Anterior cruciate ligament reconstruction with femoral direct fiber insertion: a novel technique

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Anterior cruciate ligament (ACL) tear is a common disease among sports-medicine outpatients. To restore static and dynamic stability as well as kinematics in an ACL injured knee, accurate position of the femoral and tibial tunnel plays an important role in ACL reconstruction, especially the femoral tunnel.[1] Some studies have attempted to maximize functional outcome of anteriomedial (AM) and posterolateral (PL) bundles by reconstructing ACL in the center of the entire femoral footprint[2,3]; however, instability persists after operation. Therefore, various studies concluded that single bundle and double bundle techniques could yield similar efficacy in ACL reconstruction.[4]

Iwahashi *et al*[5] initially proposed that the femoral insertion of ACL comprises direct and indirect fibers, and their cadaver study demonstrated that the direct fiber insertion was located close to the resident ridge in a ribbon-like shape. Further, Mochizuki *et al*[6] discovered that the areas of direct and indirect fiber footprint were $50.80 \pm 12.60\ mm^2$ and $91.40 \pm 23.70\ mm^2$, respectively. Direct fiber insertion provides 66% to 84% of the tibial anterior drawer test resistance of the knee joint, whereas indirect fiber only provides 11% to 15%.[7] Finite element analysis also revealed that the stress on the ACL was mainly concentrated in the direct fiber insertion area.

The foregoing facts potentially explain why the traditional double bundle ACL reconstruction has no significant advantages than single bundle ACL reconstruction, in which the tunnels located in the center of footprints are more inclined to indirect fibers.[3,5] Therefore, we believe that ACL reconstruction by direct fiber is of great significance in restoring the stability, as well as isometric and kinematic function, of knee.

In this operation, ACL rupture was confirmed under arthroscopy, using hamstring tendon autograft as the ACL grafts. Each tendon was made two or three trends, with the greater diameter of the graft for the AM bundle and the other for the PL bundle. We exposed the resident ridge and bifurcated ridge using a shaver and electrothermal device, and the posterior indirect fibers and synovium of the ACL femoral insertion were preserved. Moreover, the fibers of ACL stump at tibia insertion were preserved as much as possible. The ACL would be reconstructed with a double tunnel and double bundle, unless the lengths of the bilateral footprints of the ACL were not less than 14 mm. Locating the direct fiber insertion was the most important step in this novel surgical procedure. First, to locate the intersection of the posterior femoral cortex and Blummsat line, the direct fiber insertion point was located on the extension line of the posterior femoral cortex on the medial side of the lateral femoral condyle. The position of the AM bundle bone tunnel had to be as far back as possible, the posterior wall of the tunnel 1 to 2 mm, and the bone bridge between the AM and PL tunnel 1 to 2 mm. The knee was flexed 120° to ensure the tunnels were more horizontal and ensure the integrity of the posterior wall of the femoral anteromedial tunnel when drilling the femur tunnel using transportal technique. The tibia tunnel was drilled using a tibial drill guide system (Smith and Nephew Endoscopy, Andover, MA, USA) with a 5 to 8 mm diameter reamer. Bone files were used to grind the intra-articular tunnel outlet of tibia and femur tunnels to minimize cutting of the sharp edges.

The PL graft of ACL was initially transplanted into the PL tunnel, and the AM graft was subsequently transplanted. The femoral end was fixed with adjustable extra-cortical suspended titanium plate (Mitek, Raynham, MA, USA), and the tibial end was fixed with absorbable interference screw (Mitek) at the knee's extension position [Figure 1A–C and Supplementary Video 1, http://links.lww.com/CM9/A775].

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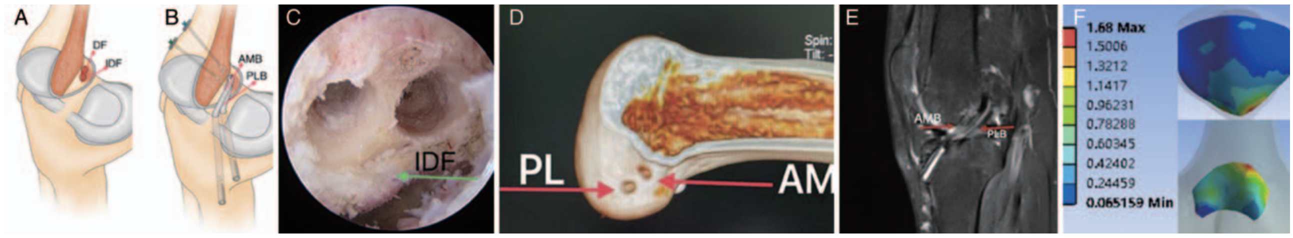

Figure 1: (A) femoral insertion of direct and indirect fiber, (B) the ACL double-bundle reconstruction of femoral direct fiber insertion, (C) the indirect fiber was preserved, (D) 3D-CT of the femoral tunnel, (E) Anteriomedial bundle (AMB) and PLB in the T2WI of MRI, (F) the Von Mises stress of patella and trochlea. 3D-CT: Three-dimensional computer tomography; ACL: Anterior cruciate ligament; DF: Direct fiber; IDF: Indirect fiber; MRI: Magnetic resonance imaging; PLB: Posterolateral bundle; T2WI: T2 weighted imaging.

After the operation, a long leg brace was worn for 2 months. The patient could perform partial or full weight-bearing endurance activities and walk with crutches; further, active-flexed and passive-extended knee movements were possible on the second day after the operation. Jogging was possible after 3 months, non-confrontational activities after 6 to 9 months, and gradual restoration of confrontational sporting activities after 12 months.

The results of Pivot shift test, Lachman test, Lyshlom score, International Knee Documentation Committee (IKDC) score, and KT-2000 side–side difference were recorded to evaluate knee function; three-dimensional computed tomography (3D-CT) of knee joint was performed during the first week after surgery to determine whether the bone tunnels in this study were in the direct fiber insertion. Three-Tesla (3.0T) magnetic resonance imaging (MRI; Magnatom Harmony, Siemens Medical Systems, Forchheim, Germany) was used to evaluate the healing progress and shaping of the grafts 2 years after operation.

This study was approved by the Ethics Committee of Affiliated Zhongshan Hospital of Dalian University (Approval No. 2019148). All operations were performed by the senior chief surgeon of sports medicine (Wang WM). Between June 2016 and June 2018, 26 patients were included in the study (15 males and 11 females), with an average age of 30.5 ± 4.6 years (18–50 years), and time between injury and surgery of 7.30 ± 3.50 days (3–30 days).

No graft rupture, fracture, tunnel fusion, and impingement occurred between intercondylar fossa and grafts during the operation. The surgery time was 56.16 ± 10.17 min (range: 50–62 min) and intra-operative bleeding volume was 35.31 ± 5.26 mL (range: 30–45 mL). No infection occurred in any of the cases. According to CT graphs, the femoral tunnels of all patients were located in the footprints of the direct fiber [Figure 1D]. No retear had occurred by the second years of follow-up, and there were no difference between the angles of flexion and extension between the bilateral knees.

Before surgery, there were two cases of grade I, 11 cases of grade II, 13 cases of grade III according to the pivot-shift test as well as no cases of grade I, 8 of grade II, and 18 cases of grade III according to the Lachman test.

After surgery, all cases were negative for the pivot-shift test and one case of grade I according to the Lachman test. Two years after the operation, all patients were followed up, and they yielded negative pivot-shift and Lachman test results, thus implying that this procedure was effective in restoring the anterior and rotation stability of the tibia. The Lysholm score increased from a pre-operative value of 56.50 ± 3.60 to 88.50 ± 2.00 at 2 years after operation ($q = 37.93$, $P < 0.001$), and the IKDC scores increased from a pre-operative value of 48.30 ± 2.80 to 92.50 ± 2.60 at 2 years after the operation ($q = 63.94$, $P < 0.001$), thus revealing that double bundle ACL reconstruction with femoral direct fiber insertion has an excellent clinical effect. The KT-2000 side–side difference decreased from 5.60 ± 0.70 mm before the operation to 1.50 ± 0.60 mm at 2 years after operation ($q = 24.50$, $P < 0.001$), indicating that double bundle ACL reconstruction with femoral direct fiber insertion could effectively maintain knee stability, with no report of graft relaxation or retear within a short period of time [Supplementary Table 1, http://links.lww.com/CM9/A776].

Twenty-six patients underwent MRI examination 2 years after surgery. No meniscus tears were observed. ACL grafts showed uniform low signal on the coronal T2-weight image, and the bone tunnels were not significantly enlarged. The two bundles in the intercondylar fossa resembled a ribbon-like appearance and were approximately parallel each other, and no impingement was observed between the grafts and the intercondylar fossa. MRI revealed mature and well-shaped grafts [Figure 1E and Supplementary Table 2, http://links.lww.com/CM9/A776].

Based on the finite element analysis, the maximum stress region of the patella and femoral trochlear of the affected knee was similar to that of the other knee, and the maximum stress value has no statistical difference between the two knees. The foregoing findings indicated that the new surgical procedure may restore the mechanical machinery of the knee [Figure 1F].

The most important characteristic of this novel procedure was the location of the femur tunnel in the center of the direct fiber insertion instead of the center of the ACL footprint, which is the key difference between the current ACL-reconstruction procedures. The grafts potentially supply more isometric effectiveness in the full flexion of knee after this procedure. Traditional ACL reconstruction of the center of footprints cannot restore the isometric characteristics of the ACL[3] because the bone tunnel is more inclined to indirect fibers insertion.

Biomechanical studies have demonstrated that the double bundle ACL reconstruction with a smaller graft diameter can better cover the footprint and restore the kinematics and rotation stability of knee joint[2,5] than the single bundle method with a larger diameter. Based on 3D-CT, finite element analysis was adopted in the study, which further confirmed that femoral direct fiber insertion was the main mechanical point of ACL, and reconstruction of the femoral direct fiber was of great significance in restoring the mechanical machinery of knee joint. All the above-mentioned facts contribute to the theoretical basis of double-tunnel double-bundle reconstruction of the ACL direct fiber.

It is of paramount important to distinguish the direct fiber from the indirect fiber under arthroscopy. We identified the direct and indirect fiber insertion area under arthroscopy through cadaveric operation and used the 3D-CT character of the bone tunnel to determine the tunnel's location and determine the accurate position of the tunnel before this study. Some studies have observed a distance of 4 mm between the ACL femur direct fiber insertion and posterior cartilage edge of the femoral condyle[8] by means of microscopic and histological observation, and this provided a reference for the preparation of the femoral tunnel.

However, there are certain limitations to this study. First, the clinical effect of this operation requires further confirmation using a large sample size. Second, second-look arthroscopy was not performed in this study, hence, the tension, retear, and synovialization of the grafts were not identified. Moreover, a long-term clinical study is warranted in this regard.

In conclusion, ACL reconstruction with femoral direct fiber insertion is an more isometric ACL reconstruction procedure with satisfied early-stage clinical effects, and it can effectively restore the anterior stability of the tibia and the rotation stability of the knee, especially the kinematics environment of knee joint.

Conflicts of interest

None.

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