Anatomic anterior cruciate ligament reconstruction: a changing paradigm
van Eck, C.F.

Citation for published version (APA):

General rights
It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations
If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: http://uba.uva.nl/en/contact, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.
CHAPTER 4

FEMORAL INTERCONDYLAR NOTCH SHAPE AND DIMENSIONS IN ACL INJURED PATIENTS

Van Eck CF, Martins CA, Vyas SM, Celentano U, van Dijk CN, Fu FH

Chapter 4: Femoral intercondylar notch shape

Abstract

The femoral intercondylar notch has been an anatomic site of interest as it houses the anterior cruciate ligament (ACL). The objective of this study was to arthroscopically evaluate the femoral notch in patients with known ACL injury. This evaluation included establishing a classification for notch shapes, identifying the shape frequency, measuring notch dimensions and determining correlation between notch shape, notch dimensions and demographic patient data. In this level clinical cohort study, 102 consecutive patients underwent diagnostic arthroscopic evaluation of the notch. Several intra-operative photos, videos and measurements were taken of the notch. Demographic data for each patient were recorded including age, gender, height, weight, and BMI. Three categories of notch shape were established: 1. A-Shaped; 2. U-shaped; and 3. W-shaped. Two blinded independent orthopedic surgeons were asked to categorize the recorded notches. Notch shape, dimensions and demographic factors were correlated. Of the 102 notches evaluated, 55 notches were found to be “A-shaped,” 42 “U-shaped,” and 5 “W-shaped”. “A-shaped” notches were narrower in all width dimensions than “U-shaped” notches. Only patient height was found to influence notch shape with a positive correlation between taller patients and “U-shaped” and “W-shaped” notches (p = 0.011). Females had a smaller a notch width at the base and middle of the notch. With this data, surgeons who enter the knee and appreciate an “A-shaped” notch should consider placing the arthroscope in the anteromedial portal and drill the femoral tunnel through an accessory medial portal to improve visualization and accuracy in anatomic femoral tunnel creation.

Keywords: femoral intercondylar notch, shape, dimensions, anterior cruciate ligament, ACL, reconstruction, gender.

Introduction

The femoral intercondylar notch has been an anatomic site of interest as it houses the anterior cruciate ligament (ACL). The femoral notch has been studied in various ways to determine if any anthropometric notch variations serve as a risk factor for ACL injury. Absolute notch width, notch width index, notch area, notch shape, and notch outlet dimensions have been evaluated with mixed results. Some studies have found a correlation between a narrow notch width - or smaller notch width index - and ACL injury while other studies have failed to reach that conclusion. It has also been shown in several studies that female athletes have a greater propensity for ACL injury compared to male athletes. Further research has suggested that a possible risk factor for this observation is that females have smaller ACLs and also have a narrower notch than males.

To date, all of these studies have used imaging or cadaveric specimens to
evaluate the notch to draw their conclusions. To our knowledge, no study has evaluated the notch arthroscopically in vivo to determine notch shape and dimensions. The objective of this study was to arthroscopically evaluate the femoral notch in patients with known ACL injury. This evaluation included establishing a classification for femoral notch shapes and identifying their frequency in ACL injured patients. In addition, the notch dimensions were arthroscopically measured and these dimensions were correlated with notch shape. The present study also sought to compare notch shape and notch dimensions to demographic patient data to evaluate demographic risk factors associated with having a particular notch shape or dimension. Finally, it was determined if any particular notch shape may discourage double-bundle ACL reconstruction.

The primary hypothesis of this study was that it is possible to identify a particular notch shape that is correlated with the smallest notch dimensions. Our secondary hypothesis was that this identified notch shape is more prevalent in the female subjects evaluated in this study, and that this study would show that females have smaller notch dimensions than males, regardless of notch shape.

Materials and Methods

Institutional review board approval was obtained prior to undertaking this study. All primary anterior cruciate ligament reconstructions performed by the senior author in a one year span between 10/1/2008 to 10/1/2009 were included in the study. Exclusion criteria were patients with morphologic knee anomalies, patients with open growth plates, patients with a history of prior knee ligament reconstruction (including ACL, meniscus and PCL) or notchplasty (including wallplasty), patients with a history of distal femoral, proximal tibial, or patellar fracture, and patients with knee arthritis (grade 3 Outerbridge or higher) with associated osteophytes seen on plain radiograph, MRI, or arthroscopy. Ultimately, 102 consecutive patients (less the exclusions) were selected for this study.

Each patient underwent a diagnostic arthroscopic evaluation of the knee followed by an evaluation of the notch. Through an anterolateral portal and an anteromedial portal with a direct view of the femoral notch, various arthroscopic photos and an arthroscopic video were taken of the notch. Next, with an arthroscopic ruler [Smith and Nephew, Andover, MA], several measurements were taken of the femoral notch. At the notch outlet, the width at the base of the notch, the width in the middle of the notch, and the width at the top of the notch were measured in millimeters with an arthroscopic ruler (Figure 1A-C). The height of the notch was also measured (Figure 1D).

Demographic data for each patient were recorded including age, gender, height, weight, and body mass index (BMI). The anterior cruciate ligament was then reconstructed along with other necessary (reconstructive) procedures. Once the digital photographs and digital videos had been compiled, a classification of
notch shapes based on a prior study by Anderson et al.\textsuperscript{1} and Ireland et al.\textsuperscript{15} was created. Three categories of notch shape were established: 1. A-Shaped; 2. U-shaped; and 3. W-shaped (Figure 2).

An “A-shaped” notch was defined as a notch shape that narrowed from base to midsection to apex by visual inspection. A “U-shaped” notch was one in which the midsection did not taper from the base. Finally, a “W-shaped” notch was one that exhibited characteristics of a “U-shaped” notch but also had two apparent apices rather than a classic flat roof.

**Figure 1:** Arthroscopic images of the femoral notch of a right knee, anteromedial portal view. The surgical ruler is used to measure the dimensions of the notch entrance. The width of the notch is measured at the bottom A., middle B. and top C. of the notch. The height is measured along the lateral wall of the notch D.

**Figure 2:** Three categories of notch shape are shown in arthroscopic images of the right knee. A. A-shaped notch, defined as a notch shape that narrows from base to midsection to apex. B. “U-shaped” notch, defined as a notch shape in which the midsection does not taper from the base. C. “W-shaped” notch, defined as a notch shape that exhibits characteristics of a “U-shaped” notch but also has two apparent apices rather than a classic flat roof.
Two blinded independent orthopedic surgeons were asked to categorize the recorded notches based on these criteria at two separate time intervals, over one week apart. The first observer was an orthopaedic surgeon with 3 years of experience while the second observer was an orthopaedic surgeon with 15 years of experience. Each was blinded to the other's classification of each notch and at the time of second-look categorization, each was blinded to his own original classification. Finally, for further statistical analysis, the observers were asked to reconcile classification differences (in the second-look data) between each other by discussion.

Statistical Analysis

Intra-observer and inter-observer reliability of the evaluation of the notch shape were run using a Kappa coefficient. Once the categorization for each notch shape had been established, the relationship between notch shape and measured dimensions (width at bottom, width at middle, width at top, and notch height) was evaluated with the Kruskal-Wallis test. Further Mann-Whitney post-hoc analysis (with Bonferroni correction) was performed to identify which of the three shapes contributed maximally to statistical significance, if any. Finally, the notch shape was compared to demographic information obtained for each patient (age, gender, height, weight, and BMI). For the continuous variables, a Kruskal-Wallis test was used while for the nominal variables, a chi-squared test with standardized residuals was used to evaluate for significance. Notch dimensions, irrespective of shape, were compared between male and female patients with an independent t-test. Finally, the frequency of single- versus double-bundle ACL reconstruction performed in the cohort was evaluated with respect to each notch shape.

Results

The age of the 102 patients evaluated was 24 years (14 - 66), with a height and weight of 1.72 m (1.52 – 1.95) and 73 kg (43 – 134), respectively. Fifty-six patients were male and 46 were female. The distribution of the notch shapes is displayed in Table 1. Intra-observer kappa score for the first observer was 0.513, that of the second observer was 0.610. Inter-observer kappa score among the two observers was 0.526.

Table 1. Frequency of notch shapes seen in 102 studied notches

<table>
<thead>
<tr>
<th>Notch shape</th>
<th>A-shaped</th>
<th>U-shaped</th>
<th>W-shaped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number (%)</td>
<td>55 (54%)</td>
<td>42 (41%)</td>
<td>5 (5%)</td>
</tr>
</tbody>
</table>

The notch width at the base, middle, and top of the notch as well as notch height for each notch shape is shown in Table 2. There was a statistically significant
difference between width at the base of the notch in the three groups (p = 0.010). Post-hoc analysis demonstrated with statistical significance that the “A-shaped” notches were narrower at the base than “U-shaped” notches (p = 0.003).

Table 2. Median notch dimensions categorized by notch shape

<table>
<thead>
<tr>
<th>Notch shape</th>
<th>A-shaped</th>
<th>U-shaped</th>
<th>W-shaped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width base (mm)</td>
<td>15 (9-21)</td>
<td>16 (12-21)</td>
<td>16 (13-18)</td>
</tr>
<tr>
<td>Median (range)</td>
<td>13.5 (8-20)</td>
<td>15.5 (10-20)</td>
<td>16 (12-18)</td>
</tr>
<tr>
<td>Width middle (mm)</td>
<td>9 (5-15)</td>
<td>11 (7-20)</td>
<td>10 (9-11)</td>
</tr>
<tr>
<td>Median (range)</td>
<td>19 (14-28)</td>
<td>21 (15-26)</td>
<td>20 (16-23)</td>
</tr>
</tbody>
</table>

There was also a statistically significant difference between the width at the middle of the notch in the three groups (p = 0.001). Post-hoc analysis demonstrated with statistical significance that the “A-shaped” notches were narrower at the middle of the notch compared to “U-shaped” notches (p < 0.001).

Additionally, there was a statistically significant difference between the width at the top of the notch in the three groups (p < 0.001). Post-hoc analysis demonstrated with statistical significance that the “A-shaped” notches were narrower at the top of the notch compared to “U-shaped” notches (p < 0.001).

No statistical significance was found when comparing notch height amongst the three groups (p = 0.514).

Evaluation of notch type when compared to gender is shown in Table 3. When relating notch shape to gender, no statistical significance was shown (p = 0.056). However a trend was seen toward more “A-shaped” than “U-shaped” notches in female patients.

Table 3. Frequency of notch shapes categorized by gender in ACL injured patients

<table>
<thead>
<tr>
<th>Notch shape</th>
<th>A-shaped</th>
<th>U-shaped</th>
<th>W-shaped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (n)</td>
<td>26</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>Female (n)</td>
<td>29</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Total (n)</td>
<td>55</td>
<td>42</td>
<td>5</td>
</tr>
</tbody>
</table>

The statistical significance of other demographic data with respect to notch shape is shown in Table 4. Of these demographic variables, only patient height was found to influence notch shape with a relation between taller patients and “U-shaped” and “W-shaped” notches (p = 0.011).
Table 4. Statistical significance of demographic variables in relationship to notch shape

<table>
<thead>
<tr>
<th>Notch shape</th>
<th>“A” vs. “U” vs. “W”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>NS</td>
</tr>
<tr>
<td>Gender</td>
<td>NS (p = 0.056)</td>
</tr>
<tr>
<td>Height</td>
<td>p = 0.011</td>
</tr>
<tr>
<td>Weight</td>
<td>NS</td>
</tr>
<tr>
<td>BMI</td>
<td>NS</td>
</tr>
</tbody>
</table>

Notch dimensions, regardless of shape, were compared between male and female patients in this study. Mean notch widths at each level as well as notch height are shown in Table 5. Notch width at the base and middle were found to be smaller with statistical significance in females as compared to males.

Table 5. Notch dimensions stratified by gender. P value of gender comparison is listed in third column for each notch dimension

<table>
<thead>
<tr>
<th>Notch dimensions</th>
<th>Mean (SD) length (mm)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notch width base male</td>
<td>16.4 (2.6)</td>
<td>0.014</td>
</tr>
<tr>
<td>Notch width base female</td>
<td>15.0 (3.0)</td>
<td></td>
</tr>
<tr>
<td>Notch width middle male</td>
<td>15.0 (2.8)</td>
<td>0.010</td>
</tr>
<tr>
<td>Notch width middle female</td>
<td>13.5 (2.6)</td>
<td></td>
</tr>
<tr>
<td>Notch width top male</td>
<td>10.6 (2.8)</td>
<td>NS</td>
</tr>
<tr>
<td>Notch width top female</td>
<td>9.7 (2.4)</td>
<td></td>
</tr>
<tr>
<td>Notch height male</td>
<td>20.7 (3.3)</td>
<td>NS</td>
</tr>
<tr>
<td>Notch height female</td>
<td>20.3 (3.2)</td>
<td></td>
</tr>
</tbody>
</table>

SD = standard deviation

Finally, for interest, the percentage of patients identified as having “A-shaped” notches that were converted to single-bundle ACL reconstruction was 14.3% while single-bundle conversion rate for “U-shaped” notches was 6.3%.

Discussion

The most important findings of the present study were that “A-shaped” notches were narrower at the base, middle, and top of the notch entrance than “U-shaped” notches. This is important as narrower shapes can have implications not only for predisposition to ACL injury, but also for the surgical technique. Notches with narrower dimensions may decrease visibility of the lateral wall, especially when viewed from an anterolateral portal. This, in turn, may lead the surgeon to perform a notchplasty to better visualize the ideal femoral insertion site. Of course, viewing from an anteromedial portal may obviate the problem of visibility. At our
Chapter 4: Femoral intercondylar notch shape

Institution, part of the surgical algorithm of the senior author to perform anatomic double-bundle ACL reconstruction instead of anatomic single-bundle reconstruction is whether the notch has enough space to accommodate two bundles. A narrower notch (in particular at the base) may affect the surgeon’s decision for double-bundle ACL reconstruction or single-bundle reconstruction (as shown by the higher percentage conversion in “A-shaped” notches compared to “U-shaped” notches). Of course, there are other factors that contribute to this decision (i.e. a small ACL insertion site, severe osteoarthritic changes, severe bone bruising, multiple ligamentous injuries, open physes) and as such, they cannot be reliably statistically compared.

In addition to our study, two other studies make an attempt to describe notch morphology. Anderson et al. described an “inverted-U” shaped notch as well as four other shapes based on slight variations in notch wall curvature as seen on CT evaluation. Ireland et al. used plain radiographs to describe a notch type that is narrower at the base than the apex and labeled this an “A-shaped” notch. Notches that did not taper as such were considered “non A-shaped” notches. It was found that A-shaped notches were smaller in width and NWI compared to non A-shaped notches based on this plain radiograph study, which corresponds with the results from the present study.

Patient height was found to be significantly greater in “U-shaped” and “W-shaped” notches compared to “A-shaped” notches. Patient height was evaluated, compared to notch volume and ACL volume by Charlton et al. This study concluded that taller patients were more likely to possess greater notch volumes and greater ACL volumes. In addition, Murshed et al. found that, anthropometrically, notch height is greater in men than women. Our study adds to previous conclusions by also suggesting that taller patients are more likely to have a “U-shaped” notch. Whereas Chaudhari et al. found a positive correlation between patient weight and notch volume, our data did not find a significant correlation between notch shape and patient weight or BMI.

When notch dimensions were compared between genders, regardless of notch shape, it was found that females had a statistically smaller mean notch width at the base and middle than males. This is consistent with other studies that determined by means of radiographic measurements that females had smaller notch dimensions than males. No difference in notch height was found in this study.

The femoral notch has been a topic of study for the past two decades. There has been a significant number of studies that suggest that the notch width (absolute width and notch width index) can be correlated to ACL rupture. Studies have also shown that females have smaller notches and NWI than males, suggesting that this smaller notch may contribute to a higher frequency of ACL rupture in women. In these studies, the notch was generally evaluated by plain radiographs. The primary drawback of plain radiography is that a precise angle of
x-ray is necessary to optimize notch visualization and that this optimal angle can vary slightly between individuals. Other studies have evaluated notch dimensions by means of three-dimensional imaging (CT or MRI). The perceived drawback of this type of evaluation is magnification error as well as difficulty in identifying the optimal cut for notch outlet evaluation. With direct arthroscopic visualization in our study, we aimed to categorize notch appearance and also to measure directly the outlet dimensions in patients with arthroscopically proven ACL rupture. Direct measurement is free of magnification error and can accurately determine the dimensions of the actual outlet of the notch, the locus where presumed stenosis and graft impingement occur.

A limitation of this study is that there was no control group (patients with intact ACLs) whose notch dimensions were measured. With this group, comparison of notch shape frequency, notch dimensions, and demographic data could be compared to assess possible notch-related risk factors to ACL injury. This is a subject for future study.

Conclusion

In conclusion, this study offered a classification of notch shapes based on arthroscopic evaluation with acceptable intra-observer and inter-observer reliability. This classification scheme was intended to categorize notch shape based on the surgeon’s visual inspection. In our study this visual inspection is further supported by numerical data verifying the surgeons’ ability to perceive notch shape based on pre-determined criteria for “A-shaped” versus “U-shaped” versus “W-shaped” notches. It has also demonstrated that “A-shaped” notches are narrower in every dimension, including the base, when compared to “U-shaped” and “W-shaped” notches. Furthermore, increased patient height has a statistically significant relation with “U-shaped” notches. Females, regardless of notch shape, have a smaller notch width at the base and middle of the notch. Ultimately, an “A-shaped” notch may result in greater technical difficulty in femoral tunnel access and drilling from the anteromedial portal. With this data, surgeons who enter the knee and appreciate an “A-shaped” notch should consider placing the arthroscope in the anteromedial portal and drill the femoral tunnel through an accessory medial portal to improve visualization and accuracy in anatomic femoral tunnel creation. Since “A-shaped” notches are narrower in every dimension, these notches may be less likely to accommodate a double bundle ACL reconstruction.

References
2. Cha JH, Lee SH, Shin MJ, Choi BK, Bin SI. Relationship between mucoid
15. Ireland ML, Ballantyne BT, Little K, McClay IS. A radiographic analysis of