Comparative evaluation of various miniplate systems for the repair of mandibular corpus fractures

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Miniplates have been used during the last decade to facilitate stability between bony fragments in the maxillofacial region and are currently the preferred surgical method for the fixation of fractures and osteotomies. The aim of this study was to evaluate and compare the biomechanical behaviors of six different types of miniplates used to reconstruct mandibular body fractures: Group 1 (straight, 2 holes, 12.0 mm spacing), Group 2 (straight, 4 holes, 9.0 mm spacing), Group 3 (straight, 6 holes, 9.0 mm spacing), Group 4 (L-shaped, 4 holes, 9.0 mm spacing, right hand plate), Group 5 (Y-shaped, 5 holes, 12.0 mm spacing), and Group 6 (double Y-shaped, 6 holes, 9.0 mm spacing). Thirty bovine hemimandibles and a custom-made 3-point biomechanical test frame mounted on a Shimadzu universal test machine were used to evaluate the six different miniplate systems. Results revealed that Group 1 (straight, 2 holes, 12.0 mm spacing) and Group 4 (9.0 mm spacing, right hand plate) had the lowest biomechanical stability, whereas Group 6 (6 holes, 9.0 mm spacing) had the highest biomechanical stability. Group 6 also provided statistically greater resistance to displacement than Group 1 and Group 4.

Keywords: Miniplates, Titanium, Rigid fixation

INTRODUCTION

Mandibular fractures are one of the most common facial skeletal injuries. They can be caused by road traffic accidents, assaults, falls, industrial injuries or sports injuries, but the relative number of each varies considerably between countries and areas. The body of the mandible is one of the most common fracture sites, followed by fractures at the condyle, angle, symphysis, ramus, and coronoid process⁴,⁵.

A mandibular fracture treatment depends on the arrangement of bone fragments in their anatomical position, and its goals are to stabilize the fracture and restore normal function with least morbidity. Treatment and repair of mandibular fractures has evolved over the years, and many repair techniques have been introduced: ranging from maxillomandibular fixation (MMF) and combinations of MMF and wire osteosynthesis to fixation with lag screws and reconstruction plates. In the last decade, rigid internal fixation using compression and noncompression plating systems has gained widespread popularity⁶-⁸. Miniplates have been used to facilitate stability between bony fragments in the maxillofacial region and are currently the preferred surgical method for the fixation of fractures and osteotomies. The advantages of using miniplates include easy handling and easy plate contouring and adaptation to the bone⁹. Miniplate osteosynthesis ensures adequate fracture stability, improves bone healing, and allows early functional mobilization⁹,¹⁰. Movement at the fracture site is a known predisposing factor for both infection and nonunion. It has been reported that the site of most nonunions was in the mandibular body⁹.

During fracture treatment planning, important decisions that must be made include determining the best position, orientation, and plate type and material. The first and foremost consideration is the rigidity of the repaired fracture section, and the second pertains to the level of stress generated in the miniplates under bite forces⁹. A variety of miniplates have been used to repair mandibular corpus fractures. In the original Champy version, a 4-hole miniplate without center space was used¹⁰. Today, although this type of plate is still applicable, alternatives that provide similar or incrementally higher stability have emerged. The aim of this study was to evaluate and compare the biomechanical behaviors of six different types of miniplates used to reconstruct mandibular body fractures.

MATERIALS AND METHODS

Hemimandible specimens

Fifteen mandibles obtained from similar bovines (mean weight of 220 kg, fed on the same diet, collected from the same abattoir, and slaughtered in similar manner) were used in this study. The mandibles were stripped of their soft tissues and divided into two pieces in the anterior midline between the central incisors. The specimens were kept moist until all tests were completed. Using a diamond disk, a uniform vertical cut was made on the mandibular corpus, in front of the first premolar, to
simulate a fracture.

**Miniplate systems**
The hemimandibles were randomly divided into six groups of five specimens per group. In each group, the hemimandibles were fixated by a different type of miniplate. These six groups of miniplate systems (Trimed®, Elektron Medikal, Istanbul, Turkey) are shown in Fig. 1 and were of the following configurations:
- Group 1 — Straight, 2 holes, 12.0 mm spacing.
- Group 2 — Straight, 4 holes, 9.0 mm spacing.
- Group 3 — Straight, 6 holes, 9.0 mm spacing.
- Group 4 — L-shaped, 4 holes, 9.0 mm spacing, right hand plate.
- Group 5 — Y-shaped, 5 holes, 12.0 mm spacing.
- Group 6 — Double Y-shaped, 6 holes, 9.0 mm spacing.

To reduce the influence of extraneous variables, all miniplates used in this study were made of Grade 4 Titanium and were 1 mm thick, and monocortical titanium screws were of 2 mm diameter and 5 mm length.

To avoid poor adaptation, the miniplates were pre-bent and adjusted. Screw holes were prepared using a drill, and a simulated osteotomy on the mandibular body was performed using an oscillating saw (Medicon, Tuttlingen, Germany), at a distance of 10 mm mesially in front of the first premolar tooth. The fractured segments were all repositioned and manually stabilized. After miniplates and screws were properly positioned, rigid fixation was performed in all groups.

**Biomechanical testing**
A custom-made 3-point biomechanical test frame (Tasarımmed) was mounted on a Shimadzu universal test machine (Autograph®, Trapezium 2 Software®, Version 2.23) using a methodology similar to that designed by Armstrong et al.10) (Fig. 2). Each hemimandible specimen was positioned to allow the load resistance of mandibular body fracture treated with miniplate osteosynthesis to be evaluated during simulated mastication (Fig. 3). The hemimandible was subjected to a compression test with a loading rate of 1 mm/min to simulate quasi-static conditions. The test machine recorded the resistance force against the load applied at a point 1 cm distally to the fracture line of the mandible. The load was measured as a unit of force in Newtons (N), and data were recorded from the start of the loading process until failure.

Failure was defined as fracture and/or osteotomy displacement, and the load was applied until loss of...
the integrity of bone-screw-plate system occurred. Maximum load was defined as the highest load recorded just before any sudden decrease in load level occurred (Fig. 4).

Statistical analysis
In each group, five hemimandible specimens were tested. Means of compression loads in six groups were statistically analyzed using Kruskal-Wallis test (SPSS 21.0).

RESULTS
Thirty hemimandibles were analyzed in this study, with five specimens in each of the six groups. Standardization of all experimental factors was ensured, except for the miniplate shape. Descriptive statistics of the six groups are shown in Table 1. Kruskal-Wallis test was used to compare the differences in median score between the groups. Group 1 (straight, 2 holes, 12.0 mm spacing) and Group 4 (L-shaped, 4 holes, 9.0 mm spacing) had the lowest biomechanical stability, whereas Group 6 (double Y-shaped, 6 holes, 9.0 mm spacing) had the highest biomechanical stability ($p<0.05$).

Pair-wise multiple comparisons showed that double Y-shaped miniplate with 6 holes and 9.0 mm spacing provided statistically greater resistance to displacement than straight miniplate with 2 holes and 12.0 mm spacing ($p<0.001$) and L-shaped miniplate with 4 holes and 9.0 mm spacing ($p<0.001$). In addition, the mean resistance score of Y-shaped miniplate with 5 holes and 12.0 mm spacing was greater than that of L-shaped plate with 4 holes and 9.0 mm spacing ($p=0.002$).

DISCUSSION
Literature review revealed that many studies have examined different kinds of rigid fixation methods in different locations of the mandible. Rigid fixation with titanium miniplates was reportedly a superior technique when compared with resorbable miniplates.$^{11-13}$

<table>
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<th>Table 1</th>
<th>Descriptive statistics of six groups of miniplate systems evaluated in this study</th>
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<tr>
<td></td>
<td>Mini plate systems</td>
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<td>Group 1 (straight, 2 holes)</td>
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<td>Group 4 (L shape)</td>
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<td>Group 5 (Y shape)</td>
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<td>Group 6 (double - Y shape)</td>
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<td>Number</td>
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<tr>
<td>Mean force (kN)</td>
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<td>Standard Deviation of the force (kN)</td>
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<tr>
<td>Median force (kN)</td>
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<tr>
<td>Minimum force (kN)</td>
<td>0.08</td>
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<tr>
<td>Maximum force (kN)</td>
<td>0.11</td>
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Therefore, the present study focused on evaluating the biomechanical stability characteristics of titanium miniplates of varied shapes instead of evaluating rigid fixation methods. The six types of miniplate systems were thus selected for this study because of the frequency of their use, based on our clinical experience and retrospective analysis of our cases. To ensure that only the biomechanical properties of the miniplates were purely tested in this study, only one miniplate fixation technique was used.

Mandibular corpus is one of the most frequently fractured sites after a traumatic event. Miniplate with screw fixation is reportedly a standard approach in managing mandibular fractures. In a report by Ellis\(^{14}\), other examples of rigid internal fixation include locking/non-locking reconstruction bone plates, multiple bone plates of the fracture site, single non-reconstruction bone plates, or multiple lag screws\(^{14}\). He stressed that anything less than rigid was non-rigid, and that these approaches provided sufficient strength to prevent fragmentary motion during function and allowed primary osseous union to proceed\(^{14}\).

In the original Champy technique, the use of a single stainless steel miniplate (1 mm thick) for the fixation of mandibular fractures was reportedly sufficient and accepted as rigid\(^{9}\). Arbag et al. also reported that one titanium miniplate (1 mm thick) positioned inferiorly provided good stability\(^{8}\). Nonetheless, in a two-miniplate fixation technique, where the first plate was positioned in the superior border as far as possible and the second plate in the inferior border, improved stability was obtained because of neutralized torsional forces at the fracture site and primary intraoperative anatomic alignment was achieved\(^{8}\).

Obviously, a two-plate technique is better if there is adequate bony substance on either side of the fracture line\(^{19}\). However, fixation with two miniplates might be a more traumatic procedure than fixation with a single miniplate\(^{8,17}\). Ellis and Walker reported that the single miniplate is the simplest and most reliable technique\(^{18}\). To the best of our knowledge, this is the first study which compared the biomechanical properties of six different types of miniplates via a 3-point biomechanical test frame, whereby fractured segments were fixed with one miniplate at each fracture region in the mandibular body.

The universal test machine used in this study recorded resistance force against the applied load until loss of the integrity of bone-screw-plate system occurred. Maximum load was defined as the highest load recorded just before any sudden decrease in load level occurred. Decrease in resistance force could be caused by plastic deformation and/or fracture of the miniplates and screws together with the increasing distance of the fractured segments.

Our results revealed that single and double Y-shaped plates demonstrated the highest biomechanical stability and provided significantly greater resistance to displacement than the other types of miniplates evaluated in this study. Y-shaped miniplates allow larger area coverage with more holes and screws, and this advantage provides the effect of double miniplates through a single construct. Additionally, Y-shaped miniplates prevent the rotational movements of immobilized fractured segments.

Our results also showed that single straight miniplate with double holes and single L-shaped miniplate presented the lowest biomechanical stability when compared with the other single miniplates. In a report by Matsushita et al.\(^{19}\), the combined use of a straight plate with a L-shaped plate presented significantly increased resistance force and improved rigidity\(^{19}\). Our results could not be compared with their study results\(^{19}\) because the design and methodology of the two studies were different from each other.

In the present study, the miniplates tested could not be discussed according to their number of holes because of different shape types. Nonetheless, Group 2 (straight, 4 holes, 9.0 mm spacing) and Group 3 (straight, 6 holes, 9.0 mm spacing) could be compared with respect to the number of holes as they were of the same plate shape with the same spacing between the holes (9 mm). The higher mean resistance score of Group 3 (p<0.05) indicated higher biomechanical stability than Group 2, which was an expected outcome because of a higher number of holes.

In the present study, resistance force was recorded and load was applied at a point 1 cm distally to the fracture line of the mandible. This location was selected for two-fold reasons: it was far enough from the dentate region of the mandible and that loading should not be located within the fracture zone.

Various methods have been used in previous studies to evaluate the biomechanical stability characteristics of titanium miniplates in vitro through the fixation of fractured mandibles. The wide variety of methods ranged from using different types of bone specimens, such as human cadaveric mandibles, animal mandibles (sheep, bovine, rabbit, etc.), bovine and porcine ribs, to artificial bone models (Synbone, Sawbones) and evaluation by finite element analysis. Bredbenner and Haug reported that different bone substitute materials behaved differently from human cadaveric bone in maxillofacial studies\(^{20}\). Using the bovine mandible instead of human mandible seemed to be a limitation of the present study.

Ideally, bone substitute materials should also alleviate concerns involving economic, ethical and health considerations associated with the use of cadaveric tissue. On the other hand, Alkan et al. claimed that fresh animal mandibles were the material of choice for this type of biomechanical studies as human cadavers may have natural variations that affect outcomes, and formalin fixation alters the physical properties of the human bone\(^{16}\). Fresh bovine mandibles were chosen for this study because they were easy to obtain and their use circumvented the aforementioned limitations and problems. In the present study, the bovine mandibles used had no effect on the biomechanical properties of the six types of miniplates under evaluation.
Functions such as mastication, phonation, and deglutition could not be replicated on the custom-made 3-point biomechanical test frame. In the present study, another limitation was the inability to evaluate the interactions at bone/plate/material interface and the specific behaviors of the reconstructed human mandible during the performance of these normal functions.

In the present study, the osteotomy mimicking the fracture line was located in the corpus, in the edentulous area in front of the first premolar tooth at a distance of 10 mm mesially. The location of the osteotomy line had no significance because the aim was to investigate the biomechanical properties of different miniplate designs at the same osteotomy line. Therefore, this region was chosen because of the ease of accessibility and monitoring during in vitro experimental procedures.

CONCLUSION

Double Y-shaped miniplate with 6 holes and 9.0 mm spacing had greater resistance to displacement and provided more favorable biomechanical behavior than the other five types of miniplates in the repair of mandibular body fractures.

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REFERENCES