusion to the most optimal location and preserving this condition until ossification. Various methods, such as Erich arc bars for MMF, Ivy Loops ligatures, Ernst ligatures, orthodontic brackets, intermaxillary fixation screws (IMFS), are used in closed reduction. The advantages of closed reduction are its simplicity, the short operation duration, the low risk of damaging adjacent anatomical structures, and its low cost. Besides unfavorable conditions such as the failure to achieve a sufficient reduction on the fracture line, difficulties in feeding, speech, and breathing, it also has disadvantages such as wire-related injuries, difficulty maintaining oral hygiene, and the possibility of the system damaging periodontal tissues.[2]

Recently, the advantages of the use of intermaxillary fixation screws have increased their application.[3] These screws that are placed in the alveolar bone are used as an anchorage for MMF by means of their screw tips specialized for ligation. IMFS with MF is an advantageous method when compared to others because it is atraumatic, it is easy to maintain hygiene, and its application is rapid and practical.[4]

Lately, the use of finite element analysis (FEA) has become popular in scientific studies, which are hard to conduct on living tissues in the maxillofacial area. Using FEA, it is possible to create three-dimensional models consistent with ideal anatomy from patient data derived from computed tomography. By creating different scenarios with the models created, it becomes possible to perform measurements and compare the results obtained in a virtual environment.[5,6]

In the current literature, many studies investigating the mechanical stress formed in the plates, bones, and screws during treatment of fractures with ORIF are available.[7,8] However, there is no FEA study that compares the fracture fixation methods that use IMFS placed in various configurations or assesses the responses that these configurations would give to simple masticatory forces.

In our study, the goal is to evaluate IMFS placed in different configurations and to compare it to the ORIF technique in cases with bilateral multiple mandibular fractures using finite element analysis.

MATERIAL AND METHOD

In this study, the localizations, number, various ligation options, the displacement amounts of the IMFS used in mandibular fractures and the stress formed in the bone, ligature wire, and screws were assessed by finite element analysis.

Mandible with a fractured parasymphysis and corpus that has "multiple" fractures was modeled using the FEA technique. Six models were prepared to analyze IMFS placed in varied locations and numbers and its ligation options. As the control group, two models of fixation with miniplate and screw systems were modeled. In one of the models, internal fixation was performed with a single plate, and in the other model 2, plates were placed superior and inferior to the fracture line based on the Champy technique.[1]

The cone beam computed tomography (CBCT) data of a twenty-three-year-old healthy female having full dentition and Angle class I occlusion obtained for diagnostic purposes was used for FEA. The Digital Imaging and Communications in Medicine (DICOM) data obtained from the CBCT were transferred to 3D Slicer software and three-dimensional skeletal modeling was performed. Tooth contacts were formed between the first and second molar teeth on the right and the left. The occlusion between the molar teeth was formed by straightening the occlusal surfaces. This was performed to minimize the margin of error that may be caused by the punctate contact points on the occlusal surfaces of teeth that have an irregular anatomic structure. Teeth contacts have been defined as cleaving-frictional surfaces. Temporomandibular joint (TMJ) was modeled the as closely as possible to its anatomy. The TMJ disc was modeled as a pillow between two joint surfaces, and it was fixated to the mandibular condyle and temporal bone. The fracture line was created as an irregular space with 0.1 mm indentations and protrusions, and not entirely planar. The tip of the IMFS was modeled with a diameter of 4 mm and height of 3 mm, and the shaft with a diameter of 2 mm and length of 11 mm. The IMFS were placed perpendicular to bone approximately 12 mm away from the fracture line in such a way that they would not come into contact with tooth roots and alveolar inferior nerve. Ligature wires with diameters of 0.5

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mm were fixated to the tip of the IMFS to facilitate IMF.

Modeling of the Scenarios

Model A: The modeling of the conventional treatment method defined as 4-point-fixation was executed. In every quadrant, one screw was placed posterior to the fracture lines, and vertical ligation was performed (Figure 1).

Model B: 8 IMFS were used. These screws were placed as 4 each on the left and right, and vertical ligation was performed. In the right mandible where the parasymphysis fracture was, the screws were placed posterior to the fracture line. There is only one screw in the middle segment that lies between the two fracture lines (Figure 1).

Model C: 8 IMFS were used, and vertical ligation was performed on the right and oblique on the left. The screws on the parasymphysis fracture line that were located on the anterior were slid medially from the fracture line. Hence, IMFS are present at both borders of the middle segment (Figure 1).

Model D: A total of 6 IMFS were used, 3 were placed on each side and formed a triangular shape on the two fracture lines. Two screws were placed in the mandible and one in the maxilla.

Model E: Oblique ligation was performed in both of the fractures. Screws were placed medial and distal to both of the fracture lines (Figure 1).

Model F: Vertical ligation was performed in both of the fractures. Screws were placed medial and distal to both of the fracture lines (Figure 1).

Model G: In this analysis, where fixation was modeled with double miniplate and screw systems, two miniplates were placed superior and inferior to the fracture line on both sides. A total of 4 miniplates was used for fixation (Figure 1).

Model H: In this model, 1 miniplate was placed inferior to each of the fracture lines. (Figure 1)

Defining the Materials

Because the mandible is a nonhomogeneous structure with anisotropic characteristics, the Youngs Module of the bone was calculated according to the formula below. The Hounsfield Unit (HU) values which are density data obtained from CBCT were used to define mechanical parameters specific to the individual. By means of the equation, the elasticity values of bone with visco-elastic and anisotropic characteristics that

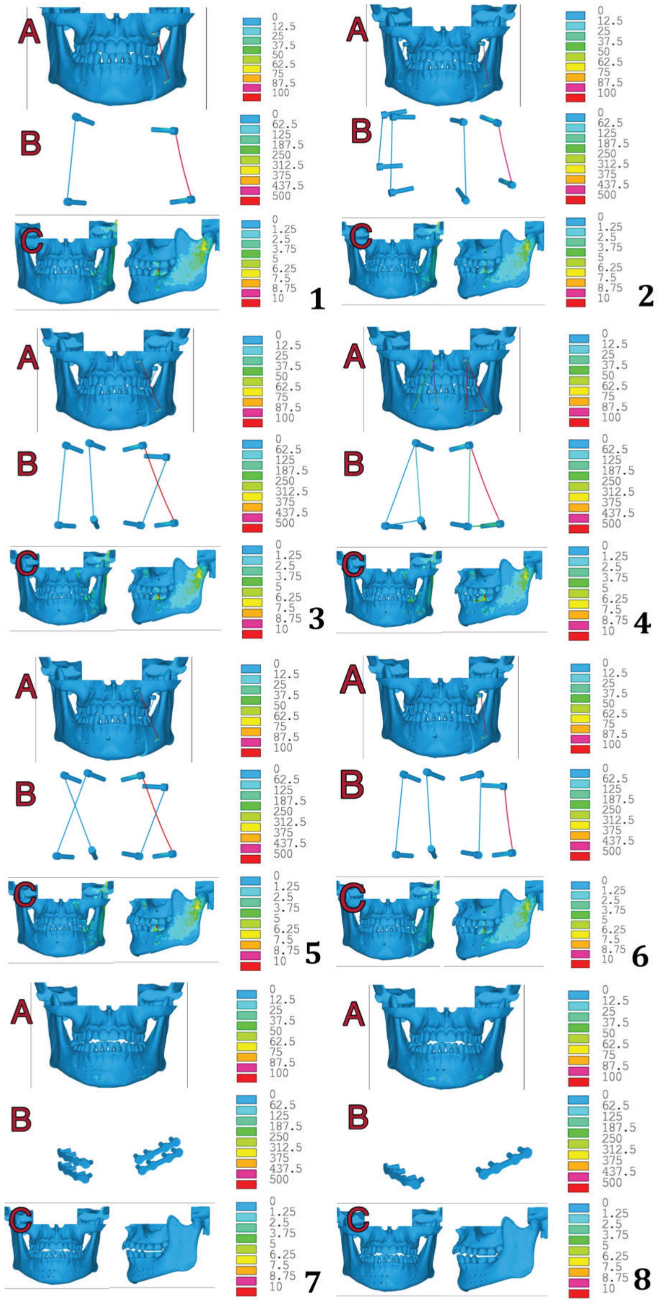

Figure 1. (1) Model A. (2) Model B. (3) Model C. (4) Model D. (5) Model E. (6) Model F (7) Model G (8) Model H. ; (A) The appearance of the fracture lines, IMFS, and ligatures on the maxilla and mandible, and beside it the scale of the stress values. (B) The stresses formed in the IMFS and ligature wires, beside it the scale of the stress values. (C) The stresses formed in osseous tissue, beside it the scale of the stress values.

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vary depending on the region were calculated closest to the actual values.[9] Because values under 0.05 GPa would exhibit excessive elasticity, the lower limit was set at 0.05 GPa for cancellous bone.[9]

Density (app) = -200 + 1.2 HU [kg/m3]

E (Youngs modulus) = 0.024 x Density (app) 1.762 [MPa].[9]

The modeling contains four contact surfaces. These surfaces are the space between the right and left teeth and two fracture lines. The coefficient of friction between teeth was defined as 0.2, and the coefficient of friction on the fracture line was 0.6110 . The elasticity coefficient and Poisson's ratio of the materials are presented in the Table 1.

Table 1. The elasticity coefficients and Poisson's ratio of the materials in the model

LIST OF MATERIALS		
MATERIALS	ELASTICITY COEFFICIENT	POISSON'S RATIO
CANCELLOUS BONE	0.05 GPa	0.3
CORTICAL BONE (min)	0.56 GPa	0.3
CORTICAL BONE (max)	14.07 GPa	0.3
TEETH[9]	150 GPa	0.3
TME DISC[10]	6 GPa	0.47
WIRES[11]	220 GPa	0.3
TITANIUM PLATES AND SCREWS[11]	110 GPa	0.3

Defining the Boundary Conditions

In this section of the analysis, the amount, direction, application time, and type of forces that will be applied and the degrees of freedom in the nodal points were defined. The locations and vectors of the masticatory muscles were calibrated in the model specific to the individual based on anatomy. The muscle forces are presented based on the calculations Korioth performed for masticatory muscles.[11]

Analysis Method

The amount of displacement was calculated by measuring the distance that appears between two coincident points on the fracture line where maximum movement is observed. And to measure the stresses received by the screws, the bone area approximately 2 mm deep surrounding the screw-tips was taken into consideration. In ligature wires, the stress received by the wires was analyzed.

RESULTS

The stresses formed in the screws, the cortical bone surrounding the screws, and the wires in the models were measured in terms of MPa (N/mm2) by employing von Mises stress analysis. The amount of displacement in the fracture line was also calculated in terms of millimeters. The results are presented in detail in Table 2.

The Amount of Displacement in the Fracture Line

It was observed that segments come into contact by falling on top of each other in the occlusal parts, while separation occurred on the inferior margin of the mandible due to the tensile forces. In terms of fixation of the corpus fracture, it became evident that the most successful IMFS formations were in the A and D models. In model A, four IMFS were used, and vertical ligation was performed. In model D, symmetric triangular ligation was performed. Although an IMF screw is present in both posterior borders of the middle fragment (model C,E,F), it is seen that displacement is slightly increased in fractures of the corpus when compared to models A and D. In the models C and E, oblique ligation was performed on the side of the fracture of the corpus. The fact that the fixation of the segment in the middle of model B was facilitated by a single IMFS placed far from the parasymphysis fracture and that this screw was ligated to a screw far from it has subjected the middle segment to posterosuperior tensile forces and caused separation on the parasymphysis fracture line. The amount of displacement in fractures of the parasymphysis in this model increased dramatically when compared to the models that contained more than four IMFS. However, in parasymphysis fractures, the maximum displacement was observed in parasymphysis fractures that occurred in model A in which four screws were used (0.003 mm). Although the displacement of the fracture line is increased when compared to the others, it is rather low when it is compared to fractures of the corpus. While there was a slight increase in the amount of displacement in the A and B models, the results of fixation with IMFS in parasymphysis fractures were nearly similar to the results of fixation with miniplates. Among fractures of the corpus, maximum displacement was measured as 0.107 and 0.108 mm in models B and F, respectively. In these models, the fracture of the corpus was measured by placing IMFS to the distal and medial, and it was ligatured vertically. While parasymphysis fractures in these models were fixated well, separation occurred in fractures of the corpus.

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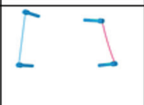
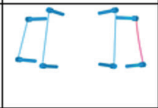
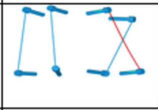
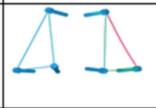
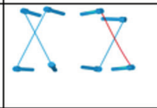
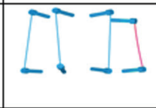
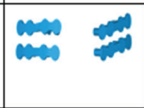
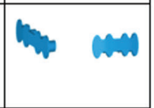
Table 2. The amount of displacement that occurred in the fracture line and the von Misses stress values

	MODEL A		MODEL B		MODEL C		MODEL D		MODEL E		MODEL F		MODEL G		MODEL H	
	Parasymphysis	Corpus	Parasymphysis	Corpus	Parasymphysis	Corpus	Parasymphysis	Corpus	Parasymphysis	Corpus	Parasymphysis	Corpus	Parasymphysis	Corpus	Parasymphysis	Corpus
Fixation types																
Maximum displacement on the fracture line (mm)	0.003	0.068	0.0012	0.107	0.0005	0.095	0.0003	0.066	0.0003	0.092	0.0001	0.108	0.0001	0.0003	0.0002	0.0003
The stresses formed in the cortical bone surrounding the screws (MPa)	0.04 0.05	2.43 2.58	0.38 0.26 0.3 0.04	0.14 2.15 0.03 2.5	0.12 0.15 0.09 0.03	14.8 0.15 0.025 11.2	0.35 0.18 0.6	3.27 1.55 3.45	0.07 0.16 0.03 0.02	2.9 0.37 0.02 2.83	0.27 0.28 0.13 0.11	0.16 2.24 0.13 2.5	0.001 0.001	0.002 0.002	1.74	1.94
The stresses formed in the wires or screws (MPa)	2	511	7 0.8	0.5 502	4 3	554 1.5	48 96 7	138 514 270	1.1 6.3	556 4.0	22 4	25 505	10.1 8.5	10.6 13.5	16.3	25.6

The Stresses Generated in the Cortical Bone Surrounding the Screws

In all of the models, the screws markedly subjected to the most stress were the screws located distal to the fracture of the corpus. The screws tied by a ligature extending from the screw placed in the anterior of the maxilla distal to the fracture of the corpus in model C, in which oblique ligation was performed were subjected to the most stress. In the model in which triangular ligatures were used, it was observed that the stress in the bone surrounding the screw was higher than it was in the other models. In the model fixated with a single plate placed inferiorly, the stress that forms in the cortical bone is close to the models where horizontal and triangular ligatures were used. Despite this, less stress formed in the bone as well due to less movement. Among the models of fixation with plates, the least stress formed in the scenario of fixation with a double plate. Increasing the number of plates and screws has contributed to the distribution of stress.

The Stress Formed in the Wires and Plates

In models of MMF, the ligatures that are subjected to the most stress are those tied to the screw that is placed posterior to the fracture of the corpus (min 502; max 556). In these areas where the effect of muscular forces is most evident, the wires also receive the most force. In the area where the parasymphysis fracture is, minimal stresses formed in the wires (max. 96 MPa - Model D). While very little stress formed with vertical ligation in the area where the parasymphysis fracture is 22 Mpa (max), an increase occurred with triangular ligation (max 96 Mpa). However, in ligatures tied obliquely, the increase is particularly high in wires tied distal to the corpus (max. 556 MPa- Model E).

In the models where fixation was performed using plates, more stress was measured in fixation with one plate placed inferiorly when compared to using double plates. In the model of double plates, the stresses formed on the plates are segregated from fixation by MMF. In fixation with MMF, while the stress received by the screws and wires in the region of the parasymphysis fracture was rather low when compared to the corpus area, in fixation with plates, the stress values measured in both

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fracture areas were similar. The comparison of the stresses formed in the cortical bone and plate shows that the plate is subjected to more stress than.

DISCUSSION

There are studies that show treating by closed reduction and MMF have a lower risk of complications than ORIF12, 13. In a study performed that investigated infection, nonunion, osteomyelitis, tissue opening, malocclusion, and nerve injuries, the complication rate of MMF was 9.1%, and this rate is 29.2% for treatment with ORIF14. However, Moreno et al. have reported that closed reduction and treatment with MMF is the treatment option where infections are encountered the least, that the risk of complications and the severity of the fracture are correlated, and that the treatment method selected does not influence the complication rates.[15]

The complications of malocclusion and nonunion are more common in posterior fractures.[14,15,16] In the study we conducted, excessive movement on the posterior fracture line supports the fact that the risk of nonunion is higher in posterior fractures than it is in parasymphysis fractures. It is clear that establishing stability on posterior fracture lines is harder than it is in anteriorly located fractures. As the fracture line slides posteriorly, it is thought that the effect of muscles on the segment that is distal to the fracture increases and consequentially displacement occurs. However, when ORIF is performed, the amount of displacement is significantly less. (max. 0,0003mm) In posterior fractures, the risk of malocclusion increases when treatment is applied using IMFS without ORIF. In minimally displaced symphysis fractures, sufficient occlusal control can be facilitated by a small number of IMFS.

Due to patient non-compliance and high screw loss ratios in closed reduction that will continue for 4-6 weeks, the use of IMFS remains in the background even though it is as successful as ORIF in terms of final occlusion and fracture healing in non-complicated fractures[17]. However, if internal fixation is not at the correct position and it is not rigid enough, the risk of postoperative malocclusion increases[15]. Hence, the proper application of MMF is a factor that increases the success of treatment. Placing IMFS balanced with a symmetrical distribution in a case with multiple fractures reduces the amount of displacement. In our study, it was observed that the vertical ligation method that is used commonly has been rather successful. However, it is seen that placing screws close to the fracture line, both distal and medial to the fracture, and horizontal ligation contributes to stability. It is observed that excessive stress forms in the wires and screws when oblique ligation is performed. Vertical and horizontal ligation of IMFS placed in the maxilla and mandible are regarded as the most ideal ligatures. When the amount of displacement under masticatory force is taken into consideration IMFS and MMF is a reliable method.

The screw loosening or falling out are also common complications. The length of the IMFS depends on the amount and density of bone in the region it is placed in and anatomical structures.[18,19] In the finite element analysis we performed, it is seen that the stress formed in the cortical bone surrounding the wires and screws increases significantly as the location of the IMFS slides towards the posterior. Due to this stress, the risk of screw loosening increases. Because screws are assessed under ideal biological conditions in finite element analysis, the complications that may develop related to the screw and wires should be assessed in in vivo studies.

It has been reported that bone requires stresses between 1.4 and 5.0 MPa to maintain healthy bone.[20] Stress outside this range causes bone resorption. In this study, the analysis of oblique ligation in the left fracture line in model C shows that the amount of stress is much higher than the ratios stated by Rieger in the bone in the cervical part of those ligatured to the anterior screw from the screw distal to the posterior fracture (max. 14.8MPa). Ligation of the screw to a screw distant from it leads to the formation of more stress than the bone can bear. In models in which oblique ligation was performed, it turns out that both the amount of displacement and the stress formed in the bone increases despite increasing the number of screws. In the models in which vertical ligation was performed, the stress formed in the bone is within biological ranges. Similarly, the stress formed in oblique ligatures also increases. As advanced to the posterior, the tension of the wires also increases.

In finite element analysis, the distribution of stress varies based on geometric modeling, material properties, and the boundary conditions. While preparing the structure of the mesh, reducing the sizes of the elements and increasing their number increases the sensitivity of the analysis and helps to obtain results close to actual values. Due to the properties the mandible possesses, its structure is nonhomogeneous and anisotropic. Due to these characteristics, it has different

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strain and elasticity module values depending on tensile stresses under compression stresses.[21] In this study, a model based on the HU values was created to be able to transfer the nonhomogeneous and anisotropic properties of the mandible and to define the material properties of the bone. Our defining of the material properties of the bones in such a manner helped us obtain a model that reduced assumptions.

One limitation of this study is that, in the study using finite element analysis models, during modeling, a fixated structure was formed under the assumption that the IMFS was placed in the bone with high torque under ideal conditions. However, in practice, the stability required may not be achieved due to the resorption that might occur or procedural errors. In treatment with closed reduction, depending on the long-term need to use IMFS, loosening of the screws or wires, and even screw losses can develop. Although the finite element analysis which assesses ideal conditions, provides results through mathematical analysis, biological responses could be different. Another imitation of the study is that it was performed in a near-ideal occlusion. It was considered possible that non-ideal occlusion could affect the fragment spacing and stress distribution. However, the evaluation of different occlusion types in such studies may lead to an excessive number of scenarios and confusion in the evaluation of the study results.

CONCLUSION

The assessment of the analysis performed shows that the balanced placement of IMFS enables the formation of a stable structure on the fracture line. It was observed that the immobilization of the segments was facilitated when the segments distal to the mandibular fracture are equally fixated to the maxilla with IMFS bilaterally. In this scenario having two fracture lines, it was discovered that independent from numbers, it is necessary to create a symmetric structure for the fixation of the segment that is in the middle of the fracture lines. It is required to increase clinical studies and to assess treatment results to develop the ideal algorithm for the use of IMFS.

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REFERENCES

1. Champy M, Loddé JP, Schmitt R, et al. Mandibular osteosynthesis by miniature screwed plates via a buccal approach. J Maxillofac Surg. 1978;6(C):14-21. doi:10.1016/S0301-0503(78)80062-9.
2. McGinn JD, Fedok FG. Techniques of maxillary-mandibular fixation. Oper Tech Otolaryngol - Head Neck Surg. 2008;19(2):117-122. doi:10.1016/j.otot.2008.04.003.
3. Qureshi AA, Reddy UK, Warad NM, et al. Intermaxillary fixation screws versus Erich arch bars in mandibular fractures: A comparative study and review of literature. Ann Maxillofac Surg. 2016;6(1):25-30. doi:10.4103/2231-0746.186129.
4. Gibbons AJ, Hodder SC. A self-drilling intermaxillary fixation screw. Br J Oral Maxillofac Surg. 2003;41(1):48-49. doi:10.1016/S0266-4356(02)00277-2.
5. Sundar SS, Nandal B, Saikrishna D, Mallesh G. Finite Element Analysis: A Maxillofacial Surgeon´s Perspective. J Maxillofac Oral Surg. 2011;11(2):206-211. doi:10.1007/S12663-011-0319-5.
6. Lisiak-Myszke M, Marciniak D, Bielinski M, Sobczak H, Garbacewicz L, Drogoszewska B. Application of Finite Element Analysis in Oral and Maxillofacial Surgery-A Literature Review. Materials (Basel) 2020;13(14):3063.doi:10.3390/ma13143063.
7. Choi BH, Yoo JH, Kim KN, et al. Stability testing of a two miniplate fixation technique for mandibular angle fractures. An in vitro study. J Cranio-Maxillofacial Surg. 1995;23(2):122-125. doi:10.1016/S1010-5182(05)80460-3.
8. Feller KU, Schneider M, Hlawitschka M, et al. Analysis of complications in fractures of the mandibular angle - A study with finite element computation and evaluation of data of 277 patients. J Cranio-Maxillofacial Surg. 2003;31(5):290-295. doi:10.1016/S1010-5182(03)00015-5.
9. Bujtr P, Sndor GKB, Bojtos A, et al. Finite element analysis of the human mandible at 3 different stages of life. Oral Surgery, Oral Med Oral Pathol Oral Radiol Endodontology. 2010;110(3):301-309. doi:10.1016/j.tripleo.2010.01.025.
10. Zhang Y, Ahn PB, Fitzpatrick DC, et al. Interfacial frictional behavior: cancellous bone, cortical bone, and a novel porous tantalum. BIOMATERIAL. J Musculoskelet Res. 1999;3(4):245-251. doi:10.1142/S0218957799000269.
11. Kim H-S, Lee Y-K, Park J-Y. Development of FEA procedures for mechanical behaviors of maxilla, teeth and mandible. Int J Precis Eng Manuf. 2016;17(6):785-792. doi:10.1007/s12541-016-0096-7.
12. Korioth TWP, Romilly DP, Hannam AG. Three-dimensional finite element stress analysis of the dentate human mandible. Am J Phys Anthropol. 1992;88(1):69-96. doi:10.1002/ajpa.1330880107.

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13. Chang C-L, Chen C-S, Huang C-H, et al. Finite element analysis of the dental implant using a topology optimization method. Med Eng Phys. 2012;34(7):999-1008. doi:10.1016/j.medengphy.2012.06.004.
14. Lamphier J, Ziccardi V, Ruvo A, et al. Complications of mandibular fractures in an urban teaching center. J Oral Maxillofac Surg. 2003;61(7):745-749. doi:10.1016/S0278-2391(03)00147-2.
15. Moreno JC, Fernández A, Ortiz J a, et al. Complication rates associated with different treatments for mandibular fractures. J Oral Maxillofac Surg. 2000;58:273-280-281. doi:http://dx.doi.org/10.1016/S0278-2391(00)90051-X.
16. Ansari K, Hamlar D, MD DDS, et al. A Comparison of Anterior vs Posterior Isolated Mandible Fractures Treated With Intermaxillary Fixation Screws. Arch Facial Plast Surg. 2011;13(4):266-270.
17. West GH, Alan Griggs J, Chandran R,et al. Treatment outcomes with the use of maxillomandibular fixation screws in the management of mandible fractures. J Oral Maxillofac Surg. 2014;72(1):112-120. doi:10.1016/j.joms.2013.08.001.
18. Coletti DP, Salama A, Caccamese JF. Application of Intermaxillary Fixation Screws in Maxillofacial Trauma. J Oral Maxillofac Surg. 2007;65(9):1746-1750. doi:10.1016/j.joms.2007.04.022.
19. Rai A, Datarkar A, Borle RM. Are maxillomandibular fixation screws a better option than erich arch bars in achieving maxillomandibular fixation? A randomized clinical study. J Oral Maxillofac Surg. 2011 ; 69 (12) : 3015 - 3018 . doi: 10.1016 /j.joms. 2010. 12.015.
20. Rieger MR, Mayberry M, Brose MO. Finite element analysis of six endosseous implants. J Prosthet Dent. 1990;63(6):671-676. doi:10.1016/0022-3913(90)90325-7.
21. Geng J-P, Tan KBC, Liu G-R. Application of finite element analysis in implant dentistry: A review of the literature. J Prosthet Dent. 2001;85(6):585-598. doi:http://dx.doi.org/10.1067/mpr.2001.115251.