Rigid Internal Fixation Methods of Unilateral Condylar Neck Fracture Combined with Contralateral Parasymphyseal Fracture

Running title: Unilateral condylar neck fracture

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Abstract: One of the most important factors for ensuring the success of fracture treatment is determining the local mechanical environment of rigid internal fixation. This work aims to determine an effective treatment for unilateral condylar neck fracture combined with contralateral parasymphyseal fracture by selecting a rigid internal fixation method from a biomechanical perspective. First, the model for the unilateral condylar neck fracture combined with contralateral parasymphyseal fracture was established. Then, a 3D finite element method was used to analyze the nodal displacement isograms and the von Mises stress isograms of the mandible, as well as the maximum von Mises value in the fixation plate with single titanium or double titanium miniplate fixation of the condylar neck. When the condylar neck was fixed with a single titanium miniplate, the displacement value of the mandible decreased in the right fracture section, but increased in the middle and the left fracture sections. The stress trajectories were interrupted at the left external oblique line and the right sigmoid notch. The maximum von Mises value in the fixation plate was 574.179 MPa. When the condylar neck was fixed with double titanium miniplates, the stress trajectories were not interrupted. Compared with using single miniplate fixation, the nodal displacement of the right fracture section was greater, whereas those of the middle and the left fracture sections were lower when double miniplate fixation was employed. The maximum von Mises values in the posterior and the anterior border of the miniplate were 263.324 and 199.122 MPa, respectively. Thus, for unilateral condylar neck fracture combined with contralateral parasymphyseal fracture, the fixation effect is better when double titanium miniplates are used on the condylar neck compared with using a single titanium miniplate.

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Keywords: condylar neck fracture; parasymphseal fracture; rigid internal fixation; 3D finite element; biomechanical; displacement

1. Introduction

Owing to its protrusion position, the mandible is vulnerable to external shock, which can cause fractures. Previous studies show that although the predilection sites of mandible fractures vary in different countries and regions, they are predominantly located in the condyle, the mandibular body, the mandibular symphysis, the parasymphyseal, and the mandibular angle (de Matos et al., 2010; Park et al., 2010; Chrcanovic et al., 2012). Zhou et al. (2013) showed that 48% of 549 patients with mandibular fracture were experiencing condylar fractures, 42.1% of which were cases of unilateral condylar neck fracture combined with contralateral parasymphyseal fracture. The use of conservative treatment or open reduction internal fixation to treat condylar fractures in adults remains controversial (Parascandolo et al., 2010; Vesnaver et al., 2012). However, for displaced fractures, most doctors adopt open reduction followed by fixation with miniplate, cortical screw, Kirschner wire, and interosseous wiring for accurate reduction and early functionating.

Experts disagree on which method is more effective in the miniplate fixation of condylar neck fractures, that is, the use of a single miniplate or utilization of double miniplates. Based on previous studies (Choi et al., 1999, 2001; de Matos et al., 2010; Parascandolo et al., 2010; Park et al., 2010; Chrcanovic et al., 2012; Vesnaver et al., 2012), single titanium miniplate is more commonly employed in rigid internal fixation of condylar neck fractures. However, this fixation method presents complications in certain cases; such complications include fracture malunion, occlusal disorders, fixation plate fracture, and screw loosening. A number of scholars believe that greater fixation stability can be achieved by using double miniplates (Meyer et al., 2002, 2006; Aquilina et al., 2013). However, double miniplate fixation poses greater surgical trauma. Parascandolo et al. (2010) used 3D finite element method to observe the width of a right condylar neck fracture after these two types of fixation. Results showed that the greater fixation stability was achieved when double miniplates were used compared with using a single miniplate. Giannoudis et al. (2007) proposed that the healing process of a fracture not only involves the growth factor, the bracket, and the mesenchymal stem cells, but the mechanical environment as well, which is an important factor that is often overlooked. Having a good mechanical environment is one of the necessary conditions for fracture healing. However, the mechanical environment of the internal fixation of multiple mandibular fractures is more complex than that of a single fracture. In clinical studies, selecting a fixation method that satisfies biomechanical requirements has become one of the key factors to ensure the successful treatment of multiple mandibular fractures. Whether the fixation of unilateral condylar neck fracture (I or V, vertical mandibular unit) combined with contralateral parasymphyseal fracture (III, central mandibular unit) in the mandible (Loukota et al., 2005; Buitrago-Téllez et al., 2008) using a single titanium miniplate or double miniplates can satisfy the requirements for stability and mechanical environment has not been reported. In this study, 3D finite element method was used to analyze the displacement isograms and von Mises stress isograms of the mandible, as well as the maximum von Mises value of the fixation plate with two fixation methods. This study aims to provide a biomechanical basis for the use of double miniplate fixation to treat unilateral condylar neck fracture combined with contralateral parasymphyseal fracture.

2. Materials and Methods

2.1 D digital model establishment

The CT image data of the exsomatized mandible with complete dentition of an adult male cadaver were input in MIMICS 8.11 software. The grayscale threshold was then defined to achieve the recognition of the cortical bone, the cancellous bone, and the teeth. After trimming using Geomagic Studio 8.0 software, the data were input into ANSYS 10.0 software to establish the 3D digital model of a normal mandible. Then, incision on the normal model was performed using Boolean operations to establish the model of a right condylar neck fracture combined with left parasymphyseal fracture. The fracture fissure was simulated with a thin layer (1 mm). This study was conducted in accordance with the declaration of Helsinki. This study was conducted with approval from the Ethics Committee of School of Stomatology, Fourth Military Medical University. Written informed consent was obtained from participant.

Clinically common four-hole titanium miniplates were used for fixation. A cylindrical fixation screw (diameter: 1.5 mm; length: 7 mm) was used in connecting the miniplate to simplify the calculation (Knoll et al., 2006). The left parasymphyseal fracture was fixed using double miniplates, which were located at the inferior border of the mandible and below the root apex, with a distance greater than 0.5 cm (Figure 1). The right condylar neck fracture was fixed using a single miniplate (along the exterior border, method 1) and double miniplates (along the posterior exterior border and anterior exterior border, method 2).

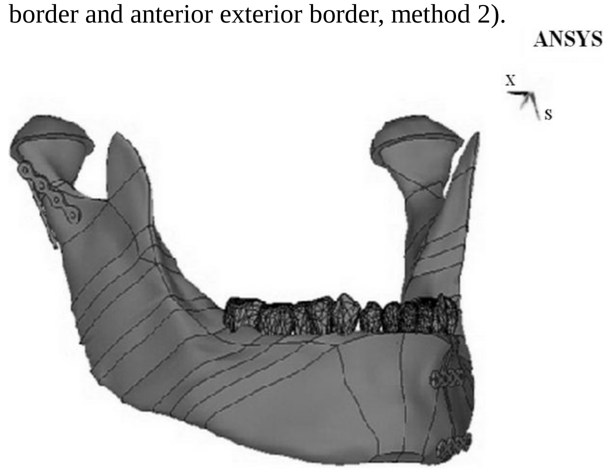


Figure 1 3D digital model of combined mandibular fracture with rigid internal fixation

2.2 Material parameter

The mechanical parameters of different materials are shown in Table 1. Linear and homogeneous elastic materials were selected in this study based on previous report (Kimura et al., 2006; Knoll et la., 2006; Mori et al., 2010; Wong et al., 2012). Using ANSYS 10.0 software, the hexahedron unit was selected for the unit division and the establishment of the 3D finite element model. The details of 3D finite element analysis are as follows: the 3D CT data of the mandible and teeth were obtained, and then the cortical bone, cancellous bone and teeth by defining gray threshold in MIMICS 8.11 software (the 3D data processing software) were identified; followed the data were corrected by the Geomagic Studio 8.0 software (the 3D data processing software). The corrected model data were imported into the ANSYS 10.0 software (the 3D finite element analysis software) and the 3D finite element models of the mandible were obtained under the setting parameters. The material and mechanical parameters were also set to be 3D spatial parameters. The node displacement isolines map of the mandible and the node von Mises stress isolines map are all described in 3D spaces were observed.

Table 1. Mechanical parameters of tissue structures and material

Tissue or material	Elastic modulus (MPa)	Poisson ratio
Cortical bone	8700	0.3
Cancellous bone	100	0.3
Articular disc	30.9	0.4
Tooth	2.0×10^4	0.3
Titanium miniplate	1.05×10^5	0.3

Functional load was exerted on three groups of muscles, namely, masseter (superficial, deep), temporalis (anterior, posterior), and medial pterygoid muscles, which are closely related with jaw movement (Parascandolo et al., 2010; Wong et al., 2012). The 3D muscle vectors are shown in Table 2.

Table2. 3D vectors of muscles related to jaw movement

Muscle	Left	Right
Masseter (superficial)	21.83i-91.11j-48.09k	-21.83i-91.11j-48.09k
Masseter (deep)	23.33i-35.31j-10.44k	-23.33i-35.31j-10.44k
Temporalis (anterior)	-30.07i-51.84j-18.35k	30.07i-51.84j-18.35k
Temporalis (posterior)	11.62i-47.49j-56.15k	-11.62i-47.49j-56.15k
Medial pterygoid muscle	10.25i+18.48j-41.33k	-10.25i+18.48j-41.33k

Note: i, j and k represented x, y and z axis in coordinate system, respectively

Two volumetric models were established in the interspace between the left and the right articular surfaces and in the corresponding mandibular articular fossa to simulate the articular disc structure. The constraint with full freedom was exerted on the outer surface of the two volumetric models so that the mandibular articular head could only freely rotate in the articular fossa with jaw movement rather than translation motion (Figure 1). Another constraint with full freedom was exerted on the bilateral occlusal surfaces of the first molar to simulate the occlusal state.

2.3 Observation indices

After performing the two types of fixation, the mandible nodal displacement isograms (which reflect fixation stability), the von Mises stress isograms (which reflect the stress conduction inside the mandible), and the maximum von Mises values of the miniplates (which reflect the mechanical environment of the fixation material) were observed.

3. Results

3.1 Nodal displacement isograms

As shown in Figure 2, when the occlusal load was applied on the normal mandible, the bilateral nodal displacement isolines were symmetrically distributed with continuous transition. The minimum displacement was located in the condyle. The displacements of the coracoid process and the mandibular angle were greater, and decreased gradually along the ascending branch to the condyle and along the mandibular body to the mental region, respectively. When the occlusal load was applied on the mandible fixed with method 1, the bilateral nodal displacement isolines were not symmetrical, with obvious interruption at the junction of the fracture section and continuous transition inside the fracture section. The displacements of the left and the middle fracture sections were greater than those in the normal mandible, and the displacement of the right articular head fracture section obviously decreased. The nodal displacement isograms of the mandible fixed with method 2 were essentially similar with those of the mandible fixed with method 1. However, the displacements of the left and the middle fracture sections of the mandible fixed with method 2 decreased compared with those of the mandible fixed with method 1. In the condylar neck fracture area, the displacement of the right articular head fracture section surrounding the lateral and the medial anterior fixation screw of the mandible fixed with method 2 was greater than that fixed with method 1. The lateral displacement was similar to, whereas the medial displacement was different from that of a normal mandible.

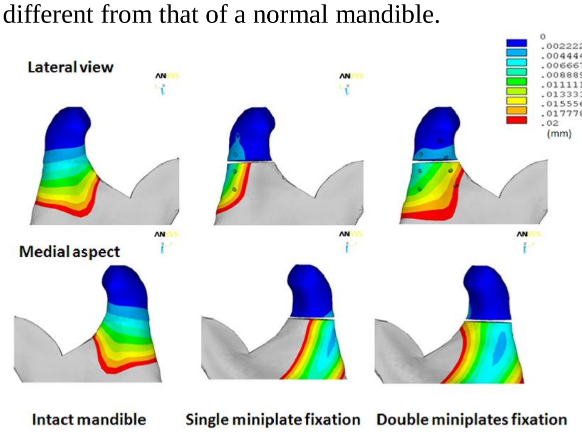
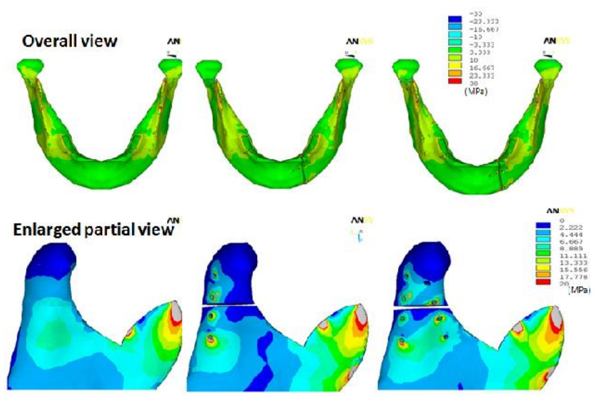


Figure 2: Nodal displacement isograms of right condyle with different fixation methods

3.2 Nodal von Mises stress isograms

The bilateral nodal von Mises stress isolines of normal mandible were symmetrically distributed with continuous transition. The stress conduction was from the mandible body to the mandibular angle. The stress trajectories were from the distal end of the posterior alveolar ridge, through the external oblique line and the anterior border of the mandible ramus, to the coracoid process. The stress trajectories behind the coracoid process were from the mandibular sigmoid notch to the condylar neck. For method 1, the bilateral von Mises stress isolines were not symmetrically distributed. The medial and lateral stress trajectories behind the right coracoid process from the mandibular sigmoid notch to the condylar neck and the left external oblique stress trajectories were interrupted. The stress of the anterior right condylar neck decreased significantly, with increased stress around the fixation holes. For method 2, the bilateral von Mises stress isolines were not symmetrically distributed. Compared with method 1, the lateral stress trajectories behind the right coracoid process from the mandibular sigmoid notch to the condylar neck were not interrupted. However, the medial stress trajectories were interrupted. The left external oblique stress trajectories were not interrupted. The stress of the anterior right condylar neck of the mandible fixed with method 2 was greater than that of the mandible fixed with method 1, but was lower than that of the normal mandible. The stresses around the fixation holes increased (Figure 3).



Intact mandible Single miniplate fixation Double miniplates fixation

Figure 3: Nodal von Mises stress isograms with different fixation methods

3.3 Fixation plate value

When the functional load was exerted on the mandible fixed with method 1, the maximum von Mises value of the miniplate was 574.179 MPa, which was located at the posterior border of the proximal articular head fracture section. For method 2, the maximum von Mises values in the posterior and the anterior borders of the miniplate were 263.324 and 199.122 MPa, respectively, and were located at the middle part of the miniplate posterior border.

4. Discussion

Direct healing is the ideal form of fracture repair. The objective of rigid internal fixation is to maintain the stability of the fracture section and to tolerate the functional load. However, in most clinical cases, micro-movement at the fracture end still exists after rigid internal fixation, and external callus forms during the process of healing. A number of scholars believe that the formation of external calluses is in fact a compensation for the unstable fixation. Appropriate micro-movement can stimulate the formation of external calluses. However, excessively strong micro-movement would affect fracture healing (Giannoudis et al., 2007). Therefore, maintaining the relative stability of the fracture end and recovering the principal stress trajectories have become the most important standards for assessing whether the fixation method can satisfy the requirements.

In this study, compared with the normal mandible, the nodal displacement isolines of the mandible fixed with the two methods both changed. The isolines were distributed at the fracture section and interrupted at the junction of the two fracture sections, with continuous transition inside the fracture section. This finding indicates that relative displacement exists between the fracture sections. The mandible fixed with double miniplates was found to be more stable than that fixed with a single miniplate, particularly in the anterior lateral area of the right condyle neck.

Results of stress-bearing observation showed that the stress conduction trajectories in the mandible fixed with a single miniplate were interrupted at the left external oblique line and the right sigmoid notch, whereas those in the mandible fixed with double miniplates were not interrupted. For single miniplate fixation, the stress was borne by the titanium miniplate at the right condylar neck, and the stress was conducted at the posterior border of the condylar neck from the titanium miniplate to the articular head fracture section. The stress at the anterior articular head fracture section was lower than that of the normal mandible. For double miniplate fixation, the stress was borne and conducted by two miniplates. The stress distribution in the articular head fracture section was closer to that of the normal mandible that that of the mandible fixed with single miniplate. This finding indicates that the fixation stability and the stress-bearing capability of double miniplate fixation are better than those of single miniplate fixation. These results are consistent with previous research (Choi et al., 1999, 2010; Parascandolo et al., 2010).

According to the stress–strain curve (Wong et al., 2010), the elastic deformation of an elastic material occurs under stress above the yield strength; plastic deformation occurs under stress between the yield strength and the ultimate strength; and plastic damage occurs under stress above ultimate strength. The yield strength of a titanium miniplate is 290 MPa (Knoll et al., 2006; Christopoulos et al., 2012). In this study, the maximum stress on the titanium miniplate in single miniplate fixation was 574.179 MPa, which is greater than yield strength but lower than ultimate strength. Under occlusal load, the titanium miniplate produces plastic deformation. The single plastic deformation does not cause the fracture of the titanium miniplate. However, multiple plastic deformations may cause stress fatigue, resulting in titanium miniplate fracture. This phenomenon explains why partial cases fixed with a single titanium miniplate present fractures and complications. In double miniplate fixation, the maximum stress of each titanium miniplate does not exceed the yield strength. Thus, only elastic deformation occurs. The titanium miniplate is restored when the occlusal load disappears, thereby preventing the occurrence of titanium miniplate fracture and complications.

5. Conclusions

The use of double miniplate fixation on the condylar neck fracture area is a more effective treatment for unilateral condylar neck fracture combined with contralateral parasymphyseal fracture compared with single miniplate fixation. If double miniplate fixation cannot be performed because of conditional restrictions, then postoperative local braking, intermaxillary ligation, or postponing functional exercise should be conducted to reduce the stimulation on the mandible function, consequently reducing the occurrence of fracture malunion, occlusion disorder, fixation plate fracture, and other complications.

Conflict of Interest: None

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