Double-Bundle and Double-Tunnel ACL Reconstruction With Looped Proximal Tibial Fixation

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Abstract: Double-bundle anterior cruciate ligament (ACL) reconstruction can be demanding and time consuming and requires twice as many implants, increasing both costs and possible complications. In this article, we present a new approach to double bundle ACL reconstruction: a biological fixation of the tibial side by means of a double tunnel and a U-shape passage of an anterior tibialis allograft, fixed into a double tunnel on the femoral condyle with 2 interference bioabsorbable screws. The technique is designed to combine 2 known procedures for the regular knee surgeon: the monotunnel technique and the medial-portal approach.

Anterior cruciate ligament (ACL) reconstruction has been a challenge for the orthopedic surgeon. Nowadays, we understand the consequences of the anteromedial and rotational instability that follow the absence of a functional ACL. Arthroscopic surgery offered not only a better scope of the anatomy and reconstruction possibilities, but also the best therapeutic tool available for solid biomechanical and anatomical reconstructions.

History has shown many different therapeutic approaches to ACL reconstructions, most of them with good results in anteromedial stability. However, many recent studies have emphasized the role of rotational stability as a major variable in the final success of ACL reconstructions, specifically on the development of meniscal and articular cartilage damage.

The use of autologous graft tissue in ACL reconstructions has been a sound strategy used worldwide with good results. The use of patellar tendon–bone grafts, hamstrings, or other similar tissues has the advantage of good and rapid integration at low cost. However, taking tissues from healthy sites has a toll. Patellofemoral pain in bone-tendon-bone grafts has been well described and decreased knee flexion power with high risk of muscle sprains in hamstring grafts has also been frequently reported in athletes. Donor sites can be painful, and sometimes even more symptomatic than the surgery itself. Other problems may arise such as hematomas or neurovascular injuries. Neuropathic pain is associated equally on the surgical portals and on the donor site in many reports.

The development of tissue banks in the past 2 decades has opened a new window for ligament reconstructions. Taking the autograft off the table is an attractive option that potentially means less time, less morbidity, and faster recovery. Integration of the bank graft is similar to autografts. Biomechanical properties of tendon allografts have shown similar behavior at long follow-ups. Risk of bacterial or viral cross infections is low, but remains a concern. Modern tissue banks must follow strict protocols for harvesting, sterilization, packaging, and delivery. Demand is high and donors are scarce, especially in underdeveloped countries. Bone-tendon-bone and hamstring allografts are commonly used, as they do not require changing the original surgical technique. However, sometimes more demand exists than available tissue, so surgeons have been exploring other tendon allografts suitable for ACL reconstructions.
The anterior tibialis tendon can be considered a good allograft for knee ligament reconstructions. It is a long tough tendon that can easily measure up to 20-cm long and 10-mm wide. It is biomechanically strong enough to take the knee forces, and long enough to play with different anatomical or biomechanical reconstruction techniques in ACL or posterior cruciate ligament reconstructions.

Most of the complications related to ACL reconstructions are related to graft placement than to fixation or tissue choice. At the end of the past century, we saw a research boom on fixation devices, showing different possible advantages, more in terms of easiness than in biomechanical fixation properties. In the past decade, we witnessed the arrival of poor graft placement complications resulting in early meniscus and cartilage damage in many patients. Some studies highlighted the relevance of associated injuries, especially posterolateral instability and residual rotational deficits. The use of anatomical landmarks for better graft placement was followed by the introduction of the double-bundle technique that biomechanically replaces the posterolateral and anteromedial anatomical bands of the native ACL.

We believe a double-bundle graft provides a better anatomical and biomechanical approach to ACL reconstruction. It has been clearly shown that on the tibial and femoral insertions, footprints exist of these 2 bundles. The biomechanical studies of Freddie Fu have shown the function of each bundle on the flexion and extension of the loaded knee joint. They play a crucial role in the rotational degrees of freedom of knee motion and provide better flexion-extension and anteroposterior (AP) gliding moments.

Anatomically and biomechanically speaking, it is logical to use double-bundle reconstruction. However, it involves designing new techniques that will require a learning curve, some complications due to these new techniques may arise, and many surgeons with good experience do not have a clear reason to switch techniques because of the good results of previous methods. All the in-vitro studies favor the double-bundle techniques, whereas the contrasts in clinical follow-ups are not as different. Cost is also an issue; in many of the new techniques, more implants are required for graft fixation.

In this article, we introduce a new anatomic technique using a double-bundle ACL allograft fixed by U-shape bone tunnels on the tibia, and 2 interference screws on the femur through transtibial and anteromedial portals. As this is a U-shape tibial fixation using 2 bundles, we named it the double-bundle and double-tunnel ACL reconstruction with looped proximal tibial fixation. This surgical procedure provides an anatomic reconstruction without increasing surgical time and using known arthroscopic portals. No need for different instruments is required and the 2 interference screws are the same as those used in conventional reconstructions, which results in equivalent cost.

**Materials and Methods**

After using anatomic models and trying to understand the rationale of the technique, the procedure was performed on cadaveric specimens. Few changes were performed for a final protocol and the clinical trial started on the first series of patients.

We used double-bundle and double-tunnel ACL reconstruction with looped proximal tibial fixation in 21 of our patients between January and December 2007. All patients had anterior knee instability and a confirmed diagnosis of a complete ACL tear. All patients had magnetic resonance images taken that confirmed the diagnosis. Standard operating room protocols and medications were used. The only different variable was the use of double-bundle and double-tunnel ACL reconstruction with looped proximal tibial fixation.

Patients were released from the hospital on the same day and treated according to standardized hospital protocols. All cases were followed using the Lysholm-Tegner scale and a descriptive functional score recording the ability to return to regular and sports activities. Lysholm-Tegner scores evaluated 8 different criteria: limping, weight bearing, knee locking, instability, pain, swelling, climbing stairs, and kneeling. A normal knee scores from 95 to 100 points. A score between 84 and 94 points and <84 points during basic activities of daily living is considered symptomatic during vigorous activity. Patients were followed at 3, 6, 12, 18 and 24 months postoperatively.

Rotational stability was evaluated at the follow-up visits by blind examiners. The evidence of rotational stability was recorded as present or absent, without degrees or scales. The examiners were orthopedic surgeons familiar with knee evaluation and with previous experience in ACL reconstruction follow-ups. We have previously recorded the presence of pivot shift in our ACL reconstructed patients treated with bone-tendon-bone or soft tissue single-bundle grafts 24 months postoperatively. Rotational stability was present in 22% of our patients. We want to evaluate the same protocol using our new technique to determine possible differences in rotational stability 2 years postoperatively.

Our study group had an average age of 30.2 years, minimum 16 years and maximum 56 years. Our sex ratio was 13 men (62%) and 8 women (38%). We recorded 65% of patients with right knees and 35% with left knees. Forty percent of our patients had associated meniscal injuries, and the medial meniscus was more commonly affected (25%). The lateral meniscus was torn in 15% of our patients. Only 5% of patients had related osteochondral lesions in our study group.

The first step is to confirm the availability of a good ante-
rior tibialis tendon at the tissue bank. The graft is thawed in saline solution and gentamicin for 5 to 10 minutes. We prefer to tubulize the graft using continued cross stitches of Vicryl (Ethicon, Inc, Somerville, NJ) to create a compact structure easy to pass through the tunnels (Figure 1). The graft is then measured on the standard hollow template.

The patient is placed in the supine position under general or regional anesthesia and a knee holder is used. Special care must be taken to allow full flexion of the knee, as the medial portal will be used as part of the procedure. A thigh-length antiembolism stocking and a foam heel protector are applied to the contralateral leg. A padded pneumatic tourniquet is used at a maximum of 280 mm Hg on the operative leg. The conventional arthroscopic portals and intraarticular diagnostic tour is then achieved.

Any chondral or meniscal lesion is repaired before the ACL reconstruction. It is crucial to clean up the ACL insertions to determine the ACL tibial and femoral insertion footprints. Using 2 separate skin portals, a standard ACL/C-shape-guide is used to direct the 2 tibial pins from the anteromedial proximal metaphysis onto the ACL footprint through a transarticular approach using a microfracture curved hook. Once this positioning is complete, we place the scope through the anterolateral portal. We look for the best position and the femoral guide is placed over the footprint through a transarticular approach using the anteromedial tibial tunnel. This is the regular mono-tunnel technique well described in the literature.

Special care is taken to protect the posterior wall, and the tunnel must be placed at least 7 mm anterior to this over-the-top edge. The first femoral tunnel is drilled using head-only drill bits of the measured size. It is preferred to use the same size of the measured graft (Figure 4).

Once the first anteromedial femoral tunnel is complete, the leg is placed in full knee flexion and the femoral guide is placed through the anteromedial portal. We look for the best approach to avoid damaging the articular surface of the medial condyle and to reach the anterior ACL footprint close to the previous drilled hole. Once measured, the second tunnel is drilled using the conventional anteromedial tunnel technique. At this point, 2 guides are in place from 2 different portals exiting on the anterior and lateral sides of the patient’s thigh. The graft is anchored to the anteromedial guide and pulled proximally through the tibial and femoral tunnels (Figure 5) for better possible position. It is also fixed with a bioabsorbable interference screw.

This end of the graft is fixed using bioabsorbable interference screws of the same size as the graft and tunnel measures. The free end of the graft is then anchored to the posterolateral guide end and pulled proximally into the femoral tunnel. At this point, flexion and extension of the knee is performed to stretch the graft to an optimal position.

The sutures that hold the graft must be pulled out to obtain the best possible tension.
The tibial fixation does not require hardware, as it is a U-shape natural fixation through the 2 tibial tunnels over the strong anteromedial cortex (Figures 6-9).

RESULTS

Because this is a preliminary report, we can only describe findings in our case series. We encountered no technical difficulties during surgery and changed none of our pharmacological or therapeutic protocols. We had no complications directly related to the technique. We followed our first 21 patients for >2 years and found a similar clinical behavior as with previous techniques. Our protocols for weight bearing and return to physical and working activities were used and no adverse effects of the technique were found.

The Lysholm score showed good or excellent results in 20 patients (95%). Fourteen patients (70%) were able to return to their previous active sport. The blind evaluation of rotational stability showed an absence of the Pivot Shift sign in 20 of 21 patients. Only 1 patient had a positive Pivot Shift sign recorded as positive at 3-month follow-up. This patient remained with a positive Pivot Shift sign throughout the 2-year follow-up. However, this patient returned to regular activities, although he practices no active sports. None of the remaining 20 patients were reported as Pivot Shift positive by the blinded examiners at 2-year follow-up, improved from 22% in our previous records using conventional single-bundle bone–tendon–bone or soft tissue graft techniques, to only 1 patient in our series after 2 years, nearly a 5% in our case series. This represents a 17% improvement in long-term rotational instability.

One of our patients had a graft rupture 9 months postoperatively as he was practicing BMX cycling at a professional level. During revision surgery, we found a torn posterolateral bundle. A revision ACL reconstruction was performed with a new allograft.

DISCUSSION

The current concepts in knee biomechanics and the outcome of the actual standards in ligament reconstruction created the necessity of changing paradigms in ACL reconstruction in the past decade. Present data shows that ACL reconstruction techniques using single bundle grafts placed by conventional transtibial drilling will not provide adequate restraint against translational and rotational forces. A clear tendency to anatomically reconstruct the torn ACL to avoid rotational instability exists. However, the use of double-bundle techniques remains controversial and has not yet become a gold standard.

Although many biomechanical and in-vitro studies favor double-bundle reconstruction, other studies have shown up to 30% residual instability at longer follow-ups. The prevalence of anatomical and biomechanical studies of ACL reconstructions has also created a clear improvement of single-bundle reconstructions both in techniques, biology, and implants. A study by Heming et al have shown that
Double-bundle ACL reconstruction pretends to mimic the anatomical shape of the ACL.\(^1\) The anteromedial bundle provides anterior to posterior stability, while the posterolateral bundle controls the rotational motion, particularly in deep flexion.\(^2,3\) Biomechanical studies in cadaveric specimens have shown that single-bundle ACL reconstruction does not provide adequate rotational stability using the current techniques and tunnel placements.\(^8\) This is a proven fact on mono-tunnel techniques. In these studies, the reconstruction of both anteromedial and posterolateral bundles provided better AP and rotational control of motion.\(^4\)

Freddie Fu has shown that there are 5 fundamental principles in anatomic double-bundle ACL reconstruction.\(^3\) The first and most important is the anatomy: the shape and function of the anteromedial and posterolateral bundles. The second principle is restoring the native insertion site anatomy of the ACL. The third principle is restoring the tension pattern of each bundle. The fourth principle is individualizing the surgery for each patient. The fifth principle is that bone morphology dictates the motion of the knee. If one takes all these parameters into account, the surgical procedure will have a close to perfect indication and results will be optimal.\(^3\)

Markolf et al\(^8\) reported a difference of 11 mm in anterior drawer between 0° and 90° of flexion in patients with single-bundle reconstructions as compared to double-bundle techniques. Markolf et al\(^9\) measured the rotational stability in a subjective assessment and showed a difference of 4° less pivot in patients treated with double-bundle ACL reconstructions.

Ibrahim et al\(^10\) compared single- versus double-bundle reconstructions in 218 patients and found that double-bundle ACL reconstructions had significantly better results both in KT1000 measurements and pivot shift assessments. Järvelä\(^11\) performed a similar prospective randomized study comparing both techniques with similar rehabilitation protocols. In his series, 65 patients were randomized; 35 patients were treated with a double bundle and 30 with a single bundle. Both techniques used hamstrings and interference screws on the femoral and tibial fixations. This study showed a better rotational subjective outcome on patients treated with double-bundle reconstruction measured by pivot shift assessment.\(^11\)

Aglietti et al\(^12\) conducted a comparative cohort study comparing both techniques. A double-bundle study group of 25 patients were treated with a single tibial tunnel technique, but they included a third study group using a double-bundle-double-tunnel technique. They found significant differences in anterior drawer and pivot shift favoring the double bundle-double-tunnel technique as compared to the other 2 study groups.

Another biomechanical issue is the valgus force control provided by the ACL graft. It has been shown that double-bundle reconstructions may control valgus forces better than any single-bundle options. This is even more relevant in athletes that require strong angular control of the knee.\(^9,13\)

Zelle et al\(^3\) introduced the concept of the double-bundle ACL reconstruction having the posterolateral graft fixed between 0° and 10° and the posterolateral bundle fixed close to 60° of flexion. This series showed a better stability of the knee.

Kim et al\(^14\) showed how a double-bundle reconstruction using a quadriceps autograft provides less anterior translation than a single-bundle bone–tendon–bone allograft.

Prodromos et al\(^15\) emphasized that the purpose of a double-bundle ACL reconstruction is to provide better rotational stability and improve knee kinematics. They also pointed out that an important issue is the higher cost of implants and surgical time. Designing new techniques to achieve anatomic reconstructions without increasing cost in implants or surgical time is an open window for research and development. A double-bundle ACL reconstruction is more demanding and complex, and it also changes the paradigms of the
previous surgery gold standards. This is why it is crucial to know the anatomy well, especially the insertions of both ACL bundles. The biodegradable interference screws have been developed as an alternative to metal screws. They have proven to be strong and safe and have the additional advantage of not causing interference on MRIs. Revision surgery is also easier because the biodegradable interference screws can be crushed with a regular drill bit. Some studies have shown a better integration of the graft when using biodegradable implants. Different biodegradable materials have different integration times. The use of these implants offers a clear advantage and this is why we preferred the biodegradable interference screws in our patients.

At least 6 recent level I and level II prospective randomized studies exist that have reported favorable clinical outcomes after double-bundle ACL reconstructions compared to traditional single-bundle ACL reconstructions at mid-term follow-up. While subjective measurements are similar to single-bundle surgery, double-bundle ACL reconstruction showed better objective outcome measures, especially in rotational control.

One of the most difficult issues in the assessment of clinical outcomes of ACL reconstructions is the evaluation of rotational stability. Clear objective devices do not exist that provide numerical and comparable data to be analyzed statistically in a solid, evidence-based manner. We must then trust the only subjective form: the pivot shift test. This clinical assessment cannot be measured on a scale, only as a positive or negative result. It must be comparative both with the contralateral knee and the pretreatment status. This way, one may determine changes that can only be measured as positive or negative, never on a scale or a degree. The technique to measure the pivot shift is also different from surgeon to surgeon. Some measure it from flexion to extension and many from extension to flexion. Besides, the real rotational instability can only be measured under anesthesia and only during examination, which cannot be repeated at follow-up. With all these issues in mind, we must be careful to determine the rotational instability in our patients, and repeat the same protocols for a pre- and postoperative assessment. The pivot shift reduction or its complete elimination is the clinical goal on the surgical ACL reconstruction. So far, the best results in pivot shift reduction or elimination after ACL reconstruction has been reported on patients treated with anatomical or double-bundle grafts.

Concerns about technical complications of double-bundle ACL reconstruction surgeries exist, including lateral femoral condyle osteonecrosis, fractures between tunnels, and difficult revision surgeries. In our series, we experienced none of these complications and the patient we had to revise required a new standard procedure where the tibial and femoral tunnels were drilled over the previous ones. We found an easier way to revise the tibia, as no hardware had to be drilled through or removed. This can be seen as an additional advantage of the double-bundle and double-tunnel ACL reconstruction with looped proximal tibial fixation.

We are comfortable with the double-bundle and double-tunnel ACL reconstruction with looped proximal tibial fixation; we were able to improve a known problem using a simple technique. We required no special instruments, hardware, or training, found no technically related complications, and changed no known protocols. Reduction of rotational instability improved from 22% in our previous records using conventional single-bundle bone-tendon-bone or soft-tissue graft techniques, to nearly 5% on these series after 2-year follow-up.

We introduce a new technique that not only provides a double-bundle double-tunnel reconstruction, but also a system that allows adequate fixation without using more implants than the regular gold standard. The surgical technique is a mix of a mono-tunnel current standard and a medial portal approach, another well-known surgical procedure used in single-bundle ACL reconstructions. This means we do not have to train surgeons in complex procedures with a large training curve, or use more implants than regular interference screws. There is no strange hardware involved in this technique. The fixation is only on the femur and the system is biologically anchored on the U-shape tunnels on the tibial side.

The goal of every surgeon is to obtain the most anatomical reconstruction possible. Although debate exists about the advantages of using a double-bundle technique, we believe the surgical procedure we propose achieves the goals of an anatomical reconstruction, requiring no additional hardware or change in previously known surgical techniques. In this short series, we found a clear advantage of double-bundle and double-tunnel ACL reconstruction with looped proximal tibial fixation in controlling rotational stability. Further biomechanical and clinical studies must be performed to prove objective benefits of this technique to validate it as a safe and sound anatomical approach to ACL reconstruction.
ate ligament and its two function-
4. Yagi M, Wong EK, Kanamori A,
Debski RE, Fu FH, Woo SL. Bio-
mechanical analysis of an ana-
tomic anterior cruciate ligament
5. Zelle BA, Vidal AF, Brucker PU,
Fu FH. Double-bundle recon-
struction of the anterior cruciate
ligament: anatomic and biome-
chanical rationale. *J Am Acad
6. Freedman KB, D’Amato MJ,
Nedeff DD, Kaz A, Bach BR Jr.
Arthroscopic anterior cruci-
ate ligament reconstruction: a
metaanalysis comparing patellar
tendon and hamstring tendon au-
7. Heming JF, Rand J, Steiner ME.
Anatomical limitations of transsti-
tial drilling in anterior cruciate liga-
tament reconstruction. *Am J Sports
8. Musahl V, Voos JE, O’Loughlin
PF, et al. Comparing stability
of different single- and double-
bundle anterior cruciate ligament
reconstruction techniques: a ca-
daveric study using navigation
(Published online ahead of print
August 9, 2010). *Arthroscopy.*
9. Markolf KL, Park S, Jackson SR,
McAllister DR. Anterior-posterior
and rotatory stability of single and
double-bundle anterior cruciate liga-
tament reconstructions. *J Bone Joint
10. Ibrahim SA, Hamido F, Al Mis-
far AK, Mahgoob A, Ghufar SA,
Alhnan H. Anterior cruciate liga-
tament reconstruction using autolo-
gous hamstring double bundle graft
compared with single bun-
11. Järvelä T. Double-bundle versus
single-bundle anterior cruciate
ligament reconstruction: a pro-
spective, randomized clinical
study (Published online ahead
of print January 10, 2007). *Knee
Surg Sports Traumatol Arthrosc.*
12. Aglietti P, Giron F, Cuomo P, Los-
co M, Mondanelli N. Single-and
double-incision double-bundle
ACL reconstruction. *Clin Orthop
13. Kocher MS, Steadman JR, Briggs
KK, Sterett WI, Hawkins RJ.
Relationships between objective
assessment of ligament stabil-
ity and subjective assessment
of symptoms and function after
anterior cruciate ligament recon-
32(3):629-634.
SB, Oh KS. Anterior cruciate liga-
tament reconstruction with use
of a single or double-bundle tech-
nique in patients with generalized
ligamentous laxity. *J Bone Joint
15. Prodromos CC, Fu FH, Howell
SM, Johnson DH, Lawhorn K.
Controversies in soft-tissue anteri-
or cruciate ligament reconstruction:
grafts, bundles, tunnels, fixation,
and harvest. *J Am Acad Orthop
16. Maestro A, Álvarez A, Del Valle
M, et al. Reconstrucción anatómi-
ca bifascicular del ligamento cru-
zado anterior. *Rev Esp Cir Ortop
17. Bellelli A, Adriani E, Avitto A,
David V. New femoral fixation
system for tendon transplanta-
tion in ACL reconstruction. Pre-
liminary experience with MR
102(4):211-216.
18. Stühelin AC, Weiler A, Rüfenacht
H, Hoffmann R, Geissmann A,
Feinstein R. Clinical degrada-
tion and biocompatibility of dif-
ferent bioabsorbable interference
screws: a report of six cases. *Ar-
throscopy.* 1997; 13(2):238-244.
19. Markolf KL, Park S, Jackson SR,
McAllister DR. Simulated pivot-
shift testing with single and dou-
ble-bundle anterior cruciate liga-
tment reconstructions. *J Bone Joint
20. Pearle AD, Kendoff D, Musahl V,
Warren RF. The pivot-shift phe-
nomenon during computer-as-
sisted anterior cruciate ligament
reconstruction. *J Bone Joint Surg
21. Longo UG, King JB, Denaro V,
Maffulli N. Double-bundle ar-
throscopic reconstruction of the
anterior cruciate ligament: does
the evidence add up? *J Bone Joint
Surg Br.* 2008; 90(8):995-999.