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

Citation for published version (APA):

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CHAPTER 7

“ANATOMIC” ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION, A SYSTEMATIC REVIEW OF SURGICAL TECHNIQUES AND REPORTING OF SURGICAL DATA

Van Eck CF, Schreiber VM, Mejia HA, Samuelsson K, van Dijk CN, Karlsson J, Fu FH

Arthroscopy 2010;26-9 Suppl:S2-12
Chapter 7: “Anatomic” ACL reconstruction: a systematic review

Abstract

Purpose: The aim of this systematic review was to evaluate studies published on anatomic double-bundle ACL reconstruction.

Methods: A systematic electronic search was performed using the MEDLINE and EMBASE databases. Studies that were published from January 1995 to April 2009 were included. The selection criteria were studies that reported on a surgical technique for “anatomic double-bundle ACL reconstruction” on skeletally mature living human subjects, and written in English. Data collected and analyzed included a variety of surgical data. Tables were created to provide an overview of surgical techniques for anatomic ACL reconstruction.

Results: Seventy-four studies were included in this review. Some surgical factors were adequately reported in the majority of the papers; visualizing the native ACL insertion sites, placing the tunnels in the footprint, graft type and fixation method. However, ACL insertion site measurement, femoral intercondylar notch measurement, individualization of surgery and intra-operative/post-operative imaging were poorly reported. Most variety was seen in knee flexion angle during femoral tunnel drilling and tensioning pattern of the grafts.

Conclusion: For most surgical data, there was a gross underreporting of specific operative technique data. We think that the details of an “anatomic” operative technique are crucial for the valid interpretations of the outcomes. Therefore, we encourage authors to report their surgical technique in a specific and standardized fashion.

Introduction

Recently, there has been a shift in interest from single-bundle to double-bundle reconstruction of the anterior cruciate ligament (ACL). The double-bundle graft is suggested to more closely restore or resemble the normal anatomy of the ACL by restoring the anteromedial (AM) and posterolateral (PL) bundles of the native ACL. The two bundles display different characteristics; the AM bundle is tight in flexion, whereas the PL bundle is tight near full knee extension. This restoration of the native ACL anatomy has been an attempt to obtain better clinical outcomes.

The development of the double-bundle reconstruction concept has increasingly led to the use of the term “anatomic” reconstruction to describe a certain surgical technique. The use of this term suggests that the ACL anatomy is restored using the described surgical technique. It is also often used in combination with the term ‘double-bundle’. However, a ‘double-bundle’ ACL reconstruction is not the same as an ‘anatomic’ ACL reconstruction. Double-bundle reconstruction indicates that the ACL is restored using two separate bundles, and does not necessarily specify the location of the tunnels. Whereas an “anatomic” ACL

93
reconstruction suggests that the tunnels are placed in the center of the native femoral and tibial insertion sites, which is independent of whether a single or double-bundle is used. This difference in linguistic terms is therefore of major importance as “anatomic” and “double-bundle” are not interchangeable. Anatomic ACL reconstruction can be applied to both single- and double-bundle reconstructions, as well as to augmentation surgery. We define “anatomic ACL reconstruction” as: the functional restoration of the ACL to its native dimensions, collagen orientation, and insertion sites (Figure 1). Complete restoration of the native ACL may not be possible, due to the complex nature of the ligament. However, the surgeon should strive towards close approximation.

Since the introduction of the term “anatomic”, many authors have reported their anatomic ACL reconstruction technique. However, little information is given in the methods section outlining their “anatomic” procedure. Our interest and goal was to assess the current studies describing anatomic double-bundle reconstruction and to evaluate the surgical data and the variety of these data among the different studies. This led us to present the following systematic review assessing the “anatomic” double-bundle ACL reconstruction techniques in the literature today. This systematic review aimed to investigate and assess studies published on anatomic double-bundle ACL reconstruction that provide a description of the surgical technique. A descriptive analysis of the reporting of a variety of surgical data was performed. We hypothesized that a substantial percentage of the reviewed surgical technique descriptions provided insufficient data needed for proper interpretation of their technique and reported outcomes.

Figure 1: Anatomic ACL reconstruction restores the native ACL anatomy. A. Arthroscopic lateral portal view of the native ACL of the right knee. B. Arthroscopic lateral portal view of an ACL graft of the right knee after anatomic double-bundle ACL reconstruction.
Chapter 7: “Anatomic” ACL reconstruction: a systematic review

Methods

This systematic review was conducted following the guidelines provided by the Cochrane Handbook³.

Criteria for Considering Studies for this Review

Types of studies

Studies that report on a surgical technique for anatomic double-bundle ACL reconstruction, either with or without outcomes, were included. Level of evidence was not a factor for inclusion or exclusion. Studies that reported on an anatomic single-bundle reconstruction technique were excluded in this review, for the purpose of creating a more homogeneous literature sample.

Types of participants

Studies describing surgical techniques for application to skeletally mature living human subjects with an ACL-rupture were eligible for inclusion. Studies focusing on children, congenitally deformed people, and patients with severe degenerative diseases, rheumatologic, neurologic and cardiovascular disorders and animals were all excluded. If studies had a mixed population of participants of the included and before mentioned excluded participants, they were only included when the data could be analyzed separately.

Types of interventions

The intervention was anatomic double-bundle ACL reconstruction. Since there were no readily available criteria for anatomic ACL reconstruction, we chose to include all papers in which the authors stated that the reconstructive surgical procedure they performed was anatomic. All studies focusing primarily on graft types and fixation methods were included. Studies comparing reconstructive techniques, such as double-bundle reconstruction to single-bundle reconstruction were included. However, in these comparative studies, only the technique for anatomic double-bundle ACL reconstruction was included for analysis. Studies focusing exclusively on revision surgery were also included.

Types of outcome measures

A descriptive review of the reporting of a variety of surgical data was performed by means of a worksheet. Demographic data that were obtained from the included papers were; authors, year and journal of publication. The data that were obtained from the included papers were: level of evidence, use of the accessory medial portal, visualization of the tibial and femoral insertion sites, visualization of the lateral intercondylar ridge and lateral bifurcate ridge, measuring of the tibial and femoral insertion site, measuring the size of the femoral
intercondylar notch, performing notchplasty, use of the o’clock face, flexion angle during femoral tunnel drilling, placing the tunnels in the center of the tibial and femoral ACL insertion sites, proof of tunnel placement (i.e. arthroscopic pictures, a diagram, figures or imaging etc.), placement of the tibial and femoral tunnels at a fixed distance from another anatomic structure (i.e. PCL, posterior wall of the notch, etc.), individualization of the surgery (determining graft type and size on the patient characteristics), use of fluoroscopy, use of navigation, tibial and femoral fixation, different tension pattern for the two bundles and post operative imaging (radiographs, Magnetic Resonance Imaging (MRI), Computer Tomography (CT) and/or 3D CT). A worksheet for data extraction was created and used to obtain information from each study, including demographics and surgical data (Table 1). The data were recorded as either ‘Yes, reported’ or ‘No, not reported’. In addition, if an item was scored as ‘Yes, reported’, more specific data were collected where possible.

Search Strategy

A systematic electronic search was performed using the MEDLINE and EMBASE databases. Studies that were published from January 1995 to April 2009 were included. The search was carried out in April 2009.

<table>
<thead>
<tr>
<th>Table 1. Demographic and surgical data recorded from included studies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author 1 - 7</strong></td>
</tr>
<tr>
<td>Year of publication</td>
</tr>
<tr>
<td>Journal of publication</td>
</tr>
<tr>
<td>Level of evidence</td>
</tr>
<tr>
<td>Use of an accessory medial portal</td>
</tr>
<tr>
<td>Visualization of the tibial insertion site</td>
</tr>
<tr>
<td>Visualization of the femoral insertion site</td>
</tr>
<tr>
<td>Visualization of the lateral intercondylar and bifurcate ridge</td>
</tr>
<tr>
<td>Measuring the tibial insertion site</td>
</tr>
<tr>
<td>Measuring the femoral insertion site</td>
</tr>
<tr>
<td>Measuring the dimensions of the femoral intercondylar notch</td>
</tr>
<tr>
<td>Performing wall or notchplasty</td>
</tr>
</tbody>
</table>

96
Chapter 7: “Anatomic” ACL reconstruction: a systematic review

Use of o’clock face for femoral tunnel position
Use of post-operative MRI
Flexion angle during femoral drilling
Use of post-operative CT-scan
Placement of the tibial tunnel in ACL footprint
Use of post-operative 3-dimensional CT-scan

The year 1995 was chosen as the starting date, since we are not aware of the term “anatomic” being used before the year 1998 and a 3 year margin was added. The following key search terms were used in all fields including MeSH (Medical Subject Heading): ‘anterior cruciate ligament’ OR ‘ACL’ AND ‘anatomic’ OR ‘anatomical’ AND ‘reconstruction’ OR ‘surgery’ AND ‘1995:2009’ (See Appendix 1 for complete search string). Only articles written in English were included. Furthermore, the reference lists of the selected studies were investigated to identify additional studies that were not found through our electronic search.

Data Collection and Analysis

Selection of studies
From the abstracts two authors independently selected relevant studies for full-text review. Studies were also included if the abstract did not provide enough data to make a correct decision. For inclusion in the review, two authors independently analyzed the full texts using the previously described criteria. The analysis was not performed in a blinded fashion, i.e. blacking out authors, title and so on. Disagreement between the two reviewers was resolved by consensus.

Data extraction and management
The data were extracted from the included papers, according to a predefined standardized data sheet. The data sheet included a column for all the data, as well as an additional column for comments. Validation of the data extracted was performed by the first author.

Statistical analysis and data synthesis
PASW Statistics (version 17.0, SPSS Inc., Chicago, IL) was used to process the data. From all the data that were recorded, a frequency table was made. The Level of Evidence was cross tabulated with the extracted surgical data to determine the influence, using chi square. This was done for Level 1 + 2, versus Level 3 + 4, versus Level 5 studies. The level of statistical significance was set at p <0.05. Post-hoc analysis was performed when a significant influence was found, using the standardized residuals.
Results

Description of Studies

Results of the search

There were 740 hits on MEDLINE and 357 on EMBASE, using the previously described search criteria (Figure 2). From these, 1097 studies, 955 were excluded on the basis of the abstracts, because they did not meet the inclusion criteria. Most of the excluded studies were either cadaveric studies, pediatric studies, not written in English or papers focusing exclusively on single-bundle reconstruction. Of the 142 remaining papers, 74 were included for final analysis. The other 68 papers were mostly excluded because they did not report that their reconstructive technique was anatomic. For example, they stated they used “anatomic fixation”.

Figure 2: Flow diagram of the search and the included and excluded studies.

Included studies

A total of 74 papers were included for further analysis in this systematic review. The demographic data of the included papers are displayed in Table 2 and the level of evidence in Table 3. There was a low percentage of level 1 and 2 studies and a high percentage of level 5 studies. The level 5 studies mainly consisted of technical notes and expert opinions. Eleven of the included studies
Chapter 7: “Anatomic” ACL reconstruction: a systematic review

described both an anatomic single- as well as a double bundle technique. However,

<table>
<thead>
<tr>
<th>Table 2. Demographics of included studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Papers</td>
</tr>
<tr>
<td>First authors</td>
</tr>
<tr>
<td>Journal</td>
</tr>
<tr>
<td>Year</td>
</tr>
</tbody>
</table>

SD: Standard deviation

in these studies only the double-bundle reconstruction was analyzed.

<table>
<thead>
<tr>
<th>Table 3. Level of evidence of included studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
</tr>
<tr>
<td>Level 2</td>
</tr>
<tr>
<td>Level 3</td>
</tr>
<tr>
<td>Level 4</td>
</tr>
<tr>
<td>Level 5</td>
</tr>
</tbody>
</table>

Data Results

Whether the recorded surgical data were reported or not reported in the included papers, is displayed in Table 4.

Level of evidence

Most of the included studies were level 5 evidence as can be seen in Table 3. Due to the low number of level 1 and 2 studies, these groups were combined into one group for further statistical analysis. There were no level 4 studies included in this review. Cross tabulation of the level of evidence with the reported surgical data was unable to show the influence due to a too small number of studies in each group for: visualization of the tibial and femoral insertion sites, visualization of the lateral intercondylar ridge and lateral bifurcate ridge, measuring of the tibial and femoral insertion site, measuring the size of the femoral intercondylar notch, performing notchplasty, placing the tunnels in the center of the tibial and femoral ACL insertion sites, proof of tunnel placement, placement of the tibial and femoral tunnels at a fixed distance from another anatomic structure, individualization of the surgery, use of fluoroscopy, use of navigation, tibial and femoral fixation, different tension pattern for the two bundles, post operative radiographs, MRI, CT or 3D CT. This would have violated the statistical assumptions.
Table 4. Reporting of surgical data in included reviews

<table>
<thead>
<tr>
<th></th>
<th>Reported (%)</th>
<th>Not reported (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of an accessory medial portal</td>
<td>51.4</td>
<td>48.6</td>
</tr>
<tr>
<td>Visualization of the tibial insertion site</td>
<td>77.0</td>
<td>23.0</td>
</tr>
<tr>
<td>Visualization of the femoral insertion site</td>
<td>70.3</td>
<td>29.7</td>
</tr>
<tr>
<td>Visualization of the lateral intercondylar and bifurcate ridge</td>
<td>12.2</td>
<td>87.8</td>
</tr>
<tr>
<td>Measuring the tibial insertion site</td>
<td>4.1</td>
<td>95.9</td>
</tr>
<tr>
<td>Measuring the femoral insertion site</td>
<td>4.1</td>
<td>95.9</td>
</tr>
<tr>
<td>Measuring the dimensions of the femoral intercondylar notch</td>
<td>1.4</td>
<td>95.9</td>
</tr>
<tr>
<td>Performing wall or notchplasty</td>
<td>12.2</td>
<td>87.8</td>
</tr>
<tr>
<td>Use of o’clock face for femoral tunnel position</td>
<td>60.8</td>
<td>39.2</td>
</tr>
<tr>
<td>Flexion angle during femoral drilling</td>
<td>59.5</td>
<td>40.5</td>
</tr>
<tr>
<td>Placement of the tibial tunnel in ACL footprint</td>
<td>85.1</td>
<td>14.9</td>
</tr>
<tr>
<td>Placement of the femoral tunnel in ACL footprint</td>
<td>81.1</td>
<td>18.9</td>
</tr>
<tr>
<td>Proof of tunnel placement provided†</td>
<td>71.6</td>
<td>28.4</td>
</tr>
<tr>
<td>Placement of the tibial tunnel at fixed distance from another anatomic structure</td>
<td>35.1</td>
<td>64.9</td>
</tr>
<tr>
<td>Placement of the tibial tunnel at fixed distance from another anatomic structure</td>
<td>35.1</td>
<td>64.9</td>
</tr>
<tr>
<td>Individualization of surgical technique based on patient characteristics</td>
<td>4.1</td>
<td>95.9</td>
</tr>
<tr>
<td>Graft type that was used†</td>
<td>91.9</td>
<td>8.1</td>
</tr>
<tr>
<td>Use of fluoroscopy</td>
<td>10.8</td>
<td>89.2</td>
</tr>
<tr>
<td>Use of navigation</td>
<td>10.8</td>
<td>89.2</td>
</tr>
<tr>
<td>Tibial fixation method†</td>
<td>89.2</td>
<td>10.8</td>
</tr>
<tr>
<td>Femoral fixation method†</td>
<td>94.6</td>
<td>5.4</td>
</tr>
<tr>
<td>Use of a different tension pattern for the anteromedial and posterolateral bundle graft</td>
<td>52.7</td>
<td>47.3</td>
</tr>
<tr>
<td>Use of post-operative radiography</td>
<td>18.9</td>
<td>81.1</td>
</tr>
<tr>
<td>Use of post-operative MRI</td>
<td>5.4</td>
<td>94.6</td>
</tr>
<tr>
<td>Use of post-operative CT-scan</td>
<td>2.7</td>
<td>97.3</td>
</tr>
<tr>
<td>Use of post-operative 3-dimensional CT-scan</td>
<td>2.7</td>
<td>97.3</td>
</tr>
</tbody>
</table>

† More specific data are provided in additional tables

Influence of ‘level of evidence’ was found on the use of the o’clock face method for femoral tunnel location (p=0.001) and the knee flexion angle during femoral tunnel drilling (p=0.014). Post-hoc analysis showed that level 5 studies
used the o’clock face methods less often than level 1, 2 and 3 studies. Level 3 studies more often did not report the knee flexion angle during femoral tunnel drilling than level 1, 2 and 5 studies. There were no differences among the different levels of evidence in the use of the accessory medial portal (p= 0.75).

**Accessory medial portal**
Of the included studies, 51.4% reported the use of an accessory medial portal. The other studies used a two-portal approach with the standard anteromedial and anterolateral portals.

**Visualization and measurement of the native ACL insertion sites**
Seventy-seven percent of the studies stated they visualized the tibial insertion site, whereas 70.3% of the studies reported visualizing the femoral insertion site. The bony ridges were identified in 12.2% of the studies for identification of the femoral ACL insertion site location. Often, this only concerned the lateral intercondylar ridge and not the lateral bifurcate ridge. Only 4.1% of the papers reported measuring the tibial and femoral insertion site dimensions and 1.4% measured the dimensions of the femoral intercondylar notch.

**Notchplasty**
Of the included studies, 12.2% performed notchplasty. Most authors described using it for adequate visualization. The notchplasty was often described as being only “minimal”, or performed “when needed”. It was also used for hardware retrieval in revision surgery. In none of the studies performing notchplasty, measurements of the notch were performed. No measurements of the notchplasty were reported either.

**O’clock face**
The o’clock face was used in 60.8% of the papers to indicate the location of the femoral tunnels. Most authors used it to clarify their femoral tunnel location in addition to describing placing the tunnels in the anatomic footprint, rather than to determine the exact location of the femoral tunnels. The reported location of the AM tunnel varied from 10.00/2.00 to 11.00/1.00 o’clock. The PL tunnel was placed between the 9.00/3.00 and 9.30/2.30 position.

**Drilling of the femoral tunnel**
Knee flexion angles during femoral tunnel drilling were reported in 59.5% of the studies. In the studies that reported the knee flexion angle, it varied between 90 and 135 degrees.

**Placing the tunnels in the ACL footprint**
The tibial tunnels were reported to be placed in the center of the AM and
PL footprints in 85.1% of the studies. The same was done in 81.1% for the femoral tunnels. Seventy-six percent of the studies provided proof of this, using either a diagram, arthroscopic pictures, radiographs, MRI, CT or 3D CT scans. Five percent used other means, such as fluoroscopic pictures, a plastic model, cadaveric pictures and navigation data. Arthroscopic pictures and diagrams were used most often. Sixty-five percent of the papers provided a combination of two or more of the above mentioned proofs (Table 5). The tibial and femoral tunnel locations were placed at a fixed distance from another anatomic structure in 35.1% of the studies. Sometimes this fixed distance determined the location of the tunnels and sometimes it was used to clarify the location of the ACL footprint. For the tibial side, authors used the tibial plateau length on radiographs/fluoroscopy, the medial tibial eminence, lateral tibial spine, posterior cruciate ligament, anterior horn of lateral meniscus, medial collateral ligament, and medial femoral condyle. For the femoral side they used Blumensaat’s line on radiographs/fluoroscopy, or the posterior edge of intercondylar notch/posterior cartilage border.

### Table 5. Proof of tunnel placement in the native ACL footprint

<table>
<thead>
<tr>
<th>Method</th>
<th>Shown † (%)</th>
<th>Not shown (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagram</td>
<td>74.3</td>
<td>25.7</td>
</tr>
<tr>
<td>Arthroscopic pictures</td>
<td>55.4</td>
<td>44.6</td>
</tr>
<tr>
<td>Radiographs</td>
<td>17.6</td>
<td>82.4</td>
</tr>
<tr>
<td>MRI</td>
<td>2.7</td>
<td>97.3</td>
</tr>
<tr>
<td>CT</td>
<td>4.1</td>
<td>95.9</td>
</tr>
<tr>
<td>3D CT</td>
<td>4.1</td>
<td>95.9</td>
</tr>
<tr>
<td>Other</td>
<td>5.4</td>
<td>94.6</td>
</tr>
<tr>
<td>Multiple of the above</td>
<td>64.9</td>
<td>35.1</td>
</tr>
</tbody>
</table>

† % of papers that use these methods to show their tunnel positions

### Individualization

The surgery was individualized in 4.1% of the studies. This meant that the authors described that they determined graft type and size based on the patient’s individual characteristics or measurements of the ACL insertion sites or intercondylar notch. However, in some studies individualization was impossible, due to randomization.

### Graft type

About 8% of the studies did not report the graft type they used for their anatomic ACL reconstruction procedure. 4% used several graft types. Most of the included studies used hamstring tendon autografts (Table 6).
Chapter 7: “Anatomic” ACL reconstruction: a systematic review

Table 6. Graft types used for anatomic ACL reconstruction

<table>
<thead>
<tr>
<th>Graft type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamstring tendon</td>
<td>68.9</td>
</tr>
<tr>
<td>Quadriceps tendon</td>
<td>2.7</td>
</tr>
<tr>
<td>Allograft</td>
<td>16.2</td>
</tr>
<tr>
<td>Multiple graft types</td>
<td>4.1</td>
</tr>
<tr>
<td>Not reported</td>
<td>8.1</td>
</tr>
</tbody>
</table>

Intra-operative assistance in tunnel placement

Eleven percent of the studies used fluoroscopy to assist in the placement of their tibial and or femoral tunnels. Another 11% used navigation to aid in tunnel placement.

Fixation technique

Of the included studies, 10.8% did not report on what method they used for tibial fixation of the grafts, whereas only 5.4% of the papers did not report on the femoral fixation methods. The majority used interference screw fixation for the tibial side and EndoButton fixation for the femoral side. An overview of the different fixation methods that were used is presented in Table 7. The category ‘other’ included: mini-plate, mini-swing bridge, double-spiked plate, suture disk/plate, press fit, leaving the autograft attached to its insertion and a suture over the bony bridge. Fifty-three percent of the studies reported the use of a different tension pattern for the AM and PL graft. Twenty-seven percent reported the same tension pattern for both grafts and the remaining studies did not report on this. When the bundles were secured in the same knee flexion angle, this angle ranged from 15-60 degrees\textsuperscript{6,7,13,15,29,31,34,38,39,42,47,55,63,64,68,71,73,76}. When there was a difference in flexion angle between the AM and PL grafts, the AM flexion angle ranged from 30-90 degrees and the PL ranged from 0-30 degrees\textsuperscript{2,4,5,9-11,14,16-18,20,22-26,28,32,33,40,41,45,46,49-54,56-58,60,62,65-67}. Many different combinations were reported.

Table 7. Fixation methods used for anatomic ACL reconstruction

<table>
<thead>
<tr>
<th>Fixation method</th>
<th>Femoral side</th>
<th>Tibial side</th>
</tr>
</thead>
<tbody>
<tr>
<td>EndoButton</td>
<td>63.5%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Post</td>
<td>1.4%</td>
<td>6.8%</td>
</tr>
<tr>
<td>Cross pin</td>
<td>1.4%</td>
<td>0%</td>
</tr>
<tr>
<td>Metal interference screw</td>
<td>4.1%</td>
<td>10.8%</td>
</tr>
<tr>
<td>Bio-absorbable interference screw</td>
<td>12.2%</td>
<td>44.6%</td>
</tr>
<tr>
<td>Staple</td>
<td>4.1%</td>
<td>9.5%</td>
</tr>
<tr>
<td>Washer lock</td>
<td>0%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Other</td>
<td>8.1%</td>
<td>14.9%</td>
</tr>
<tr>
<td>Not reported</td>
<td>5.4%</td>
<td>10.8%</td>
</tr>
</tbody>
</table>
Post-operative imaging

Almost 19% of the authors reported on performing post-operative radiographs, 5.4% on post-operative MRI and 2.7% on post-operative (3D) CT. The timing of the imaging was often not reported. The studies that do report the timing, report diverse time points ranging from 1 week to 2 years after surgery. 3D CT scan was mostly performed for pre-operative planning in revision and augmentation surgery. One study reported repeated arthroscopy of the knee to evaluate the graft.

Discussion

This systematic review aimed to investigate and assess studies published on anatomic double-bundle ACL reconstruction, which provide a description of the surgical technique. It was hypothesized that many of the recorded surgical data were underreported in the literature. The most important finding of the present systematic review was that some of the surgical factors were adequately reported in the majority of the included studies. These included visualizing the native ACL insertion sites; placing the tunnels in the footprint, graft type and fixation method. Data that were poorly reported were the measuring of the ACL insertion site dimensions and femoral intercondylar notch, individualization of the surgery and intra-operative/post-operative imaging. It needs to be emphasized that individualization cannot be performed when patients are randomly allocated to either of two specific surgical procedures.

Unlike what we expected, the level of evidence did not influence the quality of reporting in the included studies. However, this may be due the large number of level 5 studies that were included, compared with level 1 and 2 studies. Another reason may be that the level 5 studies were mostly technical notes, providing very detailed surgical descriptions.

Notchplasty is still performed by some authors (12.2%) to make the reconstruction easier by visualizing the posterolateral margin of the intercondylar space more clearly. However, use of an accessory anteromedial portal allows the surgeon excellent visualization of the intercondylar space. The disadvantage of notchplasty lies in the removal of the osseous landmarks of the femoral ACL insertion. This can therefore compromise correct anatomic tunnel placement. Moreover, it can lead to abnormal graft forces, graft failure and possible regrowth and overgrowth of the notch in the medium/long-term. None of the studies that performed notchplasty reported measuring the dimensions of the notch before deciding on performing notchplasty. In our concept of anatomic ACL reconstruction, we attempt to preserve the patient’s anatomy. Thus, in a patient with a narrow notch, we suggest converting from a double bundle to a single-bundle reconstruction, or the use of a curved drill.
The knee flexion angle during femoral tunnel drilling is reported only in about 60% of the studies. During anatomic ACL reconstruction, the knee flexion angle is very important, as it largely influences the length of the femoral tunnels. Furthermore, the large variation in the reported flexion angle suggests that it is something that is not universally applicable to the wide range of anatomic ACL reconstruction techniques. Therefore it should be reported by the author.

There is a discrepancy in the recorded data in this systematic review. Seventy-seven and 70% of the papers report on visualizing the tibial and femoral ACL insertion site, respectively, but as many as 85 and 81% report placing the tunnels in the center of the tibial and femoral ACL footprint, respectively. This was often done by locating the footprint based on the distance from another anatomic structure or by using a certain predefined o’clock position. However, the size and shape of the ACL insertion site and the tibial plateau anatomy vary considerably among patients. Therefore, using a fixed distance from another anatomic structure or a specific o’clock reference, provides a disservice to anatomic reconstruction methods as it provides a generic formula that should not be applied universally. Anatomic ACL reconstruction is, by definition, a technique based on the individual’s anatomy. Furthermore, there are often serious limitations in the literature as regards reporting on knee flexion angles as well as the viewing portal when using the o’clock reference that limits standardization in terms of surgical descriptions.

Although this review is targeted toward anatomic ACL reconstruction, 15% of the studies do not report placing the tibial tunnels in the center of the native ACL insertion site and 19% do not report placing the femoral tunnels in the center of the native ACL insertion site. This illustrates the need for a proper definition of “anatomic ACL reconstruction”. In the present review, this is defined as the functional restoration of the ACL to its native dimensions, collagen orientation, and insertion sites. A flowchart was recently published that is the first step in creating the definition and criteria for anatomic ACL reconstruction.

Some studies do not report on post-operative imaging, but do show post-operative radiographs. When authors use post-operative radiography, the moment at which this is done is sometimes not reported, although this is vital for the interpretation of tunnel widening and osteoarthritic changes. Imaging is very important in anatomic ACL reconstruction. For example, 3D CT can be used to confirm the tunnel positions post-operatively, as well as for pre-operative planning when it comes to revision surgery.

Overall, we found that a variety of surgical data were grossly underreported in current anatomic double-bundle ACL reconstruction literature. It may be concluded that not reported does not necessarily imply not performed. However, today, with the high level of medical research, authors should be held up to a certain standard. For interpretation of the results of a published study, it is important to know the surgical details of the procedure that was studied. Anatomic
ACL reconstruction can be and is performed in many ways. It is a relatively new and a technically demanding surgical procedure. We do not know yet what is the best way the execute it. As such, studies that report on an anatomic ACL reconstruction technique should provide adequate and detailed information that allows for fair comparison and interpretation of the outcomes. A limited technique does not necessarily make a paper less valid, but it causes restrictions to the interpretation of the outcomes and the possibility of pooling the outcomes with similar studies. This is especially important in order to compare double-bundle to single-bundle ACL reconstruction. Both procedures should be performed in an anatomic fashion to show a potential benefit of one over the other.

**Overall completeness and applicability of evidence**

A limitation to this review is that it was specifically focused on studies that reported on an anatomic ACL reconstruction technique. The authors had to report that their procedure was performed in an anatomic fashion for the study to be included. This was done since there is no clear cut definition available of anatomic ACL reconstruction. However, this resulted in the exclusion of studies that presented an anatomic reconstruction technique, but did not name it as such. Furthermore, the data presented in this review may not be applicable to the reporting of surgical data for overall ACL surgery. Finally, outcome data were not assessed in this systematic review due the fact that it wasn’t our goal and interest. Moreover, the heterogeneity of the studies would make any trial to report and pool outcome measures very difficult, if not impossible.

**Quality of evidence**

Another limitation may be that the majority of the included studies were level 5 evidence. Only 17.6% of the included studies were level 1 and 2 evidence.

**Potential biases in the review process**

The search was limited to English papers published on MEDLINE or EMBASE. Studies in other languages and published in other databases were therefore not included in this review. The data extraction was not performed in a blinded fashion, i.e. blacking out authors, title and so on. However, two independent reviewers selected all the papers and extracted all the data. Furthermore, the first author validated the extracted data by processing the included studies once again after data extraction.

**Conclusion**

In conclusion, this systematic review of surgical techniques in anatomic double-bundle ACL reconstruction focused on the reporting of important surgical data needed for the evaluation of the procedure. For most surgical data, there was
Chapter 7: “Anatomic” ACL reconstruction: a systematic review

gross underreporting which was independent of the level of evidence. To provide literature that meets the current high level of medical research, we encourage authors to report their surgical technique in a standardized and thorough manner.

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Chapter 7: “Anatomic” ACL reconstruction: a systematic review


Chapter 7: “Anatomic” ACL reconstruction: a systematic review


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**Appendix 1. Search string:** 