International Journal of Orthopaedics Sciences

ISSN: 2395-1958
IJOS 2018; 4(1): 922-928

www.orthopaper.com
Received: 01-11-2017
Accepted: 02-12-2017

Naser Mohamed Selim
Assistant prof. of orthopedic surgery, Knee surgery - arthroscopy and sports injuries unit, Orthopedic department, Mansoura University, Dakahlia Governorate, Egypt

Correspondence
Naser Mohamed Selim
Assistant prof. of orthopedic surgery, Knee surgery - arthroscopy and sports injuries unit, Orthopedic department, Mansoura University, Dakahlia Governorate, Egypt

Arthroscopic double bundle, double branched tunnel anterior cruciate ligament reconstruction

Naser Mohamed Selim

DOI: https://doi.org/10.22271/ortho.2018.v4.i1n.131

Abstract
Double bundle anterior cruciate ligament reconstruction is clinically better than single bundle reconstruction but it is more difficult, more complicated and less economic. This study presents a modified technique of double bundle reconstruction and assesses its clinical results. The reconstruction was done using the hamstring tendon autografts passed through branched tibial and femoral tunnels and fixed by only two interference screws (Arthrex); one at the femoral tunnel and one at the tibial tunnel. The study was carried out on forty nine patients in the period between March 2013 and April 2015 but completed on forty-four patients. The mean follow up period was 32.2 months (24.2 months: 48.3 months). The clinical assessment was done using side to side anterior laxity, pivot shift test, International Knee Documentation Committee and Lysholm scores. The results were analyzed using Statistical Package for Social Science software computer program version 17. It showed significant improvement of knee anterior laxity, pivot shift test, International Knee Documentation Committee score and Lysholm scores. The study concluded that gives statistically significant clinical results are obtained after arthroscopic double bundle, double branched tunnel anterior cruciate ligament reconstruction and the technique could be considered a valid option of reconstruction.

Keywords: double bundle ACL reconstruction – techniques of reconstruction

1. Introduction

Anatomic ACL reconstruction is the functional restoration of normal dimensions, collagen orientation and insertion sites of the native AC L [1]. Anatomically, the ACL consists of two separate; the anteromedial (AM) and the posterolateral (PL) bundle named by their insertion site location on the tibia [2-4] acting in a reciprocal fashion during knee motion [5].

With single bundle ACL reconstruction, residual instability occurs [6] and degenerative osteoarthritis occurs at long term follow up [7]. While with double bundle reconstruction there is improved anterior knee laxity, pivot-shift testing [8 – 10] and decreased failure rates down to 4% [11]. A clinical superiority of anatomic double bundle over anatomic single bundle reconstructions is reported [12].

But technically and economically; double bundle ACL reconstruction needs four independent tunnels, which is demanding and time consuming and requires many implants, increasing both costs and possible complications [13, 14]. Decrease the number of independent tunnels by tunnel branching saves implants and decreases the complications.

This prospective study uses tunnel branching for double bundle ACL reconstruction and assesses its clinical results for at least two years follow up.

2. Patients and Methods

The study is a case series of level IV evidence. It is accepted by Institutional Review Board (IRB). It was carried out on patients with chronic complete ACL tear with or without meniscal injury in the period between March 2013 and April 2015. Patients with acute tears, associated chondral lesions or associated other ligament injury were excluded.

Forty nine patients were treated by double bundle ACL reconstruction by hamstring tendon autograft through branched tunnels and fixation by two interference screws (Arthrex). Forty four patients (89.8%) were completed the follow up and five were missed.

All patients were males, with the mean age was twenty seven. Twenty patients (45.4%) were heavy manual workers and sixteen (36.4%) were football players. The clinical assessment evaluated the patients both preoperatively and postoperatively. The clinical assessment included side to side anterior laxity, pivot shift test, IKDC score and Lysholm score.

2.1 The surgical technique

2.1.1 Tunnel branching importance

The tibial and the femoral tunnels have a stem that divides into two narrower branches. The stem is distal and the branches are proximal. The branches are separated by a wedge of bone its distal part should be not less than 3 mm and its proximal base should be not less than 10 mm.

The femoral tunnel braches allow correct graft bundle orientation and position. When the grafts are fixed at femoral tunnel stem by one interference screw (Arthrex), the femoral stem and its branches will act as a single femoral tunnel.

Sergiu C, *et al*. (2016) performed anatomic double bundle ACL reconstruction with a free quadriceps tendon autograft using single femoral tunnel and two independent tibial tunnels [15].

The tibial tunnel branches give two separate apertures for the graft. Anatomically, the AM and the PL bundles are named by their insertion site location on the tibia [2-4]. The grafts are fixed at tibial stem by one interference screw at 20º of knee flexion. Different bundle tension with flexion and extension could be obtained with fixation of both bundles at the same degree (20º) of knee flexion applying 20⁄20 tensioning protocol recommended by Patrick JM et, al. (2010) [16].

2.1.2 Graft preparation

The gracilis tendon is tripled making a graft of 5 mm diameter to represent PL bundle. The semitendinosus tendon is doubled or tripled making a graft of 7 mm diameter to represent AM bundle. The diameter of bone tunnel stem and its branches is matching to the diameter of the grafts.

2.1.3 Tibial tunnel

The ACL tibial foot print is measured at first; it should be more than 16 mm to accommodate double bundle reconstruction. The AM tibial tunnel is created first then the tunnel stem then the PL tunnel branch.

The ACL tibial drill guide set to angle 55° is fitted between two points, the entry point; a point 5 cm distal to the joint line just anterior to superficial medial collateral ligament on tibial cortex [17] and the aperture point; the center of AM bundle just medial to posterior margin of anterior horn of the lateral meniscus [18] making 20° angle to sagittal plan. This distance is drilled by a guide wire 2.7 mm (Fig. 1-A). The distal 25 mm of this distance is reamed by a reamer 12 mm. This is the tibial tunnel stem. The remaining proximal 10 mm of this distance is reamed by a reamer 7 mm. This is the AM tibial tunnel branch (Fig. 1-B).

Then ACL tibial drill guide set to angle 55° is fitted between PM corner of the end of tibial tunnel stem and the center of PL bundle just medial to lateral tibial spine [18] making 40° angle to sagittal plan. This distance is drilled by a guide wire 2.7 mm (Fig.1-A). Then it is reamed by a reamer 5 mm. This is the PL tibial tunnel branch (Fig. 1-B). The PL tunnel branch and its aperture are lateral and posterior to the AM tunnel branch and its aperture. While the entry point of the PL tunnel branch is medial, posterior and superior to the entry point AM tunnel branch.

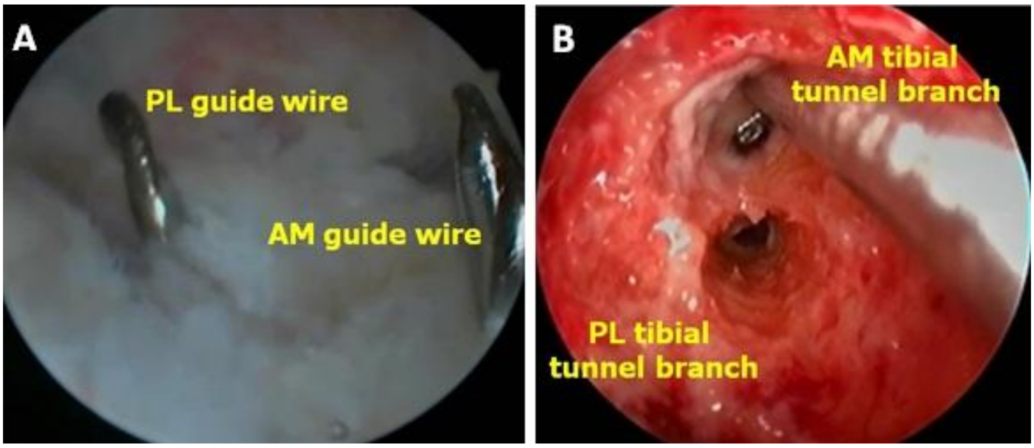

Fig 1: Arthroscopic view of right knee. A: through the lateral portal showing AM and PL guide wires. The aperture of PL bone tunnel branch is lateral and posterior to aperture of AM bone tunnel branch. B: inttra-tunnel view through the tibial tunnel showing AM and PL tibial tunnel branches. The PL tunnel branch is lateral and posterior AM tunnel branch.

2.1.4 Femoral tunnel

The freehand technique without a guide is used to achieve a better flexibility for AM and PL tunnel positioning. Using the standard AM portal with the knee flexed 90º [15], a guide wire 2.7mm is drilled through the entry point of the femoral tunnel that is present along osseous landmarks on the lateral intercondylar and bifurcate ridges on the posterior aspect of the medial wall of the lateral femoral condyle [19].

The distal 25 mm distance is reamed by a reamer 12 mm. This is the femoral tunnel stem. The proximal 5 -10 mm distance is reamed by a reamer 7 mm. This is the AM femoral tunnel branch (Fig. 2-A). Then AM passage sutures are passed through (Fig. 2-B).

Then through the accessory AM portal which is medial and inferior to the standard AM portal with the knee flexed 120º [18], a guide wire 2.7mm is drilled through the PL corner of the end of the tunnel stem. The proximal 5 mm distance is reamed by a reamer 5 mm. This is the PL femoral tunnel branch (Fig. 2-A). Then PL passage sutures are passed through (Fig. 2-B).

The entry point of the AM tunnel branch is medial, posterior and superior to the entry point PL tunnel branch (Fig. 2-A).The PL passage sutures are retrieved first to PL tibial tunnel branch then stem to exterior then AM passage sutures are retrieved to AM tibial tunnel branch then stem to exterior (Fig. 2-B).

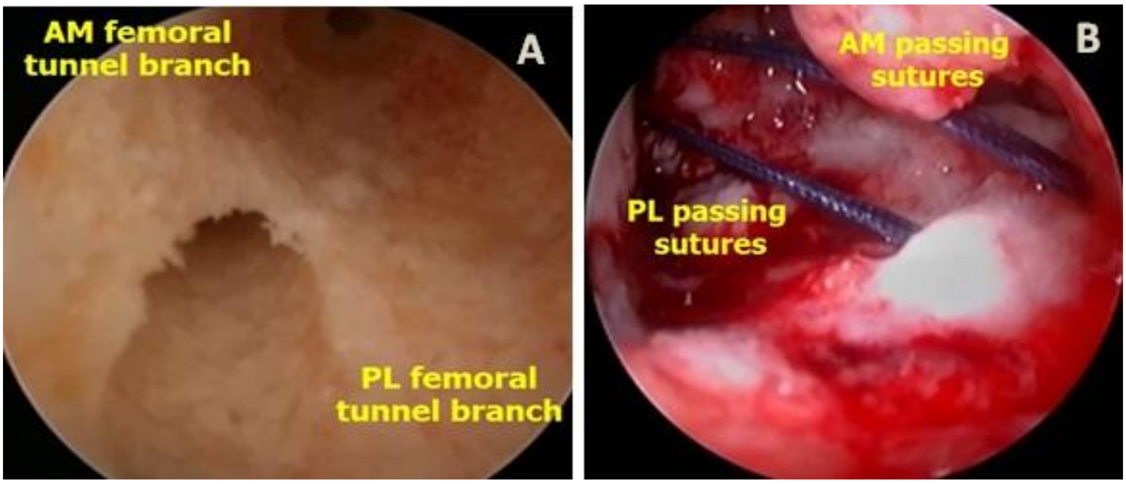

Fig 2: Arthroscopic view of right knee. A: inttra-tunnel view through the femoral tunnel using AM portal showing AM tunnel branch medial, posterior and superior PL femoral tunnel branches. B: through the lateral portal showing AM and PL passage sutures.

2.1.5 Graft passage and fixation

The gracilis tendon graft is passed first, then the semitendinosus tendon graft [17]. The AM bone tunnels are created first. While the PL passage sutures and PL bundle graft are passed first. Then a bio absorbable interference screw (Arthrex) is used for graft fixation at stem of the femoral tunnel then at stem of the tibial tunnel with the knee flexed 20° applying more tensioning on AM than PL grafts.

At the end of the procedure arthroscopic evaluation is done (Fig. 3). The bundles should be crossed in flexion, parallel in extension and occupy most of the foot print of native ACL at its femoral and tibial attachments with no posterior cruciate ligament or notch impingement. The AM bundle should be tight in flexion and while the PL bundle should be tight in extension. The two bundles should act in reciprocal fashion during flexion and extension [16].

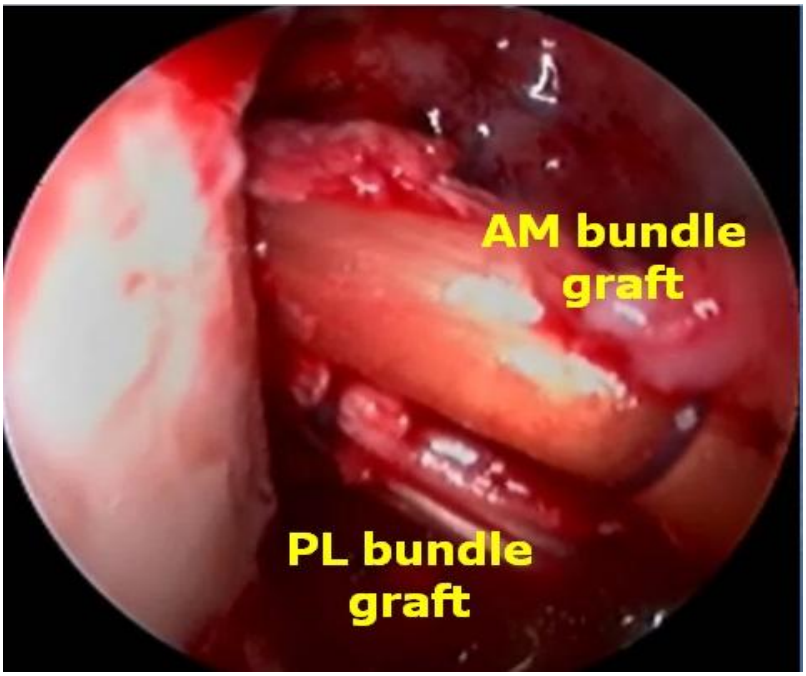

Fig 3: Arthroscopic view of right knee through the lateral portal showing AM and PL bundle grafts

Routine ACL follow up regimen was done for all patients. The preoperative clinical data included side to side anterior laxity, pivot shift test, IKDC score and Lysholm score were recorded (Tab.1). The mean follow up period was 32.2 months (24.2 months: 48.3 months and the final results were recorded (Tab.2).

2.2 Statistical analysis

Data was analyzed using Statistical Package for Social Science software computer program version 17 (SPSS, Inc., Chicago, IL, USA). Quantitative parametric data were presented in mean and standard deviation, while Quantitative non parametric data were presented in median and interquartile range (IQR). Student's t-test (paired) was used for comparing two related groups (quantitative parametric data) while Wilcoxon signed rank test was used for comparing two related groups (quantitative non parametric data). P value less than 0.05 was considered statistically significant.

3. Results

The preoperative (Tab.1) and postoperative (Tab.2) clinical assessment included side to side anterior laxity, pivot shift test and IKDC and Lysholm scores.

Table 1: Preoperative clinical Results

Patient	anterior laxity (mm)	Pivot shift test	IKDC score (%)	Lysholm score (%)
1.	5.5	III	65.5	66
2.	6.0	III	63.2	67
3.	4.4	II	73.6	76
4.	5.1	III	58.6	66
5.	5.6	III	56.3	66
6.	5.0	III	66.7	67
7.	5.2	III	67.8	66
8.	5.3	III	69	71
9.	5.5	III	70	66
10.	4.8	II	71.3	76
11.	4.9	II	72.4	76
12.	5.7	III	67.8	67
13.	5.2	III	69	66
14.	5.5	III	66.7	67
15.	5.6	III	65.5	67
16.	5.0	III	56.3	66
17.	5.0	III	74.7	76
18.	4.4	II	73.6	71
19.	5.2	III	74.7	71
20.	5.1	III	63.2	67
21.	5.6	III	72.4	71
22.	5.9	III	74.7	71
23.	5.4	III	66.7	67
24.	5.0	III	67.8	67
25.	4.5	II	77	76
26.	5.0	III	70	66
27.	5.6	III	67.8	62
28.	5.8	III	63.2	71
29.	5.5	III	58.6	67
30.	5.9	III	56.3	62
31.	5	III	66.7	71
32.	5.1	III	74.7	71
33.	5.2	III	72.4	76
34.	5.1	III	63.2	62
35.	5.2	III	63.2	65
36.	4.8	II	77	71
37.	5.5	III	67.8	65
38.	5.7	III	69	65
39.	5.8	III	70	71
40.	5.3	III	71.3	71
41.	4.4	III	63.2	67
42.	5.0	III	63.2	67
43.	5.3	III	70	71
44.	4.4	III	66.7	67

Table 2: Postoperative clinical Results

Patient	anterior laxity (mm)	Pivot shift test	IKDC score (%)	Lysholm score (%)
1	2.1	II	86.2	85
2	2.5	II	87.8	85
3	1.8	1	85.1	86
4	1.5	0	83.9	87
5	2.3	1	92	86
6	1.5	0	85.1	90
7	1.3	0	94.3	98
8	1.1	0	93.1	96
9	2.2	0	85.1	87
10	1.8	0	94.3	95
11	1.4	0	90.8	97
12	1.6	0	93.1	95
13	1.3	0	94.3	98
14	1.4	0	86.2	86
15	1.2	0	89.7	87
16	1.1	0	86.2	88
17	1.3	0	85.1	90
18	1.1	0	95.4	99
19	1.2	0	94.3	95

20	1.7	II	88.5	88
21	1.1	0	86.2	96
22	2	1	85.1	87
23	1.9	11	86.2	85
24	1.4	0	95.4	96
25	1.1	0	87.8	87
26	1.5	1	93.1	95
27	1.4	0	85.1	86
28	1.3	0	94.3	96
29	1.4	0	86.2	87
30	1.5	0	94.3	97
31	1.2	0	93.1	97
32	1.1	0	93.1	98
33	1.3	0	94.3	95
34	1.1	0	85.1	86
35	1.2	0	83.9	87
36	1.4	0	94.3	96
37	1.0	0	93.1	95
38	1.1	0	94.3	99
39	1.1	0	70	95
40	1.4	0	90.8	96
41	1.2	II	85.1	86
42	1.3	0	86.2	87
43	1.0	1	85.1	88
44	1.3	0	93.1	90

After at least two years follow up, the double bundle ACL reconstruction through branched tunnels resulted in statistically significant (P value <0.001) improvement of the side to side anterior laxity, the pivot shift test, the IKDC and Lysholm scores (Tab. 3). The mean side to side anterior laxity was 1.4, negative pivot shift test was 81.8%, the mean IKDC score was 89.2 and the mean Lysholm score was 91.4. AM bundle failure occurred in one patient (2.3%) and tibial tunnel branches merged in two patients (4.5%).

Table 3: Results of double bundle ACL reconstruction by branched tunnels

	Pre-operative		Post-operative		P value
anterior laxity (Mean ± SD)	5.23	±.42	1.43	±.36	< 0.001*
pivot shift test median (IQR)	3	3-3	0	0-0	< 0.001*
IKDC score (Mean ± SD)	67.70	±5.43	89.22	±5.00	< 0.001*
Lysholm score (Mean ± SD)	68.66	±3.89	91.48	±4.92	< 0.001*

(SD: standard deviation, IQR: interquartile range, P: Probability*: significance <0.05)

Regarding the side to side anterior laxity, double bundle ACL reconstruction through branched tunnels was found to have the same results of double bundle ACL reconstruction done by Aglietti 2007 [20] and Muneta 2007 [21]. Regarding the pivot shift test results, double bundle ACL reconstruction through branched tunnels was found to have the same results of double bundle ACL reconstruction done by Jarvela 2008 [22] and Kondo 2008 [10] (Tab. 4).

Table 4: Results of double bundle ACL reconstruction by many authors

Authors	Patients	anterior laxity (mm)	Negative pivot-shift test (%)
Yasuda 2006 [8]	72	1.1	87.5
Aglietti 2007 [20]	75	1.4	84.0
Muneta 2007 [21]	68	1.4	85.3
Yagi 2002 [26]	60	1.3	(24001)
Jarvela 2007 [9]	55	1.12	96.7
Jarvela 2008 [22]	77	1.3	81.8
Kondo2008 [10]	328	1.2	81.3
Streich 2008 [32]	49	1.1	95.8
This study	44	1.43	81.8

4. Discussion

Anatomically, the ACL consists of two separate - functionally distinct bundles; the AM bundle and the PL bundle acting in a reciprocal fashion during knee motion [5]. During flexion, the AM bundle tightens and the PL bundle relaxes. The AM bundle resists anterior tibial translation in relative knee flexion. During extension, the PL bundle tightens and the AM bundle relaxes. The PL bundle resists anterior translation and internal rotation of tibia on femur in relative knee extension [23-25].

Biomechanically, double bundle reconstruction is similar to normal ACL in response to anterior translation force and represent 91% of normal ACL in response to valgus & internal rotation force while single bundle reconstruction represent 66% of normal ACL in response to valgus & internal rotation force [26]. Single bundle ACL reconstruction can restore the anteroposterior stability, but not able to restore rotational stability [27].

Clinically, with single bundle ACL reconstruction less than 50% of patients only can return to their previous level of activity, more than 90% of patients develop degenerative osteoarthritis at 7 years follow up [7] and about 30% of patients had residual instability at longer follow-up [6]. ACL failure after single bundle ACL reconstruction was 11% in one series [28] and 15% in another series [11] were recorded. With double bundle reconstruction there was improved anterior laxity, improved pivot-shift testing [8-10] and decreased failure rates to 4%. A clinical superiority of anatomic double bundle over anatomic single bundle reconstructions was reported [12].

But technically and economically, double-bundle ACL reconstruction needs two independent tibial tunnels, two independent femoral tunnels, four anatomical attachments and four points of fixation. This is demanding and time consuming and requires twice as many implants, increasing both costs and possible complications [13, 14]. The use of only two interference screws is advantageous from economic and biologic point of view [14].

Some recorded complications associated with double bundle ACL reconstruction as confluence of the tunnels [18], over constrained knee and tension imbalance within AM and PL grafts were reported [29, 30]. Lateral femoral condyle osteonecrosis, fractures between tunnels, difficult revision surgery were also reported [31].

The ACL reconstruction through branched tunnels needs single branched tibial tunnel, single branched femoral tunnel, three anatomical attachment sites and two points of fixation. This saves implants and decrease incidence of complications. In the literature the results are variable. A study showed no statistical differences in all clinical evaluations between single and anatomic double bundle reconstructions. [32]. On the other hand another study showed significant differences in the anterior laxity, the pivot shift test and the IKDC evaluation between single and anatomic double bundle reconstructions [20].

In this study, after at least two years of follow up when comparing between preoperative and postoperative findings, the double bundle ACL reconstruction using the hamstring autografts through branched tunnels resulted in statistically significant (P value < 0.001) improvement of the knee anterior laxity, the pivot shift test, the IKDC and Lysholm scores. When comparing between results in the literature, this study had the same results of Aglietti 2007 [20] and Muneta 2007 [21] as regard side to side anterior laxity and the same results of Jarvela 2008 [22] and Kondo 2008 [10] as regard the frequency of negative pivot shift test.

A point of weakness of the study is the small number of patients, and the procedure has some limitations; the ACL tibial foot prints less than 16 mm, the diameter of the gracilis tendon graft and the semitendinosus tendon graft less than 5 mm and 7 mm respectively and the tibial tunnel length less than 35 mm.

5. Conclusion

Arthroscopic double bundle, double branched tunnel ACL reconstruction saves implants used in graft fixation and gives statistically significant clinical improvement as regard side to side anterior laxity, pivot shift test and IKDC and Lysholm scores. It could be considered a valid option of treatment of chronic ACL tear.

6. References

1. Van Eck CF, Lesmiak BP, Schreiber VM, Fu FH. Anatomic single- and double-bundle anterior cruciate ligament reconstruction flowchart. Arthroscopy, 2010; 26:258-268.
2. Kopf S, Musahl V, Tashman S, Szczodry M, Shen W, Fu FH. A systematic review of the femoral origin and tibial insertion morphology of the ACL. Knee Surg Sports Traumatol Arthrosc, 2009; 17:213-219.
3. Zantop T, Petersen W, Sekiya JK, Musahl V, Fu FH. Anterior cruciate ligament anatomy and function relating to anatomical reconstruction. Knee Surg Sports Traumatol Arthrosc, 2006; 14:982-992.
4. Murawski CD, Wolf MR, Araki D, Muller B, Tashman S, Fu FH. Anatomic anterior cruciate ligament reconstruction: current concepts and future perspective. Cartilage, 2013; 4:27S-37S.
5. Dienst M, Burks RT, Greis PE. Anatomy and biomechanics of the anterior cruciate ligament. Orthop Clin North Am, 2002; 33:605-620.
6. Freedman KB, D'Amato MJ, Nedeff DD, Kaz A, Bach BR Jr. Arthroscopic anterior cruciate ligament reconstruction: a metaanalysis comparing patellar tendon and hamstring tendon autografts. Am J Sports Med. 2003; 31(1):2-11.
7. Fithian DC, Paxton EW, Stone ML *et al*. Prospective trial of a treatment algorithm for the management of the anterior cruciate ligament-injured knee. Am J Sports Med. 2005; 33:335-346.
8. Yasuda K, Kondo E, Ichiyama H, Tanabe Y, Tohyama H. Clinical evaluation of anatomic double-bundle anterior cruciate ligament reconstruction procedure using hamstring tendon grafts: Comparisons among 3 different procedures. Arthroscopy, 2006; 22:240-251.
9. Jarvela T. Double-bundle versus single-bundle anterior cruciate ligament reconstruction: A prospective randomized clinical study. Knee Surg Sports Traumatol Arthrosc, 2007; 15:500-507
10. Kondo E, Yasuda K, Azuma H, Tanabe Y, Yagi T. Prospective clinical comparisons of anatomic double-bundle versus single-bundle anterior cruciate ligament reconstruction procedures in 328 consecutive patients. Am J Sports Med. 2008; 36:1675-1687.
11. Suomalainen P, Moisala A, Paakkala A, Kannus P, Järvelä T. Double-bundle versus single-bundle anterior cruciate ligament reconstruction: randomized clinical and magnetic resonance imaging study with2-year follow-up. Am J Sports Med. 2011; 39(8):1615-22.
12. Hussein M, van Eck CF, Cretnik A, Dinevski D, Fu FH. Prospective randomized clinical evaluation of conventional single-bundle, anatomic single-bundle, and anatomic double-bundle anterior cruciate ligament reconstruction: 281 cases with 3- to 5-year follow-up. Am J Sports Med. 2012; 40:512-520.
13. Berumen-Nafarrate E, Leal-Contreras C, Double-Bundle, Double-Tunnel ACL. Reconstruction With Looped Proximal Tibial Fixation. Orthopedics. 2011; 34(6):441-246.
14. Prodromos CC, Fu FH, Howell SM, Johnson DH, Lawhorn K. Controversies in soft-tissue anterior cruciate ligament reconstruction: grafts, bundles, tunnels, fixation, and harvest. J Am Acad Orthop Surg. 2008; 16(7):376-384.
15. Sergiu C, Dan VN, Adrian T. Anatomic Double-Bundle Anterior Cruciate Ligament Reconstruction With a Free Quadriceps Tendon Autograft. Arthroscopy Techniques, 2016; 5(5):e1063-e1067.
16. Patrick JM, Jerry WA, Jonathan EG, Kurt DI, Philip CN, Walter RL. Anatomic Double-Bundle Anterior Cruciate

Ligament Reconstruction: Kinematics and Knee Flexion Angle-Graft Tension Relation. Arthroscopy. 2010; 26(2):202-213.

17. Christian L, Boris AZ, Mario F, Anikar C, Fu FH. Anatomic Double-Bundle Anterior Cruciate Ligament Reconstruction. Techniques in Orthopaedics. 2005; 20(4):414-420.
18. Ari Z, Ricardo SS, Mario CF. Anatomical ACL reconstruction with double bundle: first 40 cases. Rev Bras Ortop. 2011; 46 (3):262-265.
19. Ferretti M, Ekdahl M, Shen W, Fu FH. Osseous landmarks of the femoral attachment of the anterior cruciate ligament: An anatomic study. Arthroscopy, 2007; 23:1218-1225.
20. Aglietti P, Giron F, Cuomo P, Losco M, Mondanelli N. Single-and Double-incision Double-bundle ACL Reconstruction. Clin Orthop Relat Res. 2007; 454:108-113.
21. Muneta T, Koga H, Mochizuki T *et al*. A prospective randomized study of 4-strand semitendinosus tendon anterior cruciate ligament reconstruction comparing single-bundle and double-bundle techniques. Arthroscopy 2007; 23:618-628.
22. Jarvela T, Moisala AS, Sihvonen R, Jarvela S, Kannus P, Jarvinen M. Double-bundle anterior cruciate ligament reconstruction using hamstring autografts and bioabsorbable interference screw fixation: prospective, randomized clinical study with two-year results. Am J Sports Med. 2008; 36:290-297.
23. Gabriel MT, Wong EK, Woo SL *et al*. Distribution of in situ forces in the anterior cruciate ligament in response to rotatory loads. J Orthop Res. 2004; 22:85-89.
24. Mae T, Shino K, Matsumoto N *et al*. Force sharing between two grafts in the anatomical two-bundle ACL reconstruction. Knee Surg Sports Traumatol Arthrosc, 2006; 14:505-509.
25. Zantop T, Herbort M, Raschke MJ, Fu FH, Petersen W. The role of the anteromedial and posterolateral bundles of the anterior cruciate ligament in anterior tibial translation and internal rotation. Am J Sports Med. 2007; 35:223-227.
26. Yagi M, Wong EK, Kanamori A *et al*. Biomechanical analysis of an anatomic anterior cruciate ligament reconstruction. Am J Sports Med. 2002; 30:660-666.
27. Tashman S, Collon D, Anderson K *et al*. Abnormal rotational knee motion during running after anterior cruciate ligament reconstruction. Am J Sports Med. 2004; 32:975-983.
28. Van Eck C, Schkrohowsky JG, Working ZM, Irrgang JJ, Fu FH. Prospective analysis of failure after anatomic ACL reconstruction with allograft. Am J Sports Med. 2012; 40(4):800-807.
29. Muneta T, Koga H, Ju Y, Yagishita K, Sekiya I. Effects of different initial bundle tensioning strategies on the outcome of double-bundle ACL reconstruction: a cohort study. Sports Med Arthrosc Rehabil Ther Technol. 2011; 3:15.
30. Murray PJ, Alexander JW, Gold JE *et al*. Anatomic double-bundle anterior cruciate ligament reconstruction: kinematics and knee flexion angle-graft tension relation. Arthroscopy. 2010; 26 (2):202-213.
31. Zelle BA, Vidal AF, Brucker PU, Fu FH. Double-bundle reconstruction of the anterior cruciate ligament: anatomic and biomechanical rationale. J Am Acad Orthop Surg. 2007; 15(2):87-96.
32. Streich NA, Friedrich K, Gotterbarm T, Schmitt H. Reconstruction of the ACL with a semitendinosus tendon graft: a prospective randomized single blinded comparison of double-bundle versus single-bundle technique in male athletes. Knee Surg Sports Traumatol Arthrosc. 2008;16:232-238.