Design of Clavicle Reconstruction Plate: Dependence of Biomechanical Strength on Plate Thickness

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A metallic bone plate for open reduction-internal fixation of clavicle fractures should have an enough biomechanical strength with as small profile as possible for the patient to feel comfortable with the implanted plate. To study the effect of the clavicle bone plate design on the strength of the plate, 3 types of reconstruction plate with a thickness at 2.45, 2.7, and 3.42 mm were developed, named as the thin, the standard, and the thick plate, respectively. The biomechanical properties of the plates were determined using a four-point bending test. The maximum bending load of the plate of the thin, the standard, and the thick design was, 212, 680, and 931 N, respectively, and the bending strength of the plate was 0.87, 3.85, and 4.18 N-m, respectively. Both the maximum bending load and the bending strength of the plates with the standard design and the thick design were comparable to the ones reported in the literature for commercial plates, but those of the plate with the thin design was smaller. Since the plate with the thick design occupies a larger space under the skin, the reconstruction plate with a thickness at 2.7 mm appears to be an optimal design for clavicular nonunion.

Key words: Clavicular nonunion, Reconstruction plate, Biomechanical study, Maximum bending load, Bending strength

Introduction

Clavicle fractures are very common, accounting for 5-10% of all fractures. Most of them are treated conservatively, as the healing rate without surgical intervention is very high.¹ The incidence of nonunion of clavicle fractures had been reported low at around 1%; however, Złowdkzi et al reported a much higher nonunion rate of 5.9% from a recent meta-analysis study of 2144 patients.²

Symptomatic nonunion usually requires a surgical intervention, known as the open reduction-internal fixation (ORIF), and various devices have been tried for ORIF such as plates and screws, intramedullar fixation devices, and external fixators. Plates and screws have advantages over the intramedullar fixation devices; it is difficult to navigate the curved clavicle medulla cavity with the intramedullar devices and the intramedullar devices have a lower resistance against rotational movement than the plates and screws.³ Many types of plates and screws have been tried for ORIF of clavicle non-union, including 2.7-mm dynamic compression, 3.5-mm reconstruction, 3.5-mm limited contact dynamic compression (LCDC), semi-tubular, and 1/3 tubular plates.⁴-¹³ Semi-tubular and 1/3 tubular plates frequently resulted in plate breakage due to lack of strength against high stresses and fatigue and are no longer recommended. Reconstruction plates have an advantage as they conform to the contour of the clavicle, and, thus are less prominent. Shahid et al reported that they had to remove the plate in 8 of patients who underwent the ORIF with a 3.5 mm dynamic compression plate due to the patients’ complaints about the prominence, but that there was no complaint from the patients from the group of 24 patients with a 3.5 mm reconstruction plate and thus none of the recon plates had to be removed.⁴ This result suggests that the 3.5 mm reconstruction plate is better than the 3.5 mm dynamic compression plate as far as the prominence problem is concerned. It would be desirable to have the plate thickness as small as possible for the patient to be more comfortable with the plate, but one has to worry that the plate could be broken due to lack of enough strength during the rehabilitation period.

To further minimize the prominence problem and the patient’s discomfort with the clavicle plate, we explored in this paper the possibility of decreasing the clavicle plate thickness from 3.5 mm. We designed reconstruction plates with smaller thickness, and examined the biomechanical strength of 3 design types of the reconstruction plate to optimize the plate profile.

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Materials & Methods

Designs of the reconstruction plate

The reconstruction plate was designed in 3 types as shown in Figure 1. The bottom of the plate is slightly concave to accommodate the superior convex surface of the clavicle. Three thicknesses were defined to describe the plate design: \( a \) is the screw contacting thickness and was the same for all 3 types of designs, \( b \) is the plate thickness and was varied from 2.45 mm to 3.42 mm, and \( c \) is the edge thickness, and it was varied from 0.4 mm to 1.33 mm. The group I design was aimed at minimizing the prominence problem and the plate thickness \( b \) was decreased by 9.1% from that of the plate in group II, and the thickness decreases steeply with the distance from the screw hole, and it reaches 0.4 mm at the edge, which is 34.1% of the edge thickness of the plate in Group II. This design was named a thin design. The plate in group III was designed to fortify the plate strength and the plate thickness was increased by 27% from that of the plate in Group II, and the edge thickness by 14%. This design was named a thick design. The design in group II was named a standard design. The details of the plate dimensions of the three designs are collected in Table I., and 3-dimensional diagrams of the designs are shown in Figure 2.

Bending test

Four test recon plates were manufactured for each design type using Titanium Grade 2 (ASTM F67). The Four-point bending test was done for each test plate, using universal test machine DUT-300CM (Daekyung Engineering Co. Ltd., Seoul, Korea), employing the ASTM F382 procedure that describes the standard specification and test method for metallic bone plates. The distance between the holes of the plate was 11 mm; the distance between the loading rollers, center span distance, was 22 mm, and the distance between the loading roller and supporting roller, loading span distance, was also 22 mm. The bending load was applied at a rate of 5 mm/min. 0.2% offset displacement in this study corresponds to 0.2% center loading span or 0.044 mm. The maximum bending load \( P \) and 0.2% offset displacement of a plate were determined from the load-displacement curve, shown in Figure 3. The bending strength was determined from the bending moment of the plate at 0.2% offset displacement from the following relationship:

\[
\text{Bending Strength} = \frac{(P \cdot h)}{2} \ [N-m]
\]

where \( P \) represents the load at 0.2% offset displacement and \( h \) the center span distance.

Results

The bending test results of a set of the recon plates with the design type I, II, and III are shown in Figure 3, and the results for 4 sets of the plates are summarized in Table 2, and plotted in Figure 4. The maximum bending load depended very strongly on the plate design; it decreased by a factor of 3.2, from 680(±38) N for the standard design to 212(±14) N for the thin design. Bending strength of the thin design also decreased remarkably by a factor of 4.4. On the other hand, the change in biomechanical properties of the plate from the standard design to the thick design was not remarkable; the maximum load increased by only 37% and bending strength only by 8.6%. There was no particular relationship found in 0.2% offset displacement among the 3 design types.

The maximum bending load was more sensitive to both the edge thickness and plate thickness than the bending strength (Figure 4). Both the maximum bending load and the bending strength of the plate increased consistently with the edge thickness, but the increase of the two values were negligible.
when the plate thickness was increased from 2.72 mm to 3.42 mm. Also the bending strength was more sensitive than the maximum bending load to both the plate thickness and edge thickness.

**Discussion**

Although the plate fixation has been a treatment of choice for clavicle malunion, there still remain problems from the patient’s perspective. The plate is prominent and sensitive to pressure, and some patients find it uncomfortable and often want to remove the plate after bone reunion. The thickness of the plates in group III is comparable to the 3.5 mm AO pelvic reconstruction plate that is commonly used for clavicle fractures, but the thickness of the standard design and the thin design are considerably smaller than the AO recon plate. Shahid et al reported that the patients with a 3.5 mm pelvic reconstruction plate did not find the plate too uncomfortable to ask for the removal of the plate due to the prominence problem. The plate thickness of the standard and thin designs of the plates in this study are thinner than the one used in Shahid et al’s study, and thus should be an improvement in the prominence problem. The plate with the thin design was particularly aimed at minimizing the prominence problem, where the smaller thickness in the edge area, away from the screw hole, should be helpful to minimize the tenting effect of the plate fixation.

The metal clavicle plate breakage after fixation of the clavicle fracture has been reported only with the tubular plate. Tavitian et al reported a semi-tubular plate breakage after a surgical treatment of a clavicular nonunion, and Pederson et al reported one case of plate breakage and 3 more cases of plate loosening among 5 patients treated with the semitubular plate. It thus can be concluded that the semi-tubular plate has the smallest biomechanical strength and that any clavicle plate should have a larger biomechanical strength than that of the semitubular plate. The strength of the semi-tubular plate couldn’t be found in the literature, but the strength of a 1/3 tubular plate has been reported by Harnroongroj and Vanadurongwan. They studied the maximum load and bending strength of a 1/3 tubular with the plate at superior and anterior position of the clavicle and the maximum load determined in this study corresponds to their result reported for the plate strength determined with the plate at the superior position with an inferior cortical defect. They reported maximum load of the plate 197.9 N, and bending strength of 7.87 N-m. The bending strengths of the plates in this study are smaller

**Table 2.** Results of the bending tests for recon plates with 3 design types

<table>
<thead>
<tr>
<th></th>
<th>Maximum Load (N)</th>
<th>0.2% offset displacement (mm)</th>
<th>Bending Strength (N-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>212±14</td>
<td>0.75±0.06</td>
<td>0.87±0.06</td>
</tr>
<tr>
<td>II</td>
<td>680±38</td>
<td>1.92±0.26</td>
<td>3.85±0.2</td>
</tr>
<tr>
<td>III</td>
<td>931±61</td>
<td>1.04±0.16</td>
<td>4.18±0.3</td>
</tr>
</tbody>
</table>

**Figure 3.** Load-displacement curves of the recon plates.

**Figure 4.** Plate thickness dependence (A) and edge thickness dependence (B) of the maximum bending load and bending strength of the reconstruction plate.
than that of the 1/3 tubular plate, but this is inevitable for the reconstruction plate that is designed to conform to the contour of the clavicle. The recon plates of standard design and thick design in this study have 3.4 and 4.5 times larger values in the maximum load than that of the 1/3 tubular plate, but the maximum load of the recon plate with the thin design in this study has a similar value in the maximum bending load with the 1/3 tubular plate. Thus, assuming that the biomechanical strength of the semi-tubular plate is about the same as that of the 1/3 tubular plate, we can argue that the recon plates with the standard design and the thick design might be safe for clinical application but that the plate with the thin design might be too weak for use in clavicle fractures.

Iannotti et al. studied the axial strength of the 3.5 mm reconstruction plate, 3.5 mm limited contact dynamic compression, and 2.7 mm direct compression plates, and found out that the load to failure of the plate was 690 N, 940 N, 880 N, respectively. The values of the maximum bending load of the reconstruction plate with the standard design and thick design are comparable to the axial strength of the 3.5 mm reconstruction plate in Iannotti et al’s study. However, the experimental methods of the two studies are different, and thus we should not give too much meaning to the similar values obtained in these two studies.

Comparing the plates with the standard and the thick designs, there was no significant differences both in the maximum bending load and the bending strength between them, despite the fact that the plate thickness of the plate b was increased by 26.7%. This result indicates that the edge thickness of the plate c is a more important factor in maximum bending load and the bending strength between them, designing orthopaedic trauma working group., J Orthop Trauma., 9(7), 504-507 (2005).


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**Conclusion**

Among the three clavicle reconstruction plates investigated in this study, the thin design type appeared to be too weak to bear the stress of the shoulder movement, and the standard type with a 2.7 mm thickness seemed to be the best one considering both the biomechanical strength of the plate and the patient’s discomfort level.

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**References**


