"ACL Reconstruction - Single vs Double-Bundle"

Chair: Jon Karlsson

Faculty: Konsei Shino; Takeshi Muneta; Freddie Fu; Pascal Christel

Introduction: Jon Karlsson

Rationale for Anatomic Double-Bundle ACL Reconstruction: Freddie Fu

Double-Bundle Anterior Cruciate Ligament reconstruction; why and when it may be better and why and when not: Pascal Christel

Double Bundle Concept ACL reconstruction with Hamstring or Patellar Tendon Graft: Konsei Shino

17 year experience of 4-strand semitendinosus Double-Bundle ACL reconstruction: Takeshi Muneta

Discussion
The Anterior Cruciate Ligament (ACL) is approximately 30 mm long and 10 mm wide. It consists of two bundles; the antero-medial (AM) and the postero-lateral (PL), which display different characteristics; the AM bundle is tightened in flexion, while the PL bundle is tightened in extension of the knee. Proximally, the ACL originates from the postero-medial surface of the lateral femoral condyle and inserts distally on the anterior aspect of the medial tibial plateau. New scientific information has focused on single- versus double-bundle ACL reconstruction. Many researchers now discuss “anatomic ACL reconstruction”.

Injury to the ACL is very common among athletes, resulting from a hyperextension injury in combination with a valgus-internal rotation of the knee. ACL injury is functionally disabling and predisposes the knee to further injury, while also promoting early onset of degenerative changes of the knee. However, and in spite of this, there are no absolute indications and no absolute contraindications for ACL reconstruction. The functional limitations are primarily attributable to the loss of the essential function of the ACL, which is to prevent the anterior displacement of the tibia relative to the femur and restrain internal rotation and valgus angulation of the tibia. However, the ACL is not merely a mechanical stabilizer of the knee; it also has important proprioceptive properties as it contains different sets of mechanoreceptors which provide the central nervous system with afferent information of the joint position via the tibial nerve. After an ACL rupture, recurring episodes of joint instability (“giving way”) are associated with meniscal injury, damage to the joint cartilage, and abnormal osseous metabolism. In the long term, this leads often to degeneration of the knee, in some cases with frank osteoarthritis.

There are numerous studies on ACL injuries and Anterior Cruciate Ligament Reconstruction, but only a minority of them present high level of evidence. Systematic reviews of appropriate studies are often the best form of evidence based medicine and reviews of level I and II studies constitute the highest level of evidence. However, results and conclusions from a Randomized Controlled Trial are not always reliable, since such a trial can be performed and reported with methodical errors, something which is often the case in current orthopaedic and sports traumatology literature.

Anatomic ACL reconstruction intends to replicate normal anatomy, restore normal kinematics and protect long-term knee health. In the long run, researchers aim at lesser risk of osteoarthritis. Although double-bundle ACL reconstruction has been shown to result in improved rotational stability in both biomechanical and clinical studies, it is vital to differentiate between anatomic and double-bundle ACL reconstruction. The latter is a step closer to reproduce the native anatomy of the ACL; however, double-bundle reconstruction can still be done non-anatomically. The studies pertaining anatomic ACL reconstruction has been shown to be of great heterogeneity and a proper description of the prerequisites for anatomic ACL reconstruction is not yet available

This ICL will first of all focus on the current evidence on Anterior Cruciate Ligament reconstruction, single- vs double-bundle; we will clarify relative strengths and weaknesses of the selected studies, resolve literature conflicts and finally evaluate the need for further studies. A major part of current literature is based on weak
evidence, in most cases level IV. Few level I or level II studies are available and even in case of level I or level II RCT:s the evidence strength is often limited due to low power, small cohorts, concomitant injuries and short follow-up. In terms of double-bundle ACL reconstruction, the most important scientific challenges are:

- Graft selection; allograft versus autograft
- Exact tunnel placement
- Footprint coverage
- Kinematics
- Long-term follow-up, especially prevention of osteoarthritis
- Cost-benefit analysis
I. Rationale for Anatomic Double-Bundle ACL Reconstruction

- Anatomy is the basis of orthopedic surgery. The goals of anatomic ACL reconstruction are to restore 80-90% of the native ACL anatomy, and to maintain a long term knee health.
- Traditional ACL-R has been successful in returning patients to sports activities. However, radiographic evidence of degenerative changes has been observed in up to 90% of patients at mid-term follow-up study after traditional single-bundle ACL reconstruction.\(^1\)
- Critical review of the literature from the last ten years reveals that between 10% and 30% of patients complain of pain and residual instability following traditional single-bundle ACL reconstruction. Meta-analysis showed that no more than 60% of the patients will make a full recovery after their ACL reconstruction.

II. The principle of anatomic ACL double bundle reconstruction

- Reproducing the two bundle anatomy of ACL
  - The ACL is composed of two functional bundles, the anteromedial (AM) bundle and the posterolateral (PL) bundle. Cadaveric studies have demonstrated that the AM bundle is approximately twice as long as the PL bundle, and that the two bundles have a similar cross-sectional diameter.

- Reproducing the insertion sites of ACL
  - The insertion sites of the AM and PL bundle should be identified and marked for anatomic tunnel placement. The femoral insertion sites of the AM and PL bundle are oriented vertically with the knee in extension and become horizontal in 90° of knee flexion (surgical position for ACL reconstruction surgery). In extension the two bundles are parallel and in flexion they become crossed.

- Reproducing the tension pattern of ACL
  - The AM bundle has its highest tension at 45 degrees of knee flexion, and was taut throughout the range of motion. The PL bundle has its highest tension at full extension, and becomes lax as the knee flexes. The AM and PL graft should be fixed at these angles of knee flexion to closely reproduce the native tension pattern.

- Individualized surgery
  - The insertion sites of each bundle should be identified and marked, and the size of the insertion sites should be measured to tailor the surgery for each individual. The concept
of anatomic ACL reconstruction can be applied to all ACL surgeries (single bundle, double bundle, revision, one-bundle augmentation). The decision of whether to perform a single or double bundle ACL reconstruction should be dictated by the unique anatomy of the patient.²

III. Pitfalls in Traditional ACL reconstruction

- Femoral insertion sites orientation changes with knee flexion: The femoral AM and PL insertion sites are horizontally oriented when the knee is close to 90 degrees of flexion, while they are vertically oriented in knee extension. The important concept is often neglected in ACL reconstruction.
- The use of clock face reference: The knee is a 3-dimensional structure. The clock concept is easy to use. However, it is inaccurate in describing the location of femoral tunnel placement and lead to non-anatomic tunnel position.
- Inability to observe the femoral insertion site well by using the anteromedial portal: The anteromedial portal provides a superior view of the lateral wall of the notch and the femoral insertion site of ACL than the anterolateral portal, which is sufficient in observing the tibial insertion site.
- Graft impingement: It is a concept created by us because of non-anatomic tunnel placement. The native ACL does NOT impinge with notch and PCL. As long as the tunnels were placed in an anatomic fashion, there will be no impingement. However, if the tunnel is placed non-anatomically, impingement may occur.
- Mismatch tunnels: With fear of impingement, we traditionally mismatch our tunnel placement by placing the tibial tunnel more posteriorly (close to the PL insertion site), and placing the femoral tunnel at the native AM or high AM position.³⁴ This non-anatomic ACL reconstruction leads to inferior biomechanical properties and biological healing due to non-physiological biomechanical stress to the graft.
- Double bundle ACL-R does not necessarily mean anatomic reconstruction, if the native anatomy was not followed as a guideline for double tunnel placement.

IV. Anatomic Double Bundle ACL Reconstruction

- Anatomic double-bundle ACL reconstruction is an “Insertion Site Surgery”. We utilize three portals: Lateral Portal (LP), Medial Portal (MP), and Accessory Medial Portal (AMP).
- We routinely place the arthroscope in the MP and work through the AMP. In doing so, visualization of the femoral insertion of the ACL is greatly enhanced and the need for notchplasty is virtually eliminated.⁵
The anatomic insertion sites of each native ACL bundle are marked on the femur and tibia with a thermal device, with care taken to preserve the border of the bundles for later reference. This is a critical step in identifying the correct placement of the tunnels, and is performed prior to resection of any residual ACL tissue. In addition, the length and width of the AM and PL bundle insertion site are measured as references to decide tunnel diameters. The surgery is individualized for each patient.

There is a large area on the lateral wall of intercondylar notch for potential non-anatomic tunnel placement. Our preliminary data suggested that it may occupy more than 65% of the area on the wall.

A “lateral bifurcate ridge” is often seen on the femoral insertion between the AM and PL bundles, where as a “lateral intercondylar ridge” is often seen on the upper limit of both the AM and PL bundles. These are useful surgical landmarks in addition to the native insertion fibers.6

The tibial and femur tunnels are placed at their native insertion site, which were previously marked by thermal device.

Finally, the PL graft is passed first, followed by the AM graft. Femoral fixation is typically performed with an EndoButton.

V. Anatomic Single Bundle ACL Reconstruction

Except for the one bundle augmentation (performed when only one of the two native bundles are torn), there are a few other scenarios where we prefer to perform single bundle surgery (30%):7 Small native ACL insertion site (< 14mm), Open growth plate, Severe arthritic changes, Multiple knee ligament injuries, Severe bone bruises, Narrow intercondylar notch
Our single bundle surgery is performed with careful attention to soft tissue and bony landmarks. The tibial tunnel is placed at between the native insertion sites of the AM bundle and PL bundles, or at the center of the entire tibial insertion site.

- The distance from anterior margin of ACL footprint to center of tibial tunnel should be measured, and the femoral tunnel should be placed at the same distance from the posterior margin (knee in 90° flexion) of the femoral ACL footprint.

IX. Clinical Outcome of ACL double bundle reconstruction

- Clinical improvements have been demonstrated in recent prospective and randomized level I and level II studies. These studies have shown superior outcomes for double bundle reconstruction than single bundle reconstruction.
- To fully assess the outcome of ACL reconstruction, we need to improve our outcome measures. New outcome measures should be accurate, precise and reliable. Examples are in vivo kinematics with dynamic stereo x-ray, high resolution/3D MRI and 3D CT scan.
- Only when we have good outcome measurements, can we improve our surgical technique and protect the long-term knee health of our patients.

X. Conclusion

- The goals of anatomic ACL reconstruction are to restore 80-90% of the native ACL anatomy, and to maintain a long term knee health.
- The double bundle anatomy, insertion sites, and tension pattern need to be reproduced to restore native ACL anatomy and knee kinematics.
- Anatomic Double-Bundle ACL Reconstruction is a principle that can be applied to single bundle, one-bundle augmentation and revision ACL surgeries.
- We need better, more objective outcomes measures, including biology, kinematics and imaging.

17-year experience of 4-strand semitendinosus double-bundle ACL reconstruction

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How to improve the postoperative stability using hamstring tendon graft?

Double-bundle ACL reconstruction using EndoButtons

- Two tibial tunnels and two femoral tunnels
- Four-strand semitendinosus tendon
- Arthroscopic procedures
- Pull-out fixation
- Started at July, 1994

The procedure was done under better understanding of ACL anatomy, esp. notch impingement

Greater tendon-bone junction area is achieved in double-bundle technique

- Greater tendon-bone junction area initiates better stabilize function of the graft
- Greater tendon-bone junction area facilitates graft healing

1.4 1.4
6mm x 2
1 9mm x 1

Anterior notch plasty is less performed.
More ideal graft initial setting can be performed
Mid-Term Outcome between single- and double-bundle

<table>
<thead>
<tr>
<th>Year</th>
<th>Single-bundle</th>
<th>Double-bundle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992 - 1996</td>
<td>4ST tendon graft</td>
<td>AM femoral in 0:30 and PL in 1:30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>26 (12-53)</td>
<td>26 (16 - 67)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>71:35</td>
<td>36:43</td>
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<tr>
<td></td>
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<td></td>
<td>46 (24-119)</td>
<td>42 (24 - 91)</td>
</tr>
</tbody>
</table>

Male:Female

No. patients > 24 months FU

Mid-Term Outcome between single- and double-bundle

<table>
<thead>
<tr>
<th>Test</th>
<th>Single-bundle</th>
<th>Double-bundle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lachman test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADT</td>
<td>N.S.</td>
<td>N.S.</td>
</tr>
<tr>
<td>Pivot-shift test</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rotational stability is not quite better in the first series.

KT measurements at manual max (side-to-side differences)

Single: 2.7 ± 2.3 mm
Double: 1.9 ± 1.9 mm

RCT between single- and double-bundle ACL reconstructions

2002.7 – 2004.3

- 4 ST tendon graft
- Arthroscopic transtibial technique

Femoral tunnel position
2 o’clock

Femoral fixation
one EndoButton
one anchor staple

Tibial fixation

- Standardized initial tension
- Same rehabilitation program
- Standardized evaluation by two examiners

Single-bundle (34)
AM 1:30, PL 3:30
two EndoButtons
two anchor staple

Double-bundle (34)
RCT between single- and double-bundle ACL reconstructions

<table>
<thead>
<tr>
<th>Test</th>
<th>Single</th>
<th>Double</th>
<th>Single</th>
<th>Double</th>
<th>Single</th>
<th>Double</th>
</tr>
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<tbody>
<tr>
<td>Lachman test</td>
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<tr>
<td>Pivot-shift test</td>
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</tbody>
</table>

KT measurements at manual max (side-to-side differences)
Single 2.4 ± 1.4 mm  Double 1.5 ± 1.4 mm

Two segments of AM bundle  Two segments of PL bundle

in extension in flexion in extension in flexion
high deep lateral anterior
shallow

Femoral attachment  Tibial attachment

Tibial guide wire placement and tunnel creation

AM guide wire  AM enlarged drill hole
PL guide wire  PL enlarged drill hole

Roof impingement free tunnel placement  Physiological impingement accepted off-set placement
Femoral guide wire placement and tunnel creation

Normal ACL anatomy evaluated by divided small bundles

AM drill guide at 1 o’clock => Center of direct insertion
PL drill guide at 3 o’clock => Center of direct insertion
Tunnel creation deeper from “Resident Ridge”

Tibial drill hole placement: anatomic landmarks and radiographic findings

Anterior Medial Lateral
mid posterior mid posterior

Anatomical tibial tunnel placement Over the D-point

Current femoral tunnel creation in figure-4-position
Double-bundle anterior cruciate ligament reconstruction, why and when it may be better and why and when not?

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Introduction

• Even if double-bundle (2B) anterior cruciate ligament (ACL) reconstruction still raised controversial issues it has brought the opportunity to revisit ACL anatomy and biomechanics as well [1,2].

• The footprints, mostly on the femoral side, have been extensively investigated and the concept of anatomic reconstruction emerged. Anatomic reconstruction meaning the graft is attached at the native footprints. Initially applied to 2B ACL, the concept of anatomic reconstruction was recently extended to one bundle (1B) reconstruction.
Technical considerations

• Based on a 30-year experience of the author in the field of ACL reconstruction it is clear that the native femoral footprint of the ACL can’t be reached through a properly drilled tibial tunnel. This has been shown by numerous publications. In order to achieve anatomic placement of the graft(s) independent drilling of tibial and femoral tunnels using either 2-incison or anteromedial portal techniques is mandatory.
Technical considerations

• Currently ACL reconstruction is performed through 2 medial portals. One proximal portal [3] is used for the scope and a distal one’s, above the medial meniscus, for the instruments. These portals give full exposure of the femoral footprint. Drilling of the femoral tunnel(s) is done at 110-120 degrees of knee flexion using either straight or flexible drills.
Full medial approach

Right knee

1- proximal medial portal
2- distal medial portal
Technical considerations

• In 2B reconstruction, tunnels are drilled in the middle of the bundle footprints with a specific instrumentation both on femoral and tibial sides.

• In anatomic 1B both femoral and tibial tunnels are drilled between the bundles on both sides in order to include AM and PL fibres in the graft, which is called central anatomic 1B [4].
Femoral tunnel(s) position

Position of the guide wire for single bundle anatomic with regard to the bundle centres

Position of the femoral tunnel single bundle anatomic
Central anatomic 1B vs anatomic 2B

- 32 patients, isolated ACL reconstruction in 2009
  - 11 anatomic 1B with autologous hamstring tendons graft
  - 10 anatomic 1B with autologous bone-tendon-bone (BTB) graft
  - 11 anatomic 2B autologous hamstring tendon grafts [5]
## Central anatomic 1B vs anatomic 2B

<table>
<thead>
<tr>
<th>G r o u p</th>
<th>n</th>
<th>age</th>
<th>BMI</th>
<th>Disab time (mos)</th>
<th>Preop</th>
<th>FU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>KT 1000 (mm)</td>
<td>Pivot shift test</td>
</tr>
<tr>
<td>HS</td>
<td>11</td>
<td>28.4 ± 7</td>
<td>26.0 ± 2.5</td>
<td>8.5 ± 10.7</td>
<td>7.3 ± 2.8</td>
<td>0 2 8 1</td>
</tr>
<tr>
<td>BTB</td>
<td>10</td>
<td>27.7 ± 8.3</td>
<td>33.4 ± 7.0</td>
<td>8.7 ± 14.3</td>
<td>6.9 ± 2.7</td>
<td>0 2 7 1</td>
</tr>
<tr>
<td>2B</td>
<td>11</td>
<td>28.3 ± 7.4</td>
<td>28.2 ± 4.4</td>
<td>27.1 ± 34.1</td>
<td>5.0 ± 2.2</td>
<td>0 4 7 0</td>
</tr>
<tr>
<td>p</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NS</td>
<td>*</td>
</tr>
</tbody>
</table>

* BTB BMI significantly higher (p<0.009)
** Chi² test: HS vs BTB 0.006, BTB vs 2B 0.01, HS vs 2B NS
Central anatomic 1B vs anatomic 2B

- Preliminary results (6 - 12 months follow up) listed in the table show there is no statistical difference regarding the KT1000 side to side difference at follow up, with a tendency to better stability after anatomic 1B BTB. However, pivot shift test is significantly better after anatomic 1B BTB without significant difference between anatomic 1B hamstrings and anatomic 2B.
- Longer follow up is needed.
Discussion

• **Intrinsic advantages of anatomic 2B ACL reconstruction**
  – restoration of the ACL anatomy with better knee kinematics [6]
  – coverage of bundles footprints
  – better rotational control
  – larger tendon-bone tunnels interface with subsequent better healing potential

• **Problems associated with 2B technique**
  – insufficient surgeon’s experience
  – cost (more implants, more operative time) [7,8]
  – footprint length <14mm
  – PL bundle graft diameter <5mm, PL bundle damages [9]
Discussion

• Intrinsic advantages of anatomic 1B technique
  – Easier and faster graft prep
  – Faster procedure than 2B

• Problems associated with anatomic 1B
  – placement of the femoral tunnel must overlap both bundles footprints in order to include PL and AM fibres [10].
  – There is a tendency to drill the tunnel to far proximal corresponding to AM bundle footprint only.
  – As for 2B ACL, a good knowledge of ACL anatomy is mandatory and one should not overestimate an easy placement of a central anatomic femoral tunnel
Discussion

• Until now, most of the randomized clinical trial outcomes which have been published have compared anatomic 2B with non anatomic 1B.

• Following 2B ACL reconstruction, the vast majority of the publications have concluded to significantly less residual positive pivot shift tests and more IKDC grade A compared to 1B [11]. However, there are currently not enough publications available in the literature comparing anatomic 2B with anatomic 1B reconstruction.

• On the ligament examination standpoint, our preliminary results do not show superiority of anatomic 2B over anatomic 1B which is supported by laboratory evidences [4,12]
Discussion

• Despite laboratory investigations which demonstrate 2B superiority in terms of biomechanics and knee kinematics, there is currently not enough evidence to conclude to a better clinical outcome of anatomic 2B with regard to anatomic 1B.

• However, based on the laboratory evidences the author still continues to perform anatomic 2B ACL reconstruction.
References

My firm belief as a reconstructive surgeon is as follows: the more closely we mimic the anatomy, the better patients do. Thus, I have been pursuing the anatomical reconstructive techniques.

For hamstring reconstruction, two double-looped hamstring tendon tendons have been used. To closely mimic the natural ACL as well as to maximize graft-tunnel wall contact, the triple bundle ACL-R had been established. With the newly developed drill guide system, Endobutton-CL femoral fixation and tension-controllable tibial fixation device: DSP (Double Spike Plate)+screw, its short-term results are very much encouraging without any specific complications. However, second-look arthroscopy has occasionally shown incomplete healing of the posterolateral graft to the femoral tunnel, which may potentially lead to recurrence of instability or graft failure in long-term. Slower rehabilitation including 2-week immobilization has been overcoming this unfavorable phenomenon due partly to bungee cord graft motion inside the femoral tunnel.

For patellar tendon (B-PT-B) reconstruction, the anatomical rectangular tunnel technique to mimic the original fiber arrangement of the normal ACL had been
developed. With this technique, the anterior part of the graft functions as the anteromedial bundle, while its posterior portion behaves as the posterolateral bundle. Little space between the tunnels and the graft make the graft-tunnel healing faster. While the short-term results are very much encouraging, critical location of the interference screw used for femoral fixation far back in the notch sometimes necessitates the other backup cortical fixation.