Anthropometric Measurement of Tunnel Lengths for Anterior Cruciate Ligament Reconstruction in Chinese

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Abstract

Introduction: There is a lacking of tunnel length measurements data for primary anterior cruciate ligament (ACL) reconstruction in the Chinese population. Different tunnel lengths affect the security of the tendon graft fixation as well as bone–tendon healing. Long-term result may then be compromised. Double-bundle ACL reconstruction will work well if both grafts have good quality, size, and tendon–bone fixation. Proper rehabilitation is also an important element. However, the femoral tunnel length for posterolateral bundle will have a higher prevalence of inadequate graft bone contact because of its orientation, especially in the Chinese population with smaller knees compared with the Western population.

Methods: From January 2009 to June 2011, 148 cases of ACL reconstruction have been performed in our hospital. After excluding cases with revision, isolated bundle (anteromedial or posterolateral), and four-strand hamstring graft single-bundle ACL reconstructions, we recruited 48 cases with primary double-bundle ACL reconstruction in the study of tunnel lengths. Hamstring tendon autografts (semitendinosus and gracilis) were used. A small cohort study with Level 3 evidence was carried out.

Results: In 31.3% (15/48) of patients, inadequate graft–bone contact was observed in the posterolateral bundle using the available shortest Endobutton CL 15 (Endobutton continuous loop fixation device; Smith and Nephew, Andover, Massachusetts, USA) in femoral tunnel fixation.

Conclusion: ACL reconstruction is a complex procedure that relies on good tendon graft length, graft size, tunnel length, and secure fixation method. Inadequate posterolateral tunnel length may contribute to short-term complications as well as long-term failure. Further refining of the choices of graft, better orientation of tunnels, and a better fixation method may be important, especially in the Chinese population with smaller knees.

Keywords: anterior cruciate ligament reconstruction Chinese tunnel length

中 文 摘 要

目的: 在中國病患者進行前交叉韌帶重建隧道長度的測量結果

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Abstract

引言: 在中國人進行首次前交叉韌帶(ACL)重建術中,隧道長度的度數數據仍然很少。不同的隧道長度將影響肌腱固定以及骨肌腱融合。長期的手術後可能受到影響。ACL重建術有燒艾好的兩束韌帶移植質量，大小和股骨固定方法。適當的康復治療是一個重要因素。然而，後外側韌帶移植束(PL)的股骨隧道長度不夠將引致移植束和骨接合不良，更因為它的方向，尤其是在中國人群與西方人群相比，有較高的發病率。

方法: 從2009年1月至2011年6月，我們進行了148例ACL重建手術。除去翻修，單束(前內側或後外側)和四束肌腱肌腱單束移植ACL重建後，我們有48例首次進行ACL雙束重建術，使用膕繩肌腱(半腱肌，胭肌)移植，並進行了一個3級研究的大型研究其股骨隧道的長度。

結果: 有31.3% (15/48) 藉用了最短的內置鎖扣(Endobutton CL15)作股骨隧道固定，其後外側韌帶移植束(PL)的股骨隧道固定可能仍不足。

結論: ACL重建是一個複雜的手術，它建基於良好的肌腱長度，移植束的大小，隧道長度和固定的固定方法。PL隧道長度不足，可能會導致短期的併發症，以及長期性失敗。選擇更好的移植束，隧道方向和固定方法是更重要的，尤其是在中國病患中較小的膝關節。

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Introduction

Anterior cruciate ligament (ACL) injury is a common knee injury. Patients with symptomatic instability or high-demand sport activities require ACL reconstruction. ACL reconstruction has evolved from extra-articular procedure to arthroscopic procedure. With more understanding of the ACL anatomy, the double-bundle (DB) ACL reconstruction to reconstruct the original anteromedial bundle (AMB) and posterolateral bundle (PLB) is getting more popular. This is also a logical development as the AMB is taut at 75° of knee flexion and PLB at 15° of knee flexion, playing different roles at different angles. DB ACL reconstruction requires four separate tunnels, two in the tibia and two in the femur. Other parameters required to be considered in DB ACL reconstruction include the footprint, graft size, tunnel length, tunnel angle, choice of portal use for creating (AMB and PLB) femoral tunnels, and fixation method. The purpose of this study was to investigate the magnitude of the mismatch problem in the tendon graft length and femoral tunnel for PLB in DB ACL reconstruction.

Materials and methods

From January 2009 to June 2011, 148 patients (130 males and 18 females) underwent ACL reconstruction in our hospital. Among them, 15 cases were revision cases. There were 13 cases of failed DB ACL reconstruction revised with patellar bone-tendon-bone autografts while two cases of failed patellar bone-tendon-bone ACL reconstructions revised with DB ACL reconstruction. In 36 patients, isolated AMB reconstruction was performed; in 15 cases four-strand hamstring single-bundle ACL reconstruction was performed because of small knee joints, with a higher incidence rate in females than in males (33.3% of female patients versus 11.3% of male patients). Of the remaining 82 cases of DB ACL reconstruction, completed tunnel length data record were available for analyses for 48 cases.

These 48 Chinese patients (42 males and 6 females) who underwent DB ACL reconstruction using hamstring autografts were recruited in the study. The exclusion criteria were revision ACL reconstruction, isolated AMB reconstruction, nonhamstring tendon graft, and incomplete data collection. The average age was 24 years. All surgeries were performed by one consultant sport surgeon or under that surgeon’s supervision. The diagnosis of ACL injury was based on the history, physical examination, magnetic resonance imaging (MRI), examination under anaesthesia, and arthroscopic findings. We used examination under anaesthesia and arthroscopic findings to confirm the integrity of the PLB finally.

Surgical procedure

Our surgical procedure and rehabilitation protocol of DB ACL reconstruction were advocated by Dr Freddie Fu and the Pittsburgh Group. We carried out screw pole fixation at the tibial side instead of bone staple. We believed that the screw pole was less traumatic and performed equally well in the double fixation of the tendon grafts. Four principles were adopted: (1) the native insertions anatomical sites were restored; (2) two functional bundles of ACL were restored; (3) tension behaviour of the AMB and PLB was addressed; and (4) the procedure was individualised according to the individual anatomy, injury pattern, and size of the knee joint. A small joint with a narrow notch might not accommodate a DB ACL reconstruction. An isolated AMB injury did not require a DB ACL reconstruction.

The common misconception is that the PLB femoral footprint is more posterior than the AMB femoral footprint. During surgery, the 90° flexed knee will make the PLB femoral footprint more horizontally aligned and becomes more anterior than the AMB femoral footprint.

The shape of footprint of ACL tibial insertion is fanned-out. We used the posterior border of lateral meniscus, medial tibial eminence, and intercondylar notch in full extension as a landmark for the insertion of tibial guide pins. The femoral insertion site was located using the lateral intercondylar ridge and lateral bifurcate ridge of the lateral femoral condyle. The PLB femoral tunnel guide pin was inserted via the accessory anteromedial portal with the knee being flexed to 110°. This would give the most consistent position, allowing the measurement of the PLB femoral tunnel length. The PLB tunnel length was measured by two surgeons using a direct arthroscopic measuring gauge and a 4.5 mm cannulated reamer in order to avoid intraobserver error.

Operations were performed under tourniquet with a pressure of 240 mmHg. We used a leg holder when a posteromedial portal is necessary to treat posteromedial medial meniscus tear. A closed-end tendon graft harvester was used to harvest the hamstring autografts. We found it necessary to triple the gracilis tendon in all our cases of DB ACL reconstruction, in order to have a minimal diameter of 6 mm. In case of an inadequate tendon graft length or size, the DB ACL reconstruction procedure would be converted to single-bundle four-strand ACL reconstruction.

Results

This study of 48 cases showed that the average PL femoral tunnel length was 34 mm, with a range of 24–45 mm (Figure 1A). The average gracilis graft length was 71 mm, with a range of 60–90 mm, as shown in Figure 1B. We then used the data to select the fixation methods (e.g., Endobutton CL 15 or Endobutton Direct, Endobutton continuous loop fixation device: Smith and Nephew, Andover, Massachusetts, USA).

Discussion

Bone—patellar tendon—bone (BPTB) autograft ACL reconstruction is a common procedure performed in patients with ACL injury. The main advantage of BPTB is that graft bone plugs on both ends allow early bone-to-bone healing. The disadvantages are donor site morbidities, including anterior knee pain, kneeling pain, quadriceps weakness, possible patellar fracture, and a higher prevalence of osteoarthritis at 11 years after surgery. Different aspects have been studied, including clinical results, relationship of failure rate with age, femoral tunnel placement, and postoperative radiological assessment including plain X-ray, three-dimensional computed tomography, and MRI.

Illingworth et al. used the postoperative inclination angle (normal 55°) in sagittal MRI and femoral tunnel angle (normal 33°) on radiographs to characterise the femoral tunnel in single-bundle ACL reconstruction. They found that transibial techniques often failed to place the femoral tunnel in the anatomic position. The tibial tunnel-independent technique would have a lower femoral tunnel angle and a larger inclination angle. However, they did not study DB ACL reconstruction.

With better understanding of the anatomy of the normal ACL, the Lachman test is useful to quantify the anterior laxity. Together with the positive pivot shift test, we can diagnose a complete rupture ACL. A positive Lachman test in the absence of a pivot shift test may indicate an isolated AMB tear, though it is not agreed by some surgeons. However, it is logical to perform DB ACL reconstruction to restore the complex anatomy.
International Knee Documentation Committee score for four-tunnel DB ACL reconstruction compared to single-bundle ACL reconstruction. However, some new problems such as footprint identification, sex difference, and AMB graft impingement with PLB inadequate tendon–bone tunnel contact due to short femoral tunnel were identified in DB ACL reconstruction surgery.

Giron et al. conducted a cadaveric knee study on ACL footprint. He found that on the tibial side all guide pins (for AMB and PLB) were within the normal boundaries. On the femoral side, 24 of 28 guide wires were correct, of which 12 of 14 AMBs and nine of 14 PLBs were correct. They suggested that more anatomic validation on the PLB femoral site is needed.

Each tunnel length is affected by the knee flexion angle, footprint, entry portal, angle of jig and size of patient. Basdeakis et al. showed, using eight fresh cadaver knees, that the knee flexion angle influenced the position of femoral drilling. With the knee flexed to 90°, pin drilling led to a shorter tunnel and an increased risk of posterior wall blow out. They recommended 110° knee flexion when drilling the antero-medial (am) femoral tunnel through the AM portal. They did not study the PLB tunnel. Golish et al. in their cadaveric knee single-bundle ACL tunnel study, found that the use of the anteromedial portal would create a femoral tunnel that is shorter than the transtibial tunnel. Lubowitz and Konicek found that, in 12 cadaveric knees, the femoral tunnel was

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**Figure 1.** (A) Average PL femoral tunnel length was 34 mm (range 24–45 mm). (B) Average gracilis graft length was 71 mm (range 60–90 mm). PL = posterolateral.
longer (34.1 mm) using the outside-in technique, by inserting a FlipCutter ACL femoral guide through a stab incision at the distal midlateral femoral metaphyseal flare 4 cm proximal to lateral epicondyle, compared with the tunnel length measured using anteromedial portal (30.5 mm).

Ilahi et al. compared between the femoral tunnel length obtained using accessory anteromedial portal and that obtained using transtibial portal. They found that the average femoral tunnel length (35.6 mm) measured using accessory anteromedial portal was shorter compared with that (40.7 mm) measured using transtibial portal. This was a single-bundle ACL reconstruction study.

PL femoral tunnel is essential for DB ACL reconstruction. Our findings supported our concern of possible inadequate tendon–bone contact in the PLB femoral tunnel. Chang et al. found that in ethnic Koreans the femoral tunnel measured using the AM portal was significantly shorter than that obtained using the transtibial portal (34.2 mm vs. 43.3 mm) for four-strand hamstring ACL reconstruction. There is no human study that conclusively proves the minimal tendon–bone graft contact tunnel length for proper tendon to bone healing. Some surgeons considered 25 mm the minimum tunnel length for interference screw fixation. If we use a minimal tendon–bone contact length of 18 mm (common recommendation), then 31.3% (15/48) of our patients will possibly have inadequate tendon to bone healing using Endobutton CL 15 mm (Figure 2). For example, if the PL femoral tunnel is just 27 mm long, Endobutton CL 15 mm will allow only 12 mm of host bone contact in the femoral PL tunnel. Our choice is either to perform single-bundle reconstruction or to use Endobutton Direct (Smith and Nephew, Andover, Massachusetts, USA). However, Endobutton Direct allows direct tendon graft mounting without a loop, but will work only for long grafts because it will sacrifice the tibial side tendon to bone contact length (Figure 3). Endobutton Direct was used in four cases and Endobutton CL 15 was used in 42 cases. There was one case in which Endobutton CL 20 was used and one case in which Endobutton CL 25 was used.

By theoretical calculation, eight out of these 15 patients with inadequate graft bone tunnel contact would have potential inadequate tendon–bone contact in the tibial tunnel if Endobutton Direct was used instead of Endobutton CL 15 mm (Figure 4). More size options of Endobutton (e.g., Endobutton CL 10 mm) may be useful to solve this dilemma in the future. Long-term follow-up of these 15 cases with possible inadequate tendon–femoral bone tunnel contact and see whether their failure rate is higher than the rest is necessary. There was no difference in terms of short-term complications such as suboptimal stability, instability symptoms, arthrometer findings, range of motion, functional assessment, and rehabilitation speed among these patients. However, long-term outcomes should be studied in the future.

Cohen et al. measured the normal ACL anatomy using MRI. He found the average AMB bundle to be 36.9 ± 2.4 mm in length and the PLB 20.5 ± 2.4 mm in length, and AMB to be 5.1 ± 4.2 mm in width and PLB to be 4.4 ± 3.7 mm in width. Using the average intra-articular PLB length of 20.5 mm and 20 + 20 mm tunnel lengths (femur and tibia), the minimal length of a triplicated gracilis autograft graft to have an adequate reconstruction is at least

Figure 2. Possible inadequate tendon to bone healing in the femoral tunnel using Endobutton CL 15 mm for posterolateral bundle reconstruction with the assumption that 18 mm is the minimal tendon–bone contact (as shown in the shadowed area).
Figure 3. (A) Adequate insertional length is achieved in both femoral and tibial tunnels when there are long tunnel and long graft. (B, C) When the femoral tunnel is short and the graft is long enough, Endobutton Direct can be used to achieve adequate femoral and tibial insertional length. (D, E) When the femoral tunnel is short and the graft is not long enough, using Endobutton adequate femoral insertional length can be achieved, but the tibial insertional length will be compromised as shown.

Figure 4. Potential inadequate tendon to bone healing in the tibial tunnel using Endobutton Direct for posterolateral bundle with the assumption that 18 mm is the minimal tendon–bone contact (as shown in the shadowed area).
60 mm. A double-up gracilis autograft will have an adequate length but not enough diameter size. In our 48 cases of DB reconstruction, we had to triple fold the gracilis autograft. A quadruple gracilis graft is always too short. Therefore, it was a compromise between graft length and size.

Theoretically, had Endobutton CL 10 mm been available and used in the 15 cases of potential inadequate graft–bone contact in either the femoral or the tibial tunnel, adequate graft–bone contact would have been achieved, by simple calculation, in both the femoral and the tibial tunnel (Figure 5).

The size of Endobutton CL 10 mm will definitely fit better in this group of Chinese patients with relatively short graft and short femoral tunnel. Moreover, with the assumption that the minimal graft–bone contact is 18 mm and the intra-articular graft length of the PLB is 21 mm, we can derive an equation to facilitate quick intraoperative calculation of range of length of Endobutton used ($G = \text{graft total length}; F = \text{femoral tunnel length}; X = \text{Endobutton length in mm}, \text{and intra-articular graft length} = 21 \text{mm}$).

To ensure adequate graft–bone contact in the femoral tunnel:

$$F - X \geq 18 \text{ mm}$$  \hspace{1cm} (1)

To ensure adequate graft–bone contact in the tibial tunnel:

$$G - (F - X) - 21 \geq 18 \text{ mm}$$  \hspace{1cm} (2)

By rearrangement of these equations:

$$F - 18 \geq X \geq 40 + F - G$$  \hspace{1cm} (3)

For simplicity and easy calculation, approximation is made (in mm) and the ideal length of Endobutton $X$ could be calculated from the following equation:

$$F - 18 \geq X \geq 40 + F - G$$  \hspace{1cm} (4)

For example, if the femoral tunnel length is 38 mm and the graft length is 70 mm, the Endobutton length should be between 20 mm and 8 mm (e.g., Endobutton CL 15 mm). Then graft–bone contact in the femoral tunnel is $38 - 15 = 23$ mm. The graft–bone contact in the tibial tunnel is $70 - (38 - 15) - 21 = 26$ mm. By this simple equation, a balance can be achieved between the femoral insertion length and the tibial insertion length.

Neven et al.\textsuperscript{15} studied the posterolateral femoral tunnel length and the safety of the lateral structures. They found a mean tunnel length of 36.92 mm (range 32–44 mm). This finding also concurred with our finding of a short PL femoral tunnel.

A successful ACL reconstruction also requires proper rehabilitation. Fremerey et al.\textsuperscript{5} performed a longitudinal study of knee proprioception in the mid-range position after patellar bone–tendon–bone autograft ACL reconstruction. They found that the proprioceptive sense would gradually restore over a course of 6 months. An earlier return to full activity could be dangerous due to proprioceptive deficit. There was no study on the proprioceptive sense after DB ACL reconstruction in the literature.

Our study is the first study specifically investigating the mismatch between tunnel length and graft length in PLB reconstruction in Chinese. The limitations are a small sample size, non-randomised controlled study, and short-term follow-up. Long-term outcomes of patients with potential inadequate tunnel length for

![Figure 5](image-url)  
Figure 5. Adequate graft–bone contact can be achieved theoretically in both the femoral and the tibial tunnel if Endobutton CL 10 mm is used.
bone–graft contact has not been analysed. Further studies are required to delineate this problem.

**Conclusion**

In order to perform a successful ACL reconstructive surgery, the orthopaedic surgeon should have a proper understanding of the anatomy, be able to select the correct footprint, and be able to reconstruct according to the individual injury pattern, graft size, joint size, characteristics, and the fixation method. More anatomical data on tunnel length will help the surgeon decide the type of reconstruction and fixation method that will suit individual patients in order to give the best possible result.

Using Endobutton CL 15, however, inadequate tendon–bone contact in PLB femoral fixation can possibly occur in 31.3% cases. Other fixation methods or a new tunnel may be necessary. Further anatomical data are needed to provide references for preoperative planning and further improvements in outcome.

**Conflict of interest**

The authors declare that they have no financial or non-financial conflicts of interest related to the subject matter or materials discussed in the manuscript.

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