Anatomic anterior cruciate ligament reconstruction: a changing paradigm
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CHAPTER 8

ACL GRAFT RE-RUPTURE AFTER DOUBLE-BUNDLE RECONSTRUCTION: FACTORS THAT INFLUENCE THE INTRA-ARTICULAR PATTERN OF INJURY

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Abstract

Purpose: To determine the most common rupture patterns of previously reconstructed DB-ACL cases, seen at the time of revision surgery and to determine the influence of age, gender, time between the initial ACL reconstruction and re-injury, tunnel angle and etiology of failure.

Methods: Forty patients who presented themselves for revision surgery after previous double-bundle ACL-reconstruction were enrolled. Three orthopaedic surgeons independently reviewed the arthroscopic videos and determined the rupture pattern of both the anteromedial and posterolateral grafts. The graft rupture pattern was then correlated to the previously mentioned factors.

Results: The most common injury pattern seen at the time of revision ACL surgery was mid-substance AM and PL bundle rupture. Factors that influenced the rupture pattern (proximal vs. midsubstance and distal rupture vs. elongated but in continuity) were months between ACL reconstruction and re-injury (p = 0.002), the etiology of failure (traumatic vs. a-traumatic) (p = 0.025) and the measured graft tunnel angle (p = 0.048).

Conclusions: The most common pattern of graft re-rupture was mid-substance AM and midsubstance PL. As the interval from the initial DB-ACL reconstruction to revision surgery increased, the pattern of injury more closely resembled that of the native ACL. Evaluation of patients who have undergone double-bundle ACL reconstruction, with a particular focus on graft maturity, mechanism of injury, and femoral tunnel angles, and graft rupture pattern assists in pre-operative planning for revision surgery.

Introduction

The exact etiology of anterior cruciate ligament (ACL) injuries is still poorly understood. Although the role of the two functional bundles (anteromedial (AM) and posterolateral (PL)) has been defined, there are few studies that attempt to establish the exact pattern or patterns of injury that may occur \(^1\). Similarly, specific factors that can influence the relative pattern of injury have not been defined yet.

Biomechanical studies have shown that variations in ACL tunnel placement result in variable postoperative knee kinematics and loads \(^2\)\(^-\)\(^7\). Schenck et al. employed a straight knee hyperextension model to rupture the native ACL and demonstrated a variable pattern of ACL tears at high vs. low energy moments \(^8\). This suggests that there are various biomechanical factors that can influence the rupture pattern.

Recently, Zantop et al. studied the rupture pattern of the native ACL at the time of arthroscopy. Their results demonstrated that 24% of patients had a partial ACL rupture and that in 44% of the total cases the AM and PL bundle did not
rupture at the same level (proximal, midsubstance, distal) \(^1\).

With the increasing number of ACL reconstructions being performed each year, a subsequent increase in the number of revision cases has occurred \(^8,10\). Recently, more attention has been paid to re-rupture cases and what can be learned in this setting \(^11,12\). Biomechanical studies \(^2,4,13-15\) have shown that variations in ACL reconstruction technique, i.e. difference in tunnel placement and graft type, result in variable post-operative knee kinematics and loads. Theoretically, this exposes the reconstructed ACL graft to variable forces and potentially results in different rupture patterns when the graft is stressed to failure. To date, no studies have specifically attempted to determine the most common rupture pattern and causative or related factors in failure of double-bundle ACL reconstruction. Double-bundle ACL reconstruction may have additional causes of failure than single-bundle reconstruction, associated with 4 tunnels instead of 2. When causes of failure can be determined, as well as factors which can identify these causes, they can be prevented in the future.

The primary purpose of this study was to determine the most common rupture pattern in ACL revision cases after previous double-bundle reconstruction. Our secondary purpose was to identify variables that can be correlated with the rupture pattern of the graft. The hypothesis of this study was that it is possible to identify factors that influence the rupture pattern of the ACL graft, such as the time between the primary surgery and the failure and the mechanism of injury.

**Materials and Methods**

Between 2005 and 2009 all patients that underwent revision ACL surgery after a previous double-bundle reconstruction were evaluated. After receiving approval from our institutional review board, forty patients were identified and prospectively enrolled as a cohort. We excluded all patients that had undergone multiple (>1) revision surgeries on the knee of interest.

Three orthopaedic surgeons with sports medicine fellowship training independently reviewed the arthroscopic footage of the included subjects to determine the rupture pattern. The rupture pattern was recorded using the classification system previously described by Zantop et al.\(^1\) Specifically, each bundle was classified independently as either ruptured proximally, mid-substance or distally, functionally insufficient due to elongation, or intact/ uninjured. The observers were not blinded to information about the previous reconstructive procedure. If the observers felt they were unable to determine the rupture pattern due to insufficient footage, they could score a bundle as indeterminate. Inter-observer agreement was also determined.

Patient demographic data including age, gender, date of the initial ACL reconstruction, date of re-injury and etiology of failure were collected. The etiology of failure was classified as either traumatic or atraumatic.
Finally, the femoral graft tunnel angles were measured on standardized anterior-posterior radiographs of the knee, using a commercially available radiographic imaging system (Stentor, Philips Healthcare, Andover, MA). The tunnel angle was defined as the angle between the tunnel and the axis of the femur (Figure 1).

Statistical Analysis

Data were analyzed with PASW Statistics (version 17.0, SPSS Inc., Chicago, IL). Inter-observer agreement for the three observers was calculated using the Fleiss kappa coefficient for multiple ratings per subject. This method generates a single kappa value for all three observers combined. Statistical analysis of associated variables was performed using the rupture pattern ratings of observer number one. Descriptive statistics were calculated for all the variables including frequency counts for nominal variables and means, medians, standard deviation, and a range for all continuous variables.

Figure 1: Anterior-posterior flexion weight-bearing radiograph of the right knee after double-bundle ACL reconstruction. The tunnel angle is measured as the angle between the axis of the femur and the outline of the tunnel.

The Kruskal-Wallis one-way analysis of variance was used to determine
the influence of patient age, ACL reconstruction to re-injury time interval, and tunnel angle on the rupture pattern. When statistical significance was achieved (p < 0.05), a post-hoc Mann-Whitney U test was performed to further specify the difference. For the post-hoc analysis, the Bonferroni correction was applied to adjust the a-priori alpha level to the number of comparisons performed. This resulted in p < 0.05/3 for the AM bundle and 0.05/6 for the PL bundle as the level of significance. The Chi Square test and Cramer V correlation coefficient were used to measure the relationship between the rupture pattern and nominal variables such as gender and etiology of failure. The a-priori alpha level was p < 0.05. When statistical significance was achieved, a post-hoc analysis of the standard residuals was performed. A critical value of ±1.96 was used to further specify the difference.

Results

Forty subjects were included in this study and arthroscopic video reviewed by all examiners. The kappa for multiple observers was .80 for the AM bundle and .76 for the PL bundle.

The demographic information of the study cohort is reported in Table 1. The frequencies of the different rupture patterns are displayed in Table 2. The most frequent rupture pattern was mid-substance rupture of both the AM and PL bundle graft (35.1%). After combined midsubstance injuries, the three most common patterns seen were mid-substance rupture of the AM graft with either elongation (13.5%) or proximal rupture (8.1%) of the PL graft, and proximal rupture of the AM bundle with an intact PL bundle (8.1%) (Figure 2). Since there was an extremely low number of distal (tibial-sided) graft ruptures, distal and mid-substance ruptures were collapsed as a single category for further statistical analysis.

Isolated analysis of the AM bundle graft showed that the time between the initial ACL surgery and re-injury significantly influenced the rupture pattern.

Table 1. Demographic data: (N=40)

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male: Female</td>
<td>22:17</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>19 (median)</td>
<td>16 – 38</td>
<td></td>
</tr>
<tr>
<td>Months between initial surgery and re-injury</td>
<td>18.6</td>
<td>9.5</td>
<td>6 – 39</td>
</tr>
<tr>
<td>Etiology of failure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traumatic: Atraumatic</td>
<td>35:5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tunnel angle AM</td>
<td>23°</td>
<td>13°</td>
<td>1° – 41°</td>
</tr>
<tr>
<td>Tunnel angle PL</td>
<td>43°</td>
<td>8°</td>
<td>27° – 62°</td>
</tr>
</tbody>
</table>

SD = standard deviation. AM = anteromedial bundle graft. PL = posterolateral bundle graft
Chapter 8: ACL graft re-rupture after double-bundle reconstruction

Table 2. Frequencies (% of total) of the different rupture patterns for the AM and PL bundle graft

<table>
<thead>
<tr>
<th>PL → AM</th>
<th>Proximal</th>
<th>Mid-substance</th>
<th>Distal</th>
<th>Elongated</th>
<th>Intact</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>8</td>
<td>19</td>
</tr>
<tr>
<td>Mid-substance</td>
<td>8</td>
<td>35</td>
<td>0</td>
<td>14</td>
<td>3</td>
<td>59</td>
</tr>
<tr>
<td>Distal</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Elongated</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>Intact</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total PL</td>
<td>19</td>
<td>41</td>
<td>3</td>
<td>19</td>
<td>19</td>
<td>100</td>
</tr>
</tbody>
</table>

PL bundle graft. AM = anteromedial bundle, PL = posterolateral bundle

The interval between reconstruction and re-rupture was significantly greater in proximal ruptures as compared to distal or mid-substance ruptures (32 months vs. 14 months, p = 0.001).

Figure 2: Arthroscopic figures of the right knee in 90° of flexion displaying the four most frequent double-bundle graft rupture patterns after anterior cruciate ligament reconstruction. Together they account for 65% of the ruptures. A. Anteromedial portal view, the AM and PL bundle have ruptured mid-substance. B. Anterolateral portal view, the AM bundle ruptured mid-substance and the PL bundle is elongated. C. Anteromedial portal view, the AM bundle ruptured mid-substance and the PL bundle proximal. D. Anteromedial portal view, the AM bundle ruptured proximal and the PL bundle is still intact. AM = anteromedial, PL = posterolateral, LFC = lateral femoral condyle.
The rupture pattern of the AM graft was also significantly correlated with the etiology of failure (traumatic vs. atraumatic) (Cramer V = .436; p = 0.025). Ninety-four percent of proximal, midsbusstance or distal tears were traumatic and only fifty-seven percent of elongated grafts were the result of a traumatic event. The Kruskall Wallis test also showed a main effect of tunnel angle on the AM graft rupture pattern. However, post-hoc analysis was unable to further specify this effect. The AM rupture pattern was not significantly different on the basis of the patients' age or gender (Table 3).

With respect to the PL bundle, the time interval between the initial ACL surgery and re-injury also influenced the rupture pattern. Distal or mid-substance ruptures occurred at a significantly shorter reconstruction to re-rupture interval than the proximal ruptures (13 vs. 24 months, p = 0.006). The PL rupture pattern was not significantly different on the basis of the patients’ age, gender, etiology of failure or tunnel angle (p = 0.054) (Table 4).

<table>
<thead>
<tr>
<th>Factors</th>
<th>Proximal (n = 7)</th>
<th>Mid-substance and distal (n = 25)</th>
<th>Elongated (n = 7)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (median, [95% CI])</td>
<td>20 [18-27]</td>
<td>18.5 [19-21]</td>
<td>23.5 [16-34]</td>
<td>NS</td>
</tr>
<tr>
<td>Gender (% male)</td>
<td>57%</td>
<td>56%</td>
<td>50%</td>
<td>NS</td>
</tr>
<tr>
<td>Months out (median, [95% CI])</td>
<td>32 [21-37]</td>
<td>14 [12-18]</td>
<td>17 [14-31]</td>
<td>0.002‡</td>
</tr>
<tr>
<td>Etiology of failure (% traumatic)</td>
<td>86%</td>
<td>96%</td>
<td>57%</td>
<td>0.025†</td>
</tr>
<tr>
<td>Tunnel angle (median, [95% CI])</td>
<td>14 [8-20]</td>
<td>29 [21-31]</td>
<td>20 [11-30]</td>
<td>0.048‡</td>
</tr>
</tbody>
</table>

95% CI = 95% confidence interval.
‡ Proximal ruptures had a significantly greater time between the primary surgery and re-injury than the mid-substance and distal ruptures, p = 0.001.
† Cramer V = .436. A-traumatic injuries were more likely to be elongated.
‡ Post-hoc analysis was unable to further specify this difference.
Table 4. Factors that influence the rupture pattern of the posterolateral bundle

<table>
<thead>
<tr>
<th>Factors</th>
<th>Proximal (n = 7)</th>
<th>Mid-substance and distal (n = 16)</th>
<th>Elongated (n = 10)</th>
<th>Intact (n = 5)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (median, [95% CI])</td>
<td>21 [18-26]</td>
<td>18 [18-23]</td>
<td>19.5 [18-27]</td>
<td>19 [16-29]</td>
<td>NS</td>
</tr>
<tr>
<td>Gender (% male)</td>
<td>83%</td>
<td>56%</td>
<td>40%</td>
<td>40%</td>
<td>NS</td>
</tr>
<tr>
<td>Months out (median, [95% CI])</td>
<td>24 [15-32]</td>
<td>13 [12-29]</td>
<td>17 [12-33]</td>
<td>22 [15-21]</td>
<td>0.039†</td>
</tr>
<tr>
<td>Etiology of failure (% traumatic)</td>
<td>86%</td>
<td>100%</td>
<td>70%</td>
<td>100%</td>
<td>NS</td>
</tr>
</tbody>
</table>

95% CI = 95% confidence interval.
† The proximal ruptures had a significantly longer time between the primary surgery and re-injury than the mid-substance and distal ruptures, p = 0.006.

Discussion

The most important finding of the present study was that the most common rupture pattern in ACL revision cases after previous double-bundle reconstruction is mid-substance rupture of the AM bundle, with either mid-substance rupture, proximal rupture, or elongation of the PL bundle, as well as an isolated proximal AM bundle rupture with an intact PL graft. These four patterns characterized approximately 65% of all ruptures. This differs from the most frequent rupture pattern seen in the native ACL, as reported by Zantop et al. Their study demonstrated proximal rupture of the AM bundle with either proximal or mid-substance rupture of the PL bundle as the most common patterns of injury (Figure 3). However, despite this difference, we did see similar results for the occurrence of ruptures of both bundles at the same level, and for the relative incidence of an intact PL bundle (Table 5). In another case series of ACL revision surgeries, Kaz et al. also reported an isolated AM bundle rupture with intact PL bundle among their report of three double-bundle re-ruptures.
Table 5. Comparison of the rupture pattern in ACL revision surgery to the rupture pattern of the native ACL

<table>
<thead>
<tr>
<th>Measured data</th>
<th>Zantop et al. 2007 Rupture pattern native ACL</th>
<th>Current study Rupture pattern reconstructed ACL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two most frequent rupture patterns</td>
<td>AM proximal PL proximal AM proximal PL mid-substance</td>
<td>AM mid-substance PL mid-substance AM mid-substance PL elongated</td>
</tr>
<tr>
<td>Cases where both bundles ruptured at the same location</td>
<td>56%</td>
<td>43%</td>
</tr>
<tr>
<td>PL bundle intact</td>
<td>12%</td>
<td>18.9%</td>
</tr>
</tbody>
</table>

ACL = anterior cruciate ligament. AM = anteromedial bundle. PL = posterolateral bundle

Patient-related factors such as age and gender showed no correlation with the pattern of rupture. The time interval between the initial ACL reconstruction and the re-injury significantly influenced the rupture pattern. A longer period was associated with more proximal ruptures of the graft, whereas a shorter time resulted in more distal and mid-substance ruptures. We believe that this finding may be the result of varied degrees of healing or “ligamentization” of the reconstructed ACL graft. In other words, when the graft was given more time to heal and remodel, the resultant reinjury pattern was most similar to the native ACL, i.e. proximal rupture of the graft. Ligamentization may also be influenced by graft type (allograft vs. autograft) and procedure (single- vs. double-bundle).

Graft tunnel angle also demonstrated a significant effect on the rupture pattern. However, post-hoc analysis was unable to specify this difference. We believe that tunnel positioning is a key determinant of the biomechanical function of the knee. Theoretically, variable graft tunnel positioning should result in differences in forces seen by the graft. Therefore, we would expect differences in rupture patterns as tunnel position is changed. Further research is needed to investigate and validate these principles.
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Figure 3: Arthroscopic figure of the right knee in 90° of flexion showing the most frequent rupture pattern of the native anterior cruciate ligament. Both the AM and PL bundle are rupture proximally. When compared to the most common rupture pattern in revision surgery (Figure 2A) it clearly looks different. Anterolateral portal view. AM = anteromedial, PL = posterolateral, LFC = lateral femoral condyle, MFC = medial femoral condyle.

Lastly, this study showed a relationship between the rupture pattern and the etiology of failure. When the patient reported the actual traumatic event, the graft was more often ruptured. In comparison, the atraumatic failure group more frequently demonstrated elongation of the graft. This could be the result of the tunnel placement during the initial procedure. If the tunnel is placed outside of the native ACL insertion site, this can result in a mal-functioning graft that is exposed to unusual forces and as a result will elongate in time.

One of the limitations of the study was the small sample size of 40 patients. Moreover, the rupture pattern was established by review of arthroscopic videos captured at the time of the revision surgery. Therefore, observers were not able to control the arthroscope or to probe the ruptured ligament. Still, despite the lack of tactile data, we did find a good to excellent inter-observer reliability. Since a satisfactory correlation was seen between all observers, we deemed it appropriate to utilize a single observer’s ratings for further statistical analysis. In only one case the AM bundle was scored as indeterminate while the PL rupture pattern could be established. This subject was excluded for the analysis of the AM bundle and included for the analysis of the PL bundle. Another limitation was the sample size, resulting in only one distal rupture. Statistical analysis of these data would have resulted in violation of the statistical assumptions. This dilemma was solved by combining the distal and mid-substance ruptures, so no comparisons could be made.
between these two classes individually. Finally, the rupture pattern may be
determined by several factors assessed in this study, some of which may be
confounding. The reconstruction techniques for revision surgery after previous
double-bundle ACL reconstruction are still being developed.

The outcome of double-bundle reconstruction is generally good \textsuperscript{20,21}, but
since the incidence of ACL injuries is high, revisions are to be expected. During
revision ACL surgery, the rupture pattern of the graft should be inspected in all
cases. The pattern of injury may yield valuable information about the function of
the primary ACL graft. However, this step requires careful arthroscopic
examination. Other methods of determining the pattern of injury have not proven
reliable. Isolated rupture of the AM bundle has been shown to have a greater effect
on the anterior drawer sign than on the Lachman test. The opposite is true for PL
bundle ruptures, which can also be tested using the pivot shift \textsuperscript{22}. Determining the
exact rupture pattern with conventional magnetic resonance imaging, can be
difficult. An isolated PL bundle rupture is more difficult to diagnose because of the
oblique course of this bundle which takes the ligament out of place when standard
MRI sequences are employed. Three-dimensional reconstruction and 3D magnetic
resonance imaging (MRI) can better visualize the rupture pattern pre-operatively \textsuperscript{23},
but this requires specialized views or use of ultra high-field 3 Tesla MRI, which are
not typically available in routine clinical practice. At present, the rupture pattern
can best be observed and classified during arthroscopic examination. Visualizing
the rupture pattern during arthroscopy may present a challenge because the AM
bundle lies above the PL bundle when viewed from the standard anterolateral
portal \textsuperscript{22}. Using the image of the frontal position or viewing through the
anteromedial portal will help in the visualization of the whole ACL and both the
tibial and femoral insertion sites \textsuperscript{24}. If there is an isolated rupture of the AM or PL
graft, augmentation surgery should be considered, similar to primary ACL
reconstruction \textsuperscript{12,25}. Each situation encountered during revision surgery requires an
individual approach \textsuperscript{26}.

**Conclusion**

This study shows that after double-bundle reconstruction, the most
common rupture pattern is the failure of both grafts mid-substance. Factors that
influence the rupture pattern are the time interval between ACL reconstruction and
re-injury, etiology of failure and graft tunnel angle.

**References**

1. Zantop T, Brucker PU, Vidal A, Zelle BA, Fu FH. Intraarticular rupture


