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Trochlear Morphology in Healthy People: Implications for Osteochondral Allograft Transplantation

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ABSTRACT

Introduction: The unique anatomy of the trochlea makes Osteochondral Allograft (OCA) grafting of femoral trochlear lesions challenging but could be improved with better understanding of trochlear morphology.

Objectives: To assess trochlear width, depth, and sulcus angle via magnetic resonance imaging (MRI) in patients without patellofemoral problems and determine whether bench measurements of donor femurs can better match donors and patients.

Methods: An analysis was performed on 209 deidentified MRIs (average age: 25.8 years, ages 12-57). Trochlear width and depth were measured 15 mm and 20 mm distal to the most proximal articular surface. MRI’s were classified into groups based on trochlear depth (Group 1: 0-4.0 mm; Group 2: 4.1-6.0 mm; Group 3: > 6.0 mm). Difference in depth at the two distances was calculated. The same protocol was performed on 23 cadaveric knees.

Results: Mean trochlear depths at 15mm and 20mm were significantly different between groups. Group 3 had significantly larger trochlear widths than Groups 1 and 2. All MRIs showed an increase in trochlear depth between 15 and 20 mm (mean increase: 1.31 ± 0.78 mm). There was no significant difference in trochlear depths between MRI and cadaveric groups. For MRI groups at 15 mm, the resultant apex decreased 10° between Groups 1 and 2 and 7.4° between Groups 2 and 3.

Conclusion: Assuming trochleae are perfect isosceles triangles, one can measure trochlear width and cartilage sulcus angle via MRI to assess trochlear depth. Consideration of trochlear depth and its distribution may enable more accurate matching of OCAs.
INTRODUCTION

Symptomatic articular cartilage lesions of the femoral trochlea are a source of disabling pain and dysfunction in active patients. Multiple treatment options have been described, including osteochondral allograft (OCA) transplantation.\(^1\)\(^,\)\(^2\)\(^,\)\(^3\)\(^,\)\(^4\)\(^,\)\(^5\)\(^,\)\(^6\)\(^,\)\(^7\)\(^,\)\(^8\)\(^,\)\(^9\)\(^,\)\(^10\) The relative morphologic uniformity of the femoral condyles makes OCA grafting much more common for symptomatic lesions of the femoral condyle. The unique anatomy of the trochlea makes OCA grafting much more challenging for lesions of the femoral trochlea. Nonetheless, surgeons must to attempt to anatomically restore the articular surface while minimizing step-off at the allograft-native articular cartilage junction. Articular step-off has been shown to lead to abnormal biomechanics in the tibiofemoral articulation following OCA transplantation.\(^12\) Given that the patellofemoral articulation is weightbearing, adverse effects of articular step-off can be assumed to also occur.

Historically, surgeons that perform OCA transplant for femoral condyle lesions have used condyle width and tibial plateau width to match suitable donors to their patients. The width of the tibial plateau can help to predict the width of the distal femur and, indirectly, the femoral trochlea, but it does not take into account the depth of the trochlea. Achieving an anatomic restoration of the articular surface is the goal of OCA transplantation. As such, matching suitable donors for patients with trochlear lesions could be improved with a more thorough understanding of trochlear morphology in addition to improved methods to measure trochlear morphology in donors and patients scheduled for transplantation surgery. Selecting a suitable trochlear allograft based on sex and tibial width would seem to be very inaccurate, especially given the variability in the sulcus angle as well as the articular cartilage thickness.\(^14\)\(^,\)\(^15\)\(^,\)\(^16\)\(^,\)\(^17\)\(^,\)\(^18\)\(^,\)\(^19\)\(^,\)\(^20\)\(^,\)\(^21\) Using sex and tibial width could easily lead to gross differences in trochlear topography, and the inaccurate
The femoral trochlea has a complex geometry with an asymmetric concave surface. The lateral portion of the trochlea is often more prominent than the medial trochlea, and this anatomic feature helps to provide bony restraint to lateral patellar translations. The depth of the trochlea varies, not only between individual knees, but also from the proximal to distal aspects of the trochlea. The trochlear articular thickness can vary from less than 2 mm to as much as nearly 5 mm. The average sulcus angle, which correlates with the depth of the trochlear groove, is 135 degrees (± 10 degrees).

An isosceles triangle with the apex of 135 degrees and the base length of 40 mm has a height of 8.6 mm. If the apex angle, which would be the same as the sulcus angle, increased to 145 degrees, the height or depth of the triangle would decrease to 6.8 mm. A 1.8 mm difference would make it difficult to anatomically match the trochlear articular surface if the patient had a hypoplastic trochlea with a sulcus of 145 degrees and the donor trochlea had a sulcus angle of 135 degrees. While the trochlea is not a perfect isosceles triangle, if it is assumed that it is, then the height or depth of the trochlea is equal to the length of the side (trochlear facet) multiplied by the sine of the lesser angle. For an isosceles triangle, the apex would be the sulcus angle and the angles need to add up to 180 degrees. A change in the sulcus angle by 10 degrees results in a difference in depth of 1.6 mm (Figure 1 and Figure 2).

The purpose of this study was to assess trochlear width and depth by magnetic resonance imaging (MRI) in knees without patellofemoral problems and to determine whether bench measurements of donor femora could help to better match donors and patients.
METHODS

MRIs of the knee were obtained. Prior to analysis, all patient identifiable information was removed. Any scan showing articular pathology of the patellofemoral compartment were excluded. Width and depth of the trochlea were measured 15 mm and 20 mm distal to the most proximal articular surface of the trochlea using axial and sagittal sequences (Figure 3A, 3B). Difference in the depth of the trochlea at the two measured points was calculated.

The MRI cases were classified into three groups based on the depth of the trochlea at 15 mm distal to the most proximal portion of the trochlear articular cartilage. Group 1 included cases with a depth from 0-4 mm, Group 2 included cases with a depth of 4.1-6.0 mm, and Group 3 included cases with a depth greater than 6.0 mm (Figure 3C, 3D, 3E). We then used the same groupings of cases to assess the depth measurements at 20 mm distal to the most proximal portion of the articular surface.

In the second portion of the study, a depth gauge was used to measure the depth of the trochlea at 15 mm and 20 mm distal to the most proximal aspect of the trochlear articular cartilage on 23 cadaveric specimens (Figure 4). Difference in trochlear depth in each specimen between 15 mm and 20 mm was calculated.

To test the proof of concept, two random distal femur specimens were obtained. In one of the specimens, an MRI was obtained and measured the trochlear depth at various distances distal to the proximal most portion of the trochlear articular surface. In the other specimen, the depth of the trochlea was measured at the same distances using a perpendicular depth gauge. Using the depth measurements on the MRI of the recipient trochlea and the depth measurements obtained using a depth gauge on the donor trochlea, It was determined that the donor would be an acceptable graft source for a trochlear OCA transplant. An OCA transplantation of a 27.5 mm
graft was performed from donor to recipient (Figure 5A, 5B, 5C). A proprietary contour guide was used to help achieve a match of the articular surface with the transplant graft.

A t-test for unmatched pairs was used to compare the three MRI groups with respect to depth and width of the trochlea at 15 and 20 mm distal to the most proximal portion of the trochlear articular surface. The depths of the cadaveric specimens were also compared to the MRI groups.

RESULTS

209 MRIs (average age of 25.8 years, ages 12-57,) met inclusion criteria. The mean depth of the trochlear groove at 15 mm of Group 1 was 3.36 ± 0.59 mm (95% CI: 3.16-3.56 mm), of Group 2 was 5.21 ± 0.51 mm (95% CI: 5.12-5.30 mm), and of Group 3 was 6.83 ± 0.57 mm (95% CI: 6.68-6.98 mm). Assessing the same groups at 20 mm, the mean trochlear depth in Group 1 was 4.83 ±1.21 mm (95% CI: 4.42-5.24 mm), in Group 2 was 6.49 ± 0.92 mm (95% CI: 6.33-6.65 mm), and in Group 3 was 8.10 ± 0.92 mm (95% CI: 7.86-8.34 mm). There was a statistical difference between the 3 groups (p<0.001) (Figure 6). All MRI cases showed an increase in trochlear depth between 15 and 20 mm with a mean increase in depth of 1.31 ± 0.78 mm (95% CI: 1.2-1.42 mm). The mean width of the trochlea at 15 mm was 36.25 ± 4.21 mm for Group 1 (95% CI: 34.83-37.67 mm), 37.49 ± 3.43 mm in Group 2 (95% CI: 36.88-38.10 mm), and 39.0 ± 3.48 mm in Group 3 (38.08-39.92 mm). At 20 mm, the mean width was 36.94 ± 4.45 mm in Group 1 (95% CI: 35.44-38.44 mm), 38.10 ± 3.53 mm in Group 2 (95% CI: 37.45-38.71 mm), and 39.3 ± 3.37 mm in Group 3 (95% CI: 38.33-40.27 mm). There was no difference in trochlear widths between MRI Groups 1 and 2, but the width of the trochlea at both 15 and 20 mm in MRI Group 3 was statistically larger than Groups 1 and 2 (Table 1).
In the second part of the study, trochlear depth was measured at 15 and 20 mm in 23 cadaveric specimens using a perpendicular depth gauge (Figure 4). Like the MRI cases, the cadaveric specimens were sorted into groupings of 0-4.0 mm, 4.1-6.0 mm, and greater than 6.0 mm as referenced at 15 mm distal to the most proximal portion of the articular surface. None of the 23 specimens had a depth at 15 mm that was greater than 6.0 mm and, therefore, there were no specimens in Group 3. The same groupings were used to assess the depth of the trochlea at 20 mm. In Group 1, the mean depth was 3.13 ± 0.56 mm at 15 mm (95% CI: 2.81-3.44 mm) and 5.13 ± 0.71 mm at 20 mm (95% CI: 4.73-5.53 mm). Group 2 had a mean depth of 5.03 ± 0.45 mm at 15 mm (95% CI: 4.76-5.30 mm) and 6.13 ± 0.74 mm at 20 mm (95% CI: 5.69-6.57 mm). All cadaveric specimens showed an increase in trochlear depth between 15 and 20 mm with the mean increase in depth of 2.0 ± 0.60 mm for Group 1 (95% CI: 1.66-2.34 mm) and 1.11 ± 0.38 mm for Group 2 (95% CI: 0.885-1.34 mm) (Table 1). The depth data in MRI Groups 1 and 2 and cadaveric Groups 1 and 2 at 15 mm and 20 mm were compared. There was no statistical difference between the groups in the MRI and cadaveric cases.

If the trochlea can be considered an isosceles triangle, and the MRI data of Groups 1, 2, and 3 with respect to depth and width of the trochlea at 15 mm is used, the resultant apex (or sulcus angle) decreases 10 degrees between Groups 1 and 2 and decreases 7.4 degrees between Groups 2 and 3 (Table 2).
In the third portion of the study, a right and a left distal femoral specimen was obtained as well as an MRI of one of the specimens. The depth of the trochlea was measured by MRI at 1 cm, 2 cm, and 3 cm from the most proximal aspect of the trochlea. In the other specimen, the depths of the trochlea were measured at the same distances using a perpendicular depth gauge. There was no significant difference between the depth measurements.

**DISCUSSION**

Historically, tibial width has been used to match donor femoral condyles for patients needing an OCA transplant for a defect in the femoral condyles. The patella and the medial femoral condyle are the most common sites for a full thickness chondral defect. Trochlear lesions are certainly not as prevalent, but are common in particular patient groups, including NBA basketball players. As more surgeons are surgically treating symptomatic articular cartilage lesions, there is now a bigger demand for osteochondral trochlear allografts (Joint Restoration Foundation graft request numbers, data on file, Joint Restoration Foundation, Centennial, CO). Given the complex surface geometry of the trochlea, using tibial width to match a suitable graft for any particular patient will not assure the graft is, in fact, a suitable match. The width of the femoral trochlea varies with the size of the distal femur, but the depth of the trochlea has no correlation to the width of the trochlea or width of the distal femur.

Described in this paper is an easy way to measure the trochlea depth on an MRI as well as in the tissue processing facility using a perpendicular depth gauge. The data shows that the depth of the trochlea does become bigger as one measures more distally. The depth increases an
average of 1.30 mm between 15 and 20 mm as measured from the top of the trochlea on MRI and an average 1.74 mm when measured with a depth gauge on cadaveric distal femur specimens. This depth variability is an advantage to OCA transplant surgeons, as it potentially allows them to accept a donor graft within a range of the depths measured on their patient’s MRI.

After the MRI and specimen data were divided into three groups, the mean depths and standard deviations of the three groups show that trochlear depth data is truly distributed into the three groups and that the groups are completely independent. If tissue processing companies can adopt the proposed grouping classification, we believe that more suitable donors will be better matched with patients in need of the graft.

CONCLUSION

Assuming trochleae are perfect isosceles triangles, one can measure trochlear width and cartilage sulcus angle via MRI to assess trochlear depth. Consideration of trochlear depth and its distribution may enable more accurate matching of OCAs.

FIGURE LEGENDS

**Figure 1:** Graphic illustration of an assumed trochlea that has the symmetry of an isosceles triangle.

**Figure 2:** Graphic illustration of the increase in trochlear depth with a decrease in the sulcus angle.

**Figure 3:** MRI measurements of the trochlear depth and width of the same at 15 mm (3A) and 20 mm (3B) distal to the most proximal aspect of the trochlea, and examples of Group 1 (3C), Group 2 (3D), Group 3 (3E)

**Figure 4:** Perpendicular depth gauge to measure the depth of the trochlea at any given distance from the top of the trochlear groove.

**Figure 5:** Osteochondral allograft transplantation of a 27.5 mm graft from a cadaveric distal femur that was matched by trochlear depth measurements obtained with a perpendicular depth gauge and matched to the recipient by trochlear depth measurements obtained on an MRI

**Figure 6:** Whisker-Plot graph of MRI measured trochlear depth at 15 mm distal to the top of the trochlea in groups 1, 2, and 3
REFERENCES


[16] C. G. Richmond et al., “Patellar-Trochlear Morphology in Pediatric Patients From 2 to 11 Years of Age: A Descriptive Analysis Based on Computed Tomography Scanning.,” vol. 40, no. 2. pp. e96–e102, 01-Feb-2020.


Figure 1: Graphic illustration of an assumed trochlea that has the symmetry of an isosceles triangle.

Figure 2: Graphic illustration of the increase in trochlear depth with a decrease in the sulcus angle.
Figure 3A, 3B, 3C, 3D, 3E: MRI measurements of the trochlear depth and width of the same at 15 mm (1A) and 20 mm (1B) distal to the most proximal aspect of the trochlea, and examples of Group 1 (1C), Group 2 (1D), Group 3 (1E).

Figure 4: Perpendicular depth gauge to measure the depth of the trochlea at any given distance from the top of the trochlear groove.
**Figure 5A, 5B, 5C:** Osteochondral allograft transplantation of a 27.5 mm graft from a cadaveric distal femur that was matched by trochlear depth measurements obtained with a perpendicular depth gauge and matched to the recipient by trochlear depth measurements obtained on an MRI.

**Figure 6:** Whisker-Plot graph of MRI measured trochlear depth at 15 mm distal to the top of the trochlea in groups 1, 2, and 3

**Table 1:** Trochlear depth and width measurements in millimeters with standard deviation, and t-tests for width at 15 mm and Depth at 15 and 20 mm

<table>
<thead>
<tr>
<th></th>
<th>MRI Group 1 N=34</th>
<th>MRI Group 2 N=120</th>
<th>MRI Group 3 N=55</th>
<th>Cadaveric Group 1 N=12</th>
<th>Cadaveric Group 2 N=11</th>
<th>Cadaveric Group 3 N=0</th>
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</thead>
<tbody>
<tr>
<td><strong>Depth at 15 mm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRI Group 1 N=34</td>
<td>3.36 ± 0.59</td>
<td>5.21 ± 0.51</td>
<td>6.83 ± 0.57</td>
<td>3.13 ± 0.56</td>
<td>5.03 ± 0.45</td>
<td>No specimens</td>
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<td>MRI Group 2 N=120</td>
<td>36.25 ± 4.21</td>
<td>37.49 ± 3.43</td>
<td>39.0 ± 3.48</td>
<td>No data</td>
<td>No data</td>
<td>N/A</td>
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<tr>
<td><strong>Depth at 20 mm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRI Group 1 N=34</td>
<td>4.83 ± 1.21</td>
<td>6.49 ± 0.92</td>
<td>8.10 ± 0.92</td>
<td>5.13 ± 0.71</td>
<td>6.13 ± 0.74</td>
<td>N/A</td>
</tr>
<tr>
<td>MRI Group 2 N=120</td>
<td>36.94 ± 4.45</td>
<td>38.08 ± 3.35</td>
<td>39.30 ± 3.67</td>
<td>No data</td>
<td>No data</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Incremental increase in depth</strong></td>
<td>1.47 ± 0.92</td>
<td>1.29 ± 0.71</td>
<td>1.25 ± 0.71</td>
<td>2.0 ± 0.60</td>
<td>1.11 ± 0.38</td>
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</table>

**T-tests**

<table>
<thead>
<tr>
<th>T-test Width 15</th>
<th>Groups 1 and 2 p=0.08</th>
<th>Groups 2 and 3 p=0.007</th>
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<tr>
<td>T-test Depth 15</td>
<td>Groups 1&amp;2 p&lt;0.001</td>
<td>Groups 2&amp;3 p&lt;0.001</td>
</tr>
<tr>
<td>MRI(1)&amp;Cadaver(1) p=0.2461</td>
<td>MRI(2)&amp;Cadaver(2) p=0.2605</td>
<td></td>
</tr>
</tbody>
</table>

T-test Depth Groups MRI(1)&Cadaver(1) MRI(2)&Cadaver(2)
Table 2: MRI data of groups 1, 2, and 3 with trochlear widths and depths at 15 mm, along with the resultant apex angle, which corresponds to the trochlear sulcus angle (assumption that the trochlea is an isosceles triangle).

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trochlear Width</td>
<td>36.25 mm</td>
<td>37.5 mm</td>
<td>39.0 mm</td>
</tr>
<tr>
<td>Trochlear Depth</td>
<td>3.35 mm</td>
<td>5.21 mm</td>
<td>6.8 mm</td>
</tr>
<tr>
<td>Apex (Sulcus) Angle</td>
<td>159 degrees</td>
<td>149 degrees</td>
<td>141.6 degrees</td>
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</table>

p<0.001

p<0.001

p=0.4237

p=0.2101