THE DOVETAIL CONFIGURATION: A BIOMECHANICAL ANALYSIS OF A V-SHAPED OSTEOTOMY DOCKING SITE

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ABSTRACT
Large allograft bones are commonly used in limb salvage procedures for the reconstruction of bone defects after resection of a bone tumor. A V-shaped osteotomy may perform better than the traditional transverse osteotomy as it increases the stability of the docking site and increases the contact area between an allograft and the host cortex. The aim of this study is to investigate the biomechanical properties of a V-shaped docking site of different angles.

Porcine femurs with 45°, 60° or 90° V-shaped osteotomy were first tested with 1000 N compression, followed by 2 and 5 Nm torque. The torsional stiffness of the 45° specimen group at 5 Nm torque was significantly higher ($P < 0.05$) than the 90° group. Therefore, our results show that 45° V-shaped osteotomy is found to be the most stable docking angle.

Keywords: Biomechanics; Allograft; Docking; Limb salvage; Reconstruction; Tumour.

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INTRODUCTION

Large allograft bone transplantation is one of the most common methods for the reconstruction of long bone after bone tumor resection. Transverse osteotomy has been used as the traditional docking method, but this docking geometry by itself has the lowest torsional stiffness at the allograft-bone junction. Although an interlocking nail device is invariably used in the fixation of a large allograft bone to prevent movement at the docking site, 12%–49% of patients continue to experience delayed union and nonunion at the allograft-host bone junction when using the traditional docking method.4,6–8,10,11

Abnormal healing at the docking site, particularly nonunion, prevents the direct load transfer from the host to the allograft and may predispose the reconstructed bone to failure. Our proposed solution is to alter the geometry of the osteotomy to improve stability and increase contact surface area, thus enhance healing.2 Markel et al. reported that step-cut osteotomy might augment the stability of allograft/endoprosthetic composites of proximal femur reconstruction when comparing a step-cut osteotomy to a transverse osteotomy. However, the torsional stiffness only increased from 1.5% (transverse osteotomy) to 2.0% (step-cut osteotomy) of the intact value,9 which may have little clinical significance.

At the cortical–cortical junction of the docking site, healing takes place by bridging external callus that originates from the periosteum of the host bone and extends over the surface of the allograft.1,3,5,11 Therefore, a stable, accurate and intimate contact between the host and the allograft cortex appears to promote and accelerate union.

The authors postulated that the docking site with a V-shaped osteotomy increases the contact surface area and provide a more stable allograft-host bone junction than the step-cut or transverse osteotomy to promote union and thus lead to good functional limb. But the angle that generates the optimum stability remains unknown. The aim of this study is to investigate the biomechanical properties of V-shaped docking site of different angles.

MATERIAL AND METHOD

Seventy-five fresh frozen porcine femurs were used in this study. The age of death of the animals ranged from 10 to 11 months, and the body weights were between 75 and 80 kg. After the remaining soft tissue was removed, specimens were inspected visually and radiographically to exclude any abnormal morphology, they were then enclosed in plastic bags and stored at −30°C. Specimens were thawed to room temperature before use.

Sixty-nine femurs were randomly divided into four groups, namely, V45 (n = 17), V60 (n = 23), V90 (n = 29) and control (n = 6). V-shaped osteotomy was then performed in the first three groups with an angle of 45°, 60° and 90°, respectively [Figs. 1(a)–(c)]. Six femurs in the remaining control group were left intact.

The V-shaped osteotomy was performed as follows: a longitudinal central line was drawn on the anterior surface of the femoral shaft with a marking pen. The point at the middle of the line was made as the apex of the angle to be defined. The angle was measured precisely and two side-lines of the angle were drawn. At the apex of the angle, a 1.5 mm diameter drill bit was use to drill through the cortex. A jigsaw was put through the hole and the V-shaped osteotomy was sawed in line with the sidelines. Images of the prepared specimens are shown in Figs. 1(a)–(c). The “allograft” that was used for replacement was the distal porcine femur of the same specimen. This idealized allograft was used to minimize the size discrepancy between different specimens.
Femur ends were embedded in epoxy resin and kept in refrigerator for 24 hours to ensure that the gel was hardened before testing. Specimens were kept moist with saline-soaked sponge during preparation and testing.

Specimens were then mounted onto the Material Testing System (MTS) machine (MTS 858 Bionix machine, MTS System Inc., Minneapolis, MN) without intramedullary nailed. Three mechanical tests were performed. Specimens were first loaded with cyclic compression force between 100 and 1000 N for five cycles at the rate of 100 Ns⁻¹. Then, accompanied with 500 N compression preload, axial torque range from −2 to 2 Nm was applied for five cycles with 0.3 Nms⁻¹ ramp. This test was then repeated with 5 Nm. Two and five Nm was selected as the applied torque so that the specimens would not be loaded beyond the elastic limit and become plastically deformed.
Data was recorded by computer; the compression stiffness ($C_s$) was the gradient of the linear portion of the third segment on the compression-displacement curve (Fig. 2). Only one segment was considered in the calculation for compression stiffness because the curve for each loading cycle was fairly consistent. Torsional stiffness ($T_s$) was equal to the applied torque divided by the angle of rotation ($\theta$), where $\theta$ was equal to the angle between the maximum and minimum torque divided by two on the torque-angular displacement curve (Fig. 3).

For statistical analysis, the three docking angles were compared by the analysis of variance (ANOVA) on each mechanical property. If ANOVA indicate significant differences, independence sample $t$-test was then performed in paired specimen group. The level for statistical significance was set at $P < 0.05$.

RESULTS

Processed results are summarized in Table 1 and the percentage of intact compression and torsional stiffness are plotted against specimen groups in Fig. 4. Of the three measured mechanical properties, $P$-values from ANOVA indicated no significant differences for compression stiffness and torsional stiffness at 2 Nm torque. The average compression stiffness and torsional stiffness at 2 Nm torque of the three specimen groups were found to be about 50% of the intact value, but as the torsional load increased to 5 Nm, the average torsional stiffness decreased to about 35% of the intact value (Fig. 4). However, if the reduction in torsional stiffness from 2 to 5 Nm were to be looked at individually, then the bigger the docking angle, the bigger the reduction. Also, the torsional stiffness at 5 Nm for V45 group (4.39 ± 1.35 Nm deg$^{-1}$) was significantly higher than V90 (2.44 ± 1.26 Nm deg$^{-1}$) ($P < 0.05$).

DISCUSSION

The mechanical properties of a V-shaped docking site simulating the reconstruction of long bone were compared in an in vitro porcine model with different docking angles. The compression stiffness was not significantly different between the three docking angles under 1000 N compression. This is about 1.5 times the body weight of an average physiological person. Despite having only 50% compression stiffness of intact bone, the V-shaped docking site with an angle between 45° and 90° could support a strong compression load, enough for weight bearing.
Table 1  Result Table.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Specimen Group</th>
<th>Mean</th>
<th>SD</th>
<th>n</th>
<th>P-Value (Group)†</th>
<th>P-Value (Paired)‡</th>
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<tr>
<td></td>
<td>V45</td>
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<td></td>
<td>V60</td>
<td>2309.27</td>
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<tr>
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<td>Intact</td>
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<td>589.43</td>
<td>6</td>
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<td>N/A</td>
</tr>
<tr>
<td></td>
<td>V45</td>
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<td>2.07</td>
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<td>2.00</td>
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<td>V45</td>
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<td>1.35</td>
<td>17</td>
<td>&lt;0.0001</td>
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<tr>
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<td>V60</td>
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<td>1.31</td>
<td>23</td>
<td>0.0026**</td>
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<td>V90</td>
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<td>&lt;0.0001***</td>
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</tbody>
</table>

*Value in bold indicates statistical significance, pair-wise tests were not performed on the mechanical properties that did not show a significant difference between groups.

†versus V60, ‡versus V90, ***versus V45.

The torsional stiffness was only significantly different at 5 Nm but not 2 Nm; this suggested that the torsional stiffness was independent to the docking angles at a lower torque. Also, the minimum torsional stiffness was about 25% of the intact bone, which is still much higher than what could be achieved by the step-cut (2.0%) and the traditional transverse osteotomy (1.5%).9

V45 specimen group was found to have a significantly higher torsional stiffness than V90 at 5 Nm torque (P < 0.05) and the highest yield torque. Therefore, 45° was found to be the most stable docking angle.

During the torsion to failure test for V90 specimen group, 13 specimens dislocated at the docking site instead of fracturing. Hence, the torsion to failure test for these specimens was repeated with increased compression preload to ensure that the specimens were fractured. The increased compression for V90 (C > 500 N) specimen group had a higher torque of yield point than V90 (without pre-loading), but that was still inferior when compared to the V45 and V60 groups.

It was reported that healing took place by bridging external callos that originated from the periosteum of the host bone and extended on the surface of the allograft at the cortical–cortical junctions of allograft docking site, where it became annealed.3,5,11 Therefore, V-shaped osteotomy is more beneficial to union between the allograft to the host as it has a higher contact area than the traditional transverse osteotomy.

These types of in vitro studies provide an understanding on the mechanical properties of...
reconstructive techniques. Clinically the long-term outcome of these massive reconstructions is dependent not only on mechanical factors but also on biological ones too. Therefore, in vivo study of long-term stability should be carried out in the future.

An “ideal” allograft was used in this study to eliminate the effects of mismatching of allograft size in comparison to the host; this is because the allograft and the host was produced from the same bone, so the docking angle was the same and provided a perfect match. In reality, surgeons strive to size-match the allograft to the host bone, but more often than not, the dimension and the docking angle of the allograft are slightly different from the host bone. Future animal studies that use size-mismatched allografts should be performed to determine the change in mechanical characteristics. Although the V-shaped osteotomy may reduce rotation at the allograft-host bone junction, it should be emphasized that V-shaped osteotomy, particularly when the allograft and the host bone are different in size, are extremely difficult to perform.

We choose the V-shaped osteotomy because we felt that this cut could be reliably and easily reproduced in the operating theatre, without the need for expensive tools.

CONCLUSION

V-shaped osteotomy could be used to improve the stability of the docking site and promote union. Our study shows that the 45° of V-shaped osteotomy is found to be the most stable docking angle. We call this concept the Dovetail configuration.

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References
