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Biomechanical study to use the magnesium plates for the treatment of mandibular fractures

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Abstract
Magnesium alloy has recently been the subject of fracture fixation studies [1, 2]. The Young's modulus (42 GPa) of magnesium alloy is closer to the natural bone than titanium alloy (96 GPa), thus can reduce the stress shielding effect. As Mg alloys are biodegradable, there is no need for secondary surgery to remove the implant[1]. Compared with titanium plates, Mg plates have two times weak Young's modulus and five times weak strength. This study aimed to evaluate the mechanical behavior of the straight Mg alloy plates and mandible used for the treatment of various mandibular fractures (symphysis, parasymphysis and angle) using finite element method. The analyzed parameters are the average stress value at the critical section of the plate and the gap displacement of the fragments at the fracture surface. The results of the study confirm the clinical applicability of the straight magnesium alloy plate through the displacement of the fracture fragments and the stress distribution in the mandible and plate.

Keywords: Biomechanics, Finite element analysis, Mandibular fractures, Magnesium plates

1. Introduction

1.1 computational model

1mm CT images were taken from intact human skull. The imfinite element analysis, mandibular fractures, magnesium platesages are combined to obtain a 3D model. The obtained 3D model is imported to the design support software SolidWorks 2020, remove teeth and other parts which are not participate in the analysis, complete the calculation model of the intact mandible and transfer to the analysis software ANSYS.
Computational model of the plate and screws are created using SolidWorks 2020 and import to the analysis program ANSYS (Fig. 1).

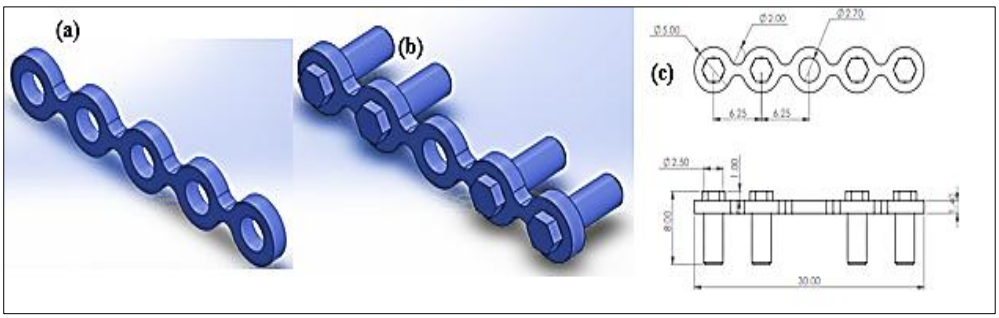

Fig 1: (a) Mg plate (b) assembly of plate and screw (c) Dimensions of the plates and screw.

From the calculation model of the intact mandible, we created symphysis, parasymphysis and angle fractures by SolidWorks 2020.
To increase the mesh density, we formed parts in the fractured zone and made holes to place the screws. Then, place Mg plates and screws in the fracture zone, complete the fractured calculation model and transfer it to the analysis software ANSYS.
In our study, parasymphysis, angle, and condylar fractures were placed on the right side of the mandible (Fig. 2).

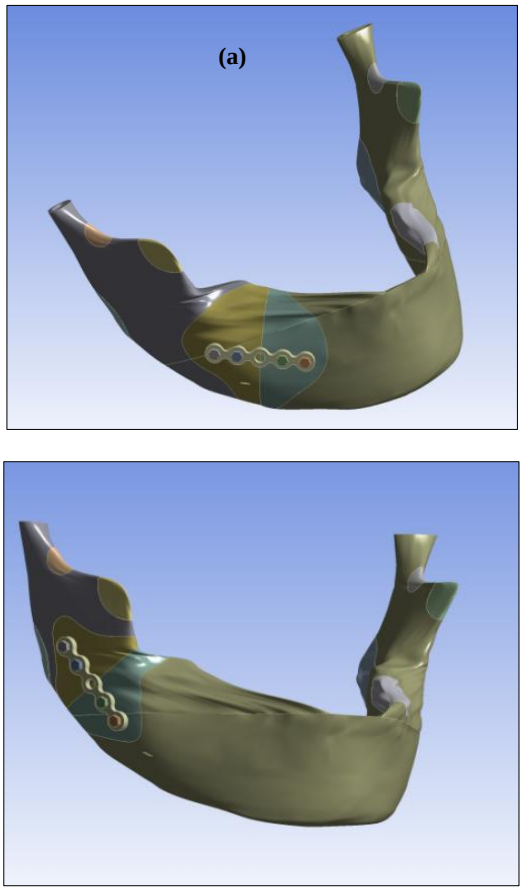

Fig 2: (a) Model of angle fractured calculation, (b) Model of parasymphysis fractured calculation.

1.2 Load and Boundary Conditions

The magnitude of the muscle forces and their coordinate components, as presented by Coombs, Meyer and Putz [3-5], were used for analysis (Table 1, Fig. 3).

Table 1: Reaction of masticatory muscle corresponding to maximum masticatory condition

Masticatory muscle	F /N	F_x / N	F_y / N	F_z / N
Anterior temporalis	400	-100	385	-45
Posterior temporalis	164	-50	120	-100
Medial pterygoid	300	135	265	40
Lateral pterygoid	400	130	55	375
Masseter	400	-	390	90

The muscles were positioned at each side of the mandible at symmetric positions in relati-on to the sagittal plane. Table 1 shows bilateral muscular loading conditions corresponding to maximum masticatory force. However, patients are instructed to avoid this maximal occlusal force most often after surgery. According to Tate GS [6] *et al*., the postoperative biting force measured in patients was up to 63N in the anterior teeth and 135N in the posterior teeth 4 weeks after surgery.

Considering the quasi-linear relationship between occlusal force and muscle force, postoperative masticatory force was applied to the maximum load condition by multiplying the reduction factor. According to Daniela Schubert [10], the utilization of the working and balancing sides in unilateral mastication is 1:0.67. Thus, we applied this ratio to bilateral masticatory load to simulate unilateral mastication.

In all simulations, displacement constraints were applied to the condyles and masticatory surfaces.

For physiological movement of the condyles, the displacements of X, Y, Z axes (3 degrees of freedom) of both condyle surfaces shown in yellow in Fig. 3, were constrained.

In addition, the displacement in the Y-axis (1 DOF) of the frontal teeth for bilateral masticatory simulation and of the molar teeth for unilateral masticatory simulation was constr-ained.

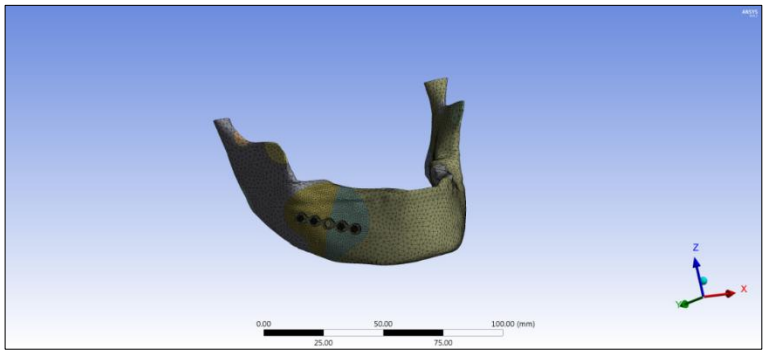

Fig 4: Mesh overview on the fracture region.

2. Results and discussion

Fig. 5 shows the maximum principal stress distribution with maximum masticatory load in the healthy mandibular computational model, with a maximum stress of 165.1 MPa at the mandibular ramus.

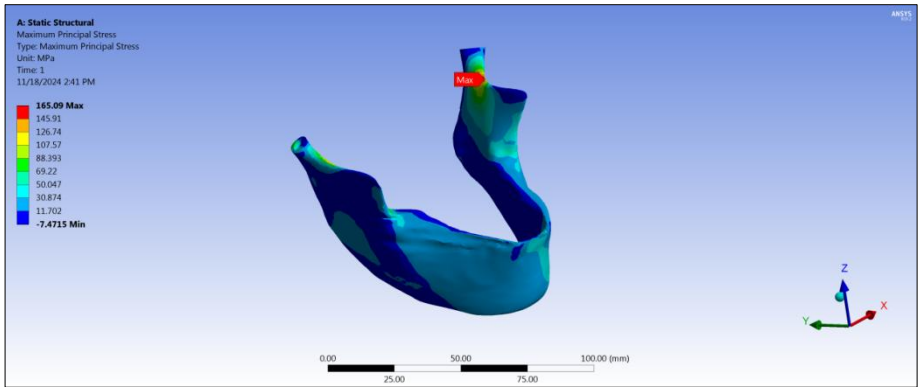

Fig 5: Maximum principal stress distribution in a healthy mandibular computational model during frontal mastication

The magnitude of the maximum principal stress in the external surface of the mandible is 30-40 MPa at the symphysis and parasymphysis fractured sites and 5-15 MPa at the fracture sites of the angle. The reaction force at the condyles and occlusal surface during maximum masticatory load in the healthy mandibular calculation model are shown in Table 3.

Table 3: Reaction of healthy mandibular condyle surface and occlusal support during maximal masticatory loading

Masticatory site	Left condyle reaction /N	Masticatory surface reaction /N	Right condyle reaction /N
Frontal region	1025.9	547.45	994.75
Molar region	786.78	680	694.57

The results in Table 3 show that the occlusal force of the frontal teeth in healthy mandible is 547 N, and the occlusal force of the molars is 680 N, which is comparable to the experimental data reported by other researchers.
According to Tate GS[6], biting force at incisors and molars were 63N and 135N respectively 4 weeks after surgery. Comparing this data with our measurements, we determined reduction factor of frontal and molar mastication as 0.115, 0.199 respectively.
The Von-Mises stress distribution in the angle fractured model with this reduction factor is shown in Fig. 6.

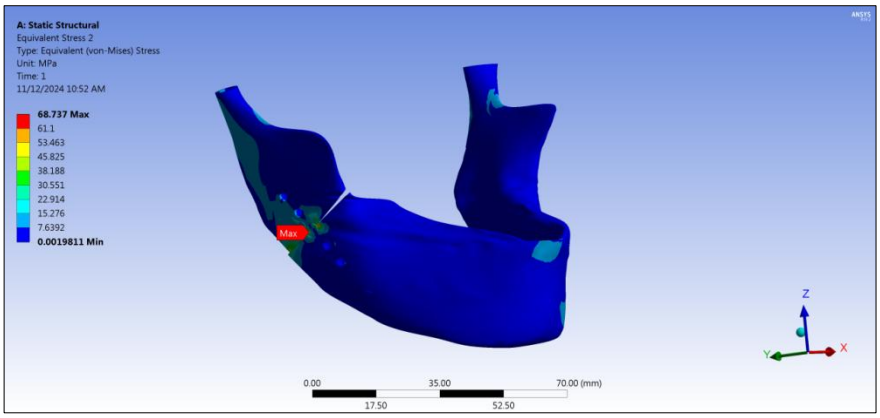

Fig 6: Stress distribution of the angle fractured model during frontal mastication

In all cases, the stress in the mandible ranged from 14.4 to 16.2 MPa. Table 4 shows the reaction forces at condylee and masticatory surfaces in all computational models.

Table 4: Reaction in the condyle and masticatory surface

Masticatory site	Fracture position	Left condyloid reaction /N	masticatory surface reaction /N	Right condyloid reaction /N
Frontal region	symphysis	132.9	63.0	152.6
	parasymphysis	116.9	62.2	111.7
	angle	119.1	63.34	114.1
Molar region	symphysis	77.7	135.36	97.3
	parasymphysis	105.7	125.63	117.6
	angle	103.5	134.45	111.8

In all computational models, the quasi-linear relationship between the muscle force and the masticatory reaction force was reflected. Table 5 shows the average tensile stress magnitude in the critical section in all the computational models.

Table 5: Mean tensile stress in the critical section of the plate

Masticatory site	Fracture position	Stress(MPa)
Frontal region	Symphysis	18.65
	Parasymphysis	93.82
	Angle	43.9
Molar region	symphysis	5.71
	parasymphysis	44.78
	angle	27.04

The magnitude of the average stress in the frontal mastication condition is 2~3 times larger than that in the molar mastication condition. The tensile stress values are

maximum in the parasymphysis fractured model, 93.8 MPa under frontal loading and 44.8 MPa under molar loading, which has a safety factor of more than 2 compared with the mechanical properties of Table 2.

The relative displacement of the fragments is the gap displacement of the fractured surface.

Table 6 shows the maximum value of the gap displacement in all the computational models.

Table 6: Maximum value of the gap displacement

Masticatory site	Fracture position	gap displacement /μm
Frontal region	Symphysis	35
	Parasymphysis	19
	Angle	145
Molar region	Symphysis	20.4
	Parasymphysis	8.7
	Angle	87

The calculated results show that the lateral displacement of the angle fractured model during frontal and molar mastication is maximum with 145μm, 87μm, and the gap displacement of the parasymphysis fractured model is the most stable with 19μm, 8.7μm.

Past finite element study of mandibular fracture treatmen reported that proper healing requires a maximum displacement of less than 150 μm at the fracture [8, 9]. The gap displacements in all fractured model were less than 150μm of the reference value.

3. Conclusion

Our results confirm the clinical applicability of the present straight Mg plate in the symphysis, parasymphysis and angular fractures.

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Conflict of interests

The author declares no conflict of interest.

Disclosure statement

No potential conflict of interest was reported by the authors.

Data Availability

The data that support the findings of this study are available within the article.

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