Massive allografts comprise a small but important percentage of the more than 150,000 musculoskeletal allografts used in the United States each year. Successful incorporation of large bone transplants into the human skeleton depends upon a delicate balance among biological and mechanical factors. The fact that these factors have yet to be mastered is evidenced by the 8%-14% nonunion rate and the 5%-18% fracture rate. The mechanical factors that may be influenced by the orthopaedic surgeon include construct stability, host-allograft contact area, and uniformity of pressure distribution across the construct. This paper focuses on the mechanical component of the incorporation process by examining the behavior of three construct geometries. The purpose of this study was to test the hypothesis that the sigmoid cut would enhance stability by reducing the stress riser effect associated with the step cut. The transverse cut, which has no inherent stability, was used as a control.

The torsional stiffness, maximum torque, and maximum angular displacement of transverse, step, and sigmoid osteotomies were compared in a cadaveric model.

Materials and Methods

Six matched left-right pairs of femora were harvested from embalmed cadavers and radiographically screened for any abnormalities. Initial preparation consisted of making transverse cuts in each femur at the level of the lesser trochanter and 12 cm proximal to the femoral condyle. The remaining middle portion of each femur was subjected to mechanical testing.

Three types of osteotomy cuts were compared: a simple transverse cut, a step cut, and a sigmoid cut. The transverse osteotomy cuts were made at the mid-point of the femur, perpendicular to the long axis, using an electric surgical saw. The step osteotomy cuts were also made with an electric saw, the longitudinal portion being 2.5 cm long. The transverse and step cuts were made without the use of a cutting guide, as is typically done during surgery.

The sigmoid osteotomy cuts were made using a template in conjunction with a pneumatic drill with a side-cutting bit. A steel sigmoid template was made without the use of a cutting guide, as is typically done during surgery. These results suggest that the use of a sigmoid cut osteotomy, prepared using a cutting template, would enhance the initial mechanical stability of an allograft construct. Although not specifically assessed in this study, the sigmoid cut also increases the contact area between the allograft and host bone, comparable to the contact area achieved with a step cut. The sigmoid cut also increases torsional stiffness, as compared to the transverse cut and the step cut.

The step cut osteotomy significantly increased torsional stiffness of the construct, as compared to the transverse cut, indicating an increased resistance to loading below that which would cause failure. The maximum torque for the step cut construct, however, was only approximately 10% greater than the transverse cut, and the presence of the 90°-angle stress riser with the step cut resulted in failure at only approximately 6° of rotational displacement.

The sigmoid cut also increased torsional stiffness, as compared to the transverse cut (by nearly a factor of 2), and similarly increased maximum torque by approximately 30%. More importantly, the maximum displacement for the sigmoid cut specimens was 11.60°, twice that of the step cut specimens. These results demonstrated that the simple transverse cut construct is inherently weaker than the step cut or the sigmoid cut, and the stability of the transverse cut construct is determined solely by the fixation applied. The transverse cut does not have any intrinsic stress risers, however, which might cause the host or allograft bone to fail prior to incorporation.

The step cut osteotomy significantly increased torsional stiffness of the construct, as compared to the transverse cut and the step cut. The sigmoid cut osteotomy in the contralateral femur.

Each specimen was mounted vertically in a mechanical testing machine. The specimen was aligned with the axis of the machine by placing the end of each femur over a guide rod through the center of a cylindrical fixture. The bottom end of the femur was then cross-pinned with K-wires and filled with casting plaster. When the plaster cured the construct was turned over, and the bottom end of the femur was cross-pinned with K-wires and filled with plaster. A lag screw was placed across each step and sigmoid osteotomy.

The first three pair of femora each had a transverse osteotomy in one femur and a step osteotomy in the contralateral femur. The second three pair of femora each had a transverse osteotomy in one femur and a sigmoid osteotomy in the contralateral femur.

A constant axial load of 50 N was applied throughout the testing. Internal rotational displacement was applied to each femur, from 0° to a maximum of 15°. If failure did not occur, five loading cycles were performed. Control of the test machine and real-time data collection was performed by an integrated digital control system (TestStar and TestWare-SX, MTS Systems Corp., Minneapolis MN).

The construct torsional stiffness (N-m/degree) was calculated by linear regression of the torque-angular displacement curves. For the transverse cuts the second through the fifth loading cycles were used for data analysis. The maximum torque and maximum angular displacement were also determined for each specimen. Statistical analysis consisted of paired and two-sample t-tests, where applicable.

Table 1 – Mechanical Testing Results

<table>
<thead>
<tr>
<th></th>
<th>Transverse Cut</th>
<th>Step Cut</th>
<th>Sigmoid Cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness, N-m/°</td>
<td>1.60 ± 0.50</td>
<td>4.36 ± 0.73</td>
<td></td>
</tr>
<tr>
<td>Max. Torque, N-m</td>
<td>19.93 ± 4.12</td>
<td>22.11 ± 2.71</td>
<td></td>
</tr>
<tr>
<td>Max. Displacement, °</td>
<td>15</td>
<td>5.73 ± 1.62</td>
<td></td>
</tr>
<tr>
<td>Stiffness, N-m/°</td>
<td>0.99 ± 0.16</td>
<td>1.90 ± 0.68</td>
<td></td>
</tr>
<tr>
<td>Max. Torque, N-m</td>
<td>14.48 ± 2.15</td>
<td>18.85 ± 6.63</td>
<td></td>
</tr>
<tr>
<td>Max. Displacement, °</td>
<td>15</td>
<td>11.60 ± 1.78</td>
<td></td>
</tr>
</tbody>
</table>

The torsional stiffness of the step cut specimens was significantly greater than the transverse cut specimens (paired t-test, p < 0.025). The maximum torque of the step cut specimens was greater than the transverse cut specimens, but was not significant (paired t-test, p = 0.08).

The sigmoid cut specimens also exhibited greater torsional stiffness and greater maximum torque than the transverse cut specimens. These differences, however, were not significant (stiffness, paired t-test p = 0.07; torque paired t-test p = 0.23).

Comparison of the step cut and the sigmoid cut specimens showed significantly greater torque for the step cut specimens (p < 0.0075), but which failed at significantly smaller angular displacement than did the sigmoid cut specimens (p < 0.0075). No direct paired comparisons of these cuts were performed, however.

Summary

These results demonstrate that the simple transverse cut construct is inherently weaker than the step cut or the sigmoid cut, and the stability of the transverse cut construct is determined solely by the fixation applied. The transverse cut does not have any intrinsic stress risers, however, which might cause the host or allograft bone to fail prior to incorporation.

The step cut osteotomy significantly increased torsional stiffness of the construct, as compared to the transverse cut, indicating an increased resistance to loading below that which would cause failure. The maximum torque for the step cut construct, however, was only approximately 10% greater than the transverse cut, and the presence of the 90°-angle stress riser with the step cut resulted in failure at only approximately 6° of rotational displacement.

The sigmoid cut also increased torsional stiffness, as compared to the transverse cut (by nearly a factor of 2), and similarly increased maximum torque by approximately 30%. More importantly, the maximum displacement for the sigmoid cut specimens was 11.60°, twice that of the step cut specimens. These results suggest that the use of a sigmoid cut osteotomy, prepared using a cutting template, would enhance the initial mechanical stability of an allograft construct. Although not specifically assessed in this study, the sigmoid cut also increases the contact area between the allograft and host bone, comparable to the contact area achieved with a step cut. The sigmoid cut eliminates the stress risers inherently associated with the step cut osteotomy. A template for producing a step cut using a high-speed cutting burr also might achieve a similar reduction in the stress risers. The use of a cutting template, regardless of the type of osteotomy, improves the overall contact fit between the allograft and the host bone.