ORIGINAL ARTICLE

Prospective study of use of single bundle 6 fold graft tendon for ACL reconstruction Clinical and functional outcome with analysis of factors affecting outcome.

Parag K Sancheti[1], Atul Patil[1], Ashok K Shyam[1,2], Rahul Jaju[1]

ABSTRACT

Background: Currently double, triple and quadruple grafts are most commonly used. We hypothesize that by further increasing the folds and using a six fold tendon graft will improve outcome. Also a six fold graft will have a larger cross sectional area and will be biomechanically more strong thus improving the knee stability

Materials and Method:

A prospective cohort study was conducted between period of June 2007 to December 2009. 153 patients undergoing ACL reconstruction were screened and 78 patients fulfilling the inclusion exclusion criteria were selected. Mean age at the time of surgery was 30.62± 7.49 years (16 to 51 years). Patients were followed for a period of 18 ± 2 months (14 to 19 months). At final follow up patients were evaluated using IKDC scoring and lysholm scoring system.

Results:

Average post operative range of motion (ROM) in degree was 139.10 ± 3.58. At the mean time of 12 months follow-up, evaluation of anterior-posterior knee laxity with standard laxity test (anterior drawer and Lachmann test) show significant decreasing knee laxity postoperatively. According to IKDC grade system 70 patients were graded as A level and 8 patient as B level. Patients were evaluated with two scoring system, IKDC subjective form (2000 edition) and modified Lysholm score. Postoperative Lysholm score was improved to 88.17 ± 4.43 than preoperative score 37.39 ± 3.58, and IKDC score was improved to 87.53 ± 2.90 from preoperative score of 34.35 ± 2.54. All the patients returned to their preinjury activity level at the end of 6 to 8 months

Conclusion:

The present results show that increasing cross-sectional area of hamstring tendons by using 6-strand graft can improve knee stability and reflected by the patient's activity in the early clinical outcomes. However, there are no differences in terms of subjective assessment.

Type of study: Prospective case series

Key words: ACL reconstruction, six fold tendon graft, IKDC score and grade, Lysholm score

[1]Department of Orthopaedics, Sancheti Institute for Orthopaedics and rehabilitation, Pune Maharashtra, India.
[2]Indian Orthopaedic Research Group, Maharashtra, India

Address for correspondence: Dr Ashok K Shyam,
Sancheti Research department, Sancheti Institute for Orthopaedics and Rehabilitation, first floor, Shivaji nagar, Pune, Maharashtra, India.
Email: drashokshyam@yahoo.co.uk

Introduction:

Anterior cruciate ligament (ACL) tear is one of the major knee injuries throughout the world. [1, 2] Number of patients undergoing ACL reconstruction has risen and more favourable results have been obtained with the advances in arthroscopic surgery and developments in ACL reconstruction equipment and fixation devices [3, 4, 5]. A number of graft types have been developed in line with the developments in surgical equipment. BTB (bone-tendon-bone) and hamstring autografts are the most commonly used grafts of choice today [6]

ACL reconstruction using autografts is a method that has consistently yielded positive and effective results[7, 8]. Graft selection in an anterior cruciate ligament (ACL) reconstruction is critical [9, 10,] and [11]. Graft selection is dependent on the surgeon's expertise, surgeon's preference, tissue availability, patient activity level, presence of co morbidity, prior surgery, and patient's preference [12]. The bone-patellar tendon-bone (BPTB) and hamstring tendon autografts are the most common grafts in ACL reconstruction9. The BPTB autograft is frequently chosen because of its excellent clinical results and high level of patient satisfaction after a long term follow-up [7, 13]. Some studies suggested that a harvest of the central third of the patellar tendon might have associated donor site morbidity, such as patellofemoral osteoarthritis, patellar tendon shortening, loss of terminal extension, and patellofemoral pain. [8, 14, 15]. Recently there has been an increase in the popularity of hamstring tendons as autografts for ACL reconstructions, which can avoid harvest site morbidity [9]. In studies conducted in vitro, hamstring grafts have been proven to be as strong as the original ACL16. But some researchers have reported inferior stability in vivo compared to BTB grafts [17, 18, 19]

Problems with the use of quadruple semitendinosus and gracilis (STG) technique, are increased knee laxity, weakness in deep flexion, the development of flexion deficit and an increased risk of tunnel widening[15, 20 21,22,23,24,25,26]. Also these grafts are of smaller size than the bone patellar bone grafts and may cause wind shield wiper and bungee effects[27, 28, 29 30]. Currently Double triple and quadruple grafts are most used and we hypothesize that by further increasing the folds and using a six fold tendon graft will decrease the incidence of such complications. Also a six fold graft will have a larger cross sectional area and will be biomechanically more strong thus improving the knee stability [31, 32, 33]. We used Six fold semitendinosus and gracilis graft for ACL reconstruction and present the clinical and functional outcome in this cohort series.

MATERIALS AND METHODS:

A prospective cohort study was conducted between period of June 2007 to December 2009. Patients with ACL deficient knee were screened. Patients with ACL tear who have completed 6 weeks of conservative management and still complain of instability while walking or running, episodes of locking were selected to for ACL reconstruction. Patients with associated grade 3 and Grade 4 medial collateral ligament and lateral collateral ligament injury or avulsion fracture, previously operated cases, ACL injuries associated with fractures including avulsion fractures, associated posterior cruciate ligament or posterolateral corner injury, grade 3 and Grade 4 osteochondral defect, and patients suffering from diagnosed prior knee pathology eg, stiffness, osteoarthritis were excluded from the study. Informed consent was taken from patients that fit the inclusion / exclusion criteria and patients willing for assessment were included. This protocol was reviewed and approved by an Independent Ethics committee. 153 patients undergoing ACL reconstruction were screened and 78 patients fulfilling the inclusion exclusion criteria were selected. Out of 78 patients 71 were male patient and 7 were female. Mean age at the time of surgery was 30.62± 7.49 years (16 to 51 years). Out of 78 patients, 23 (29.49%) had slip and fall, 39 (50.0%) had twisting injury while playing, 16 (20.51%) had direct trauma. Mean injury surgery interval was 10.30± 15.10 months (9 weeks to 230 weeks). Preoperative range of motion was 131.47±13.61° (80 to 140°) (Table 1).

SURGICAL TECHNIQUE:

Standard anteromedial and anterolateral portals were taken. Arthroscopic evaluation was done to look for other injuries and to confirm ACL tear. After confirming complete ACL tear, the semitendinosus and gracilis tendons were harvested through a 5 cm longitudinal incision over the pes anserinus semitendinosus and gracilis tendon were identified and harvested with tendon stripper (Figure 1). The length of semitendinosus tendon was ranging 30±2 cm (26 to 34 cm) and gracilis tendon was 22 ±1.5 cm (17 to 28 cm). The grafts were prepared to make 6-strand with vicryl No.1 sutures, and

Demographic distribution of patients (Table 1)

Variables		6 fold
Age		30.62 ± 7.49
Sex(male/female)		71 /7
mode of injury	Slip and fall	23
	Twisting injury	39
	Direct trauma	16
Duration of injury (months)		10.30 ± 15.10
Preoperative pain	Present	40
	Absent	38
Pre operative range of motion (degree)		131.47 ± 13.61

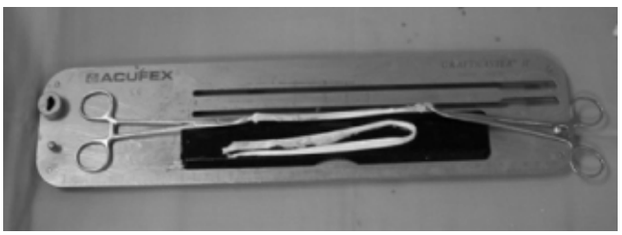


Figure1: Two fold of semitendinosus tendon and single fold of gracilis graft made.

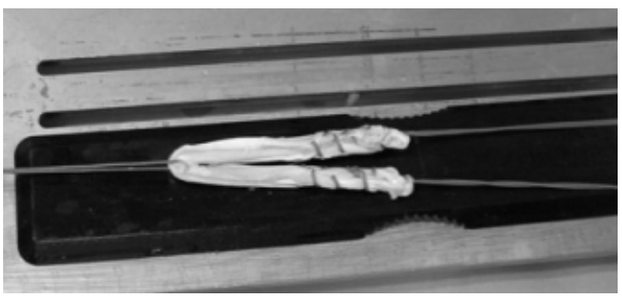


Figure 2: Graft folded in to six fold.

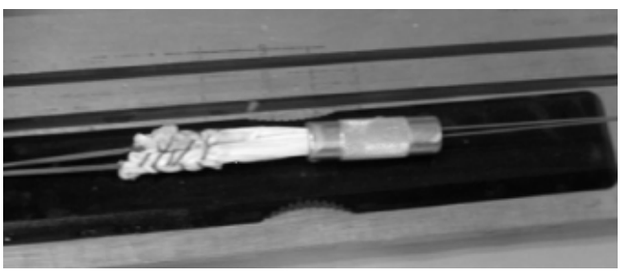


Figure 3: Final sizing of the graft.

distally with Ethibond and sizing of the graft was done (Figure2, 3). The mean length of the graft was 8.33±0.2 cm (7.8-8.6 cm) and the mean diameter was 9.73±0.5 mm (9-11 mm). Tibial entry point was taken using tip aimer 6 to 7 mm in front of PCL and tunnels were made. Tibial tunnel length was between 30 to 40 mm. After tibial entry was made, then femoral notch was cleared and prepared and resident's ridge and transverse ridge was identified for femoral entry. Femoral

entry point was just behind the resident's ridge and just inferior to transverse ridge. Femoral entry point is again confirmed through antero medial portal and then transtibial drilling was done with knee in 90 degree of flexion or otherwise tunnel was made through AM portal keeping 2 to 3 mm of bone behind. Average femoral tunnel length was 40mm±5mm (30 to 45 mm). Graft was fixed at femoral side with endobutton CL and at tibial side with interference screw (BioScrew).

Postoperative rehabilitation protocol and evaluation: Postoperatively long knee brace was given for period of 3 weeks. Partial weight bearing started on second day with the help of crutches and full weight bearing walking after 3 weeks. Gradual knee bending exercises and muscle strengthening exercises were started from day 2. Follow-up clinical and radiographic evaluations, including activity level, subjective assessment, symptoms, range of motion, laxity, and functional strength were performed every 14 days, 6 weeks, 3 months, 6 months and the end of first year. At final follow up patients were evaluated using IKDC scoring and lysholm scoring system which was done by independent data collectors at our research department[34, 35].

STATISTICAL DATA ANALYSIS:

Statistical data analysis done by using SPSS 17.0, Minitab 15.0 statistical softwares and MS-excel. To find the significance in various parameters we have used 2 independent sample t-test, paired t-test 2 sample proportion test, Wilcoxon sign rank test and Mann Whitney test. The comparison analysed at 5% level of significance.

RESULTS:

The mean length of the graft was 8.33±0.2 cm (7.8-8.6 cm) and the mean diameter was 9.73 mm (9-10 mm). Average post operative range of motion (ROM) in degree was 139.10 ± 3.58. Patients were followed for a period of 12 ± 2 months (11 to 19 months); no patients were loss to follow up. At the mean time of 12 months follow-up, evaluation of anterior-posterior knee laxity with standard laxity test (anterior drawer and lachman test) show significant decreasing knee laxity postoperatively. Postoperatively out of 78 patients lachman test and anterior drawer test was positive (grade 1) in only 3 patients and 1 patients respectively (Figure 4). Preoperatively pivot shift test was positive in 70 pts and negative in 8, postoperatively only 2 pts had positive and 76 had negative pivot shift test (Figure 6). According to IKDC grade system 70 patients were graded as A level and 8 patient as B level (Figure 7)

PATIENT SUBJECTIVE ASSESSMENT:

Patients were evaluated with two scoring system, IKDC35 subjective form (2000 edition) and Modified Lysholm score[34]. Postoperative Lysholm score (Figure 8) was improved to 88.17 ± 4.43 than preoperative score 37.39 ± 3.58, and IKDC score (Figure 9) was improved to 87.53 ± 2.90 from

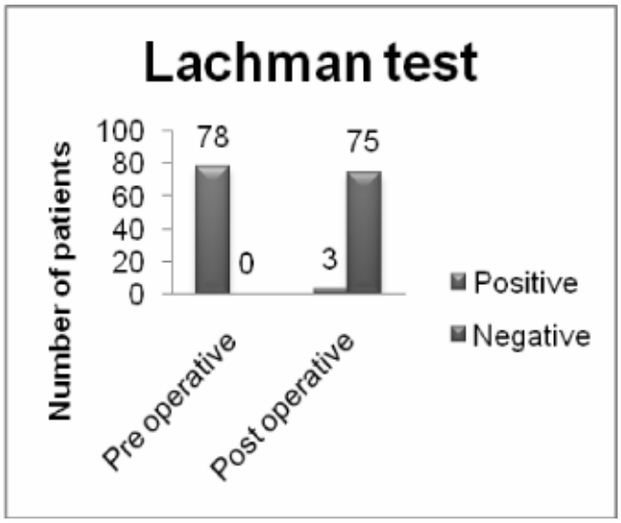
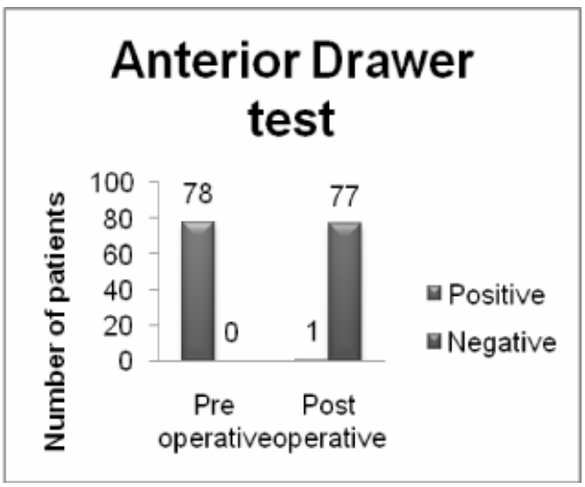


Figure 4



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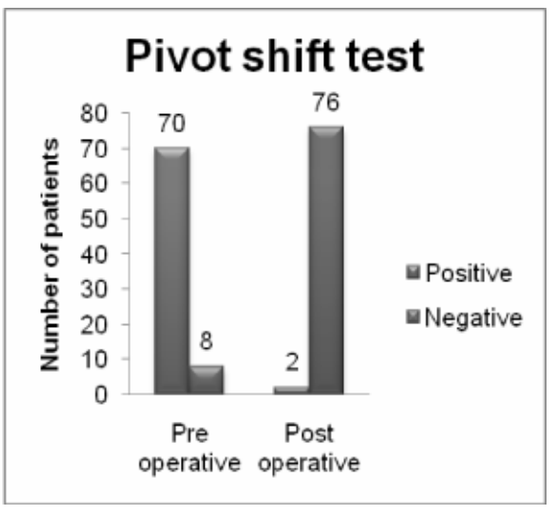
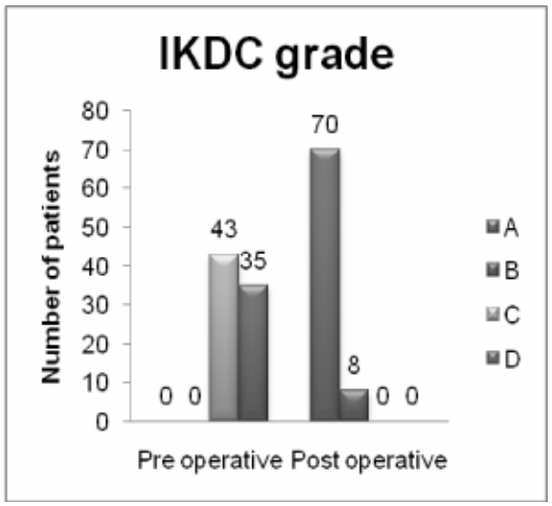


Figure 6



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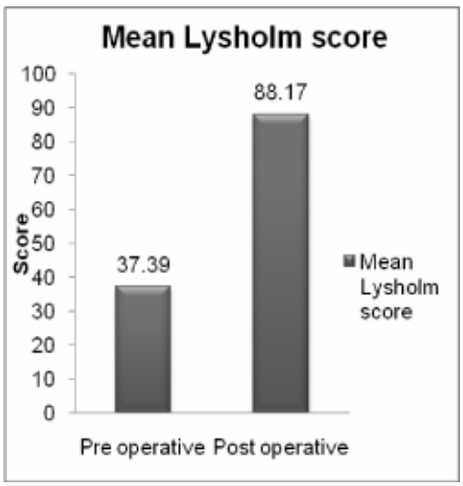

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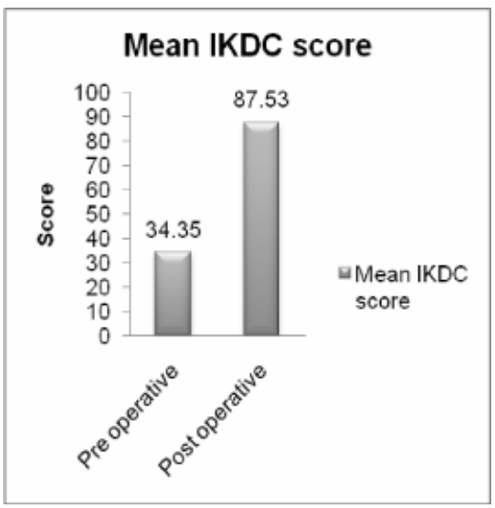

Figure 9

preoperative score of 34.35 ± 2.54. Similarly pain in terms of VAS was also improved to 2.55 ± 0.76 from preoperative score of 4.82 ± 1.85. Only 1 patient reported anterior knee pain. All the patients returned to their preinjury activity level at the end of 6 to 8 months (Table 2)

Table showing pre op and post operative results. (Table 2)

Variables		Preoperative	Postoperative	Statistically significant (Y/N)
Anterior drawer test	Positive	78	1	Y(p-value<0.001)
	Negative	0	77	
Lachman test	Positive	78	3	Y(p-value<0.001)
	Negative	0	75	
Pivot shift test	Positive	70	2	Y(p-value<0.001)
	Negative	8	76	
Range of motion (ROM) (degree)		131.47 ± 13.61	139.10 ± 3.58	Y(p-value <0.001)
Lysholm score		37.39 ± 3.58	88.17 ± 4.43	Y(p-value <0.001)
IKDC score		34.35 ± 2.54	87.53 ± 2.90	Y(p-value <0.001)
IKDC grade	Grade A	0	70	Y(p-value <0.001)
	Grade B	0	8	
	Grade C	43	0	
	Grade D	35	0	
VAS		4.82 ± 1.85	2.55 ± 0.76	Y(p-value <0.001)
Complication	Anterior knee pain	No	1(1.28%)	

DISCUSSION:

During the past decade, there has been an increased use of hamstring grafts with multiple strands to reconstruct the anterior cruciate ligament [18, 16, 36, 37, 38]. This trend is believed to be related to improved fixation techniques and the perception that hamstring grafts are associated with less morbidity than patellar ligament grafts [18, 16, 36, 37, 38, 26, 39].

The results of ACL reconstruction depend on various factors like preoperative activity level of the patient, muscle strength, associated injuries, and postoperative rehabilitation. Variations in operative techniques may also affect the outcome, like use of different graft, single or double bundle reconstruction and graft size [40]. Single bundle ACL reconstruction using tendon grafts has shown to have good results by many investigators [41, 42]. This study was conducted to observe the outcomes using two different grafting techniques namely 4 fold and 6 fold grafts.

Noyes et al[43] reported that 14mm BPTB graft represents 168% of ACL strength so, 9 or 10 mm BPTB graft would represent approximately 120%of ACL strength. He also reported ST represent 70 % of ACL strength so, doubling the graft will

produce 140% of ACL strength and a quadrupled construct exceed around 250% of ACL strength and six fold will definitely produce more than 300% of ACL strength. Thus four strand and six strand construct are stronger than any of the 10 mm BPTB graft and so six fold graft stronger than four fold graft[44].

Thickness of the graft also plays an important role in post operative stability of the knee. Normally femoral attachment of ACL is of 11 to 24 mm in diameter and tibial attachment is around 11 mm (8 to 12 mm) [44]. Generally a bone patellar bone graft is of 10 mm diameter and 40 mm2 cross sectional area and occupies 90% area of the ACL foot print. A single bundle four fold Semitendinosus tendon graft is of diameter 8 to 9 mm and 60 to 70 mm2 cross sectional area occupies 1.5 times of ACL foot print. Thus six fold graft of diameter 10 mm (average 9 to 11 mm) will have more cross sectional area and will occupy more surface area of ACL foot print and also has more surface area for tendon to bone healing with less chance of tunnel widening.

The average cross sectional quadruple hamstring graft measures 7-9 mm in diameter and six fold graft measures 9 to 10 mm in diameter

Cross Sectional Area of Grafts (Table 3)59

Hamstring	Circular graft. Tunnel Diameter Area.	6mm = 28 mm^2 7mm = 38 mm^2 9mm = 64 mm^2 10mm = 79 mm^2
Patellar	Rectangular graft. Rectangle area.	10mm X 3mm = 30 mm^2

Since the cross sectoral area occupied by 4 fold and BPTB graft is a fraction of that occupied by the original ACL, instability can be a problem stability. To counter this few technical principles are to be adhered. Finding and inserting an isometric graft may decrease this problem. Also proper tensioning of the graft is essential for this. Increasing the graft thickness is another way of achieving the similar result.

In our study average diameter of 6 fold graft was 9.73 mm. This should be able to achieve better stability. Theoretically, ultimate load to failure of the 6-strand hamstring tendons should be higher corresponding to the cross-sectional area. Similarly study conducted by Laoruengthana [45] et al showed average 6 fold diameter was 9.54(8-11 mm), and Aglietti [20] et al showed that average 4 fold diameter was 8 mm. Similarly study conducted by Tohyama H[37] demonstrated that anterior cruciate ligament grafts fashioned using multiple-strand (six and four strand) combinations of the semitendinosus and gracilis tendons result in a cross-sectional area in comparison to the 10 mm bone-patellar tendon- bone graft, which is an important finding since cross-sectional area reflects the intra-articular volume of collagenous tissue.

There is no loss of hamstring strength in our series when it is used as a graft material which corresponds to study conducted by Lipscomb AB[46] which demonstrated that confirms that there is no significant loss of hamstring strength occurred when the semitendinosus and gracilis tendons were used to construct the ACL. Similarly study conducted by Cross MJ [47]and et al demonstrated apparent regeneration of the tendons of the semitendinosus and gracilis muscles after their use for anterior cruciate ligament reconstruction. Also the results demonstrated that these tendons appear to regrow and are probably functional.

In our series, post operatively 1.28 % had positive anterior drawer test, 3.84 % had lachman test, and 2.56 % had positive pivot shift test respectively. Prodromos Chadwick [48] in his study showed Average KT-1000 side-to-side difference was 0.44mm for 5 strand hamstring tendon vs. 1.0mm for 4 strand hamstring tendon ($p = 0.01$). Also demonstrated that reconstructed knee laxity increase of ≤1mm versus the normal knee was found in 89% of 5 strand hamstring tendon vs. 66% of 4 strand hamstring tendon ($p = 0.03$); of 2-3mm in 11% 5 strand hamstring tendon vs. 31% 4HS; of 4mm in 0% 5 strand hamstring tendon vs. 3% 4 strand hamstring tendon; and of >4mm in 0% 5 strand hamstring tendon and 4 strand hamstring tendon. 5 strand hamstring tendon ACL reconstruction had higher stability than a high stability 4 strand hamstring tendon. Similarly study conducted by Chen et al[40] demonstrated that 5.1% exhibited grade 2 or higher ligament laxity with the anterior drawer test, and 6.1% had a positive pivot shift in four fold hamstring group. Also Heijne et al[49] showed that Hamstring graft led to a larger laxity, 2.4 mm compared with patellar tendon graft, 1 year and 2.5 mm and 1.5 mm, respectively, at 2 years ($P = 0.05$). Also 50 % patient had + (glide) and 20 % had ++ (clunk) pivot shift test at 1 year and 44.5 %had + and 24% had ++ at 2 years follow up.

The failure load of an evenly tensioned four-strand hamstring tendon graft has been reported to be about 4,090 N[50]. This exceeds that reported for a 10-mm patellar tendon graft (2,977 N)[51] and an intact ACL (2,160 N) [52]. The mean diameter of 6-strand hamstring tendons in the present study is 9.54 mm, which is larger than 8 mm of 4-strand hamstring tendon [53]. Theoretically, ultimate load to failure of the 6-strand hamstring tendons should be higher corresponding to the cross-sectional area.

From a biologic standpoint, it is well accepted that healing of the tendon to bone is more difficult to achieve and requires more time (usually eight to twelve weeks) than does healing of bone to bone (usually four to six weeks) [54,55,56,57,58]. The factors that may determine the strength and stiffness of the tendon-fixation device-bone complex after implantation are the tendon graft-tunnel interface and the fixation device itself. A recent study in dogs has demonstrated that pullout strength was enhanced by increasing the length and the press-fit of the tendon within the tunnel. With doubling the length of the

Tabel 4

Study	Sample size	Anterior Drawer test	Lachman test	Pivot shift test	lysholm score	IKDC score	IKDC grade
Matjaz Sajovic (2008)[60]	28	-	Grade1-5pts; Grade 2-1 pt	Grade1-4pts; Grade 2- 1pt	92 (62-100)	-	A-14; B-13; C-01.
Gauti Laxdal (2007)[61]	78	-	Grade 1- 27 pts; Grade2- 2 pts	-	90 (41–100)	-	A-15; B-27; C-29; D-07.
Mattias Ahlden (2009)[62]	25	-	Grade 1- 6pts; Grade 2- 15 pts; Grade 3 - 2 pts	-	89 (15-100)	-	-
Jon Olav Drogset (2010)[63]	57	-	Grade 2- 3 pts	Grade 1- 5pts	91±10.3 (12-100)	-	-
Our study	78	1 (1.28%)	Grade 1- 3pts (3.84%)	Grade1- 2pts (2.56%)	88.17 ± 4.43	87.53 ± 2.90	A-70; B-08

tunnel, there was a 60% gain in terms of load to failure [52, 55]. Fixation is also influenced by the total contact area of thread, which is determined by the outer diameter of the thread and especially the length of the screw. Therefore, our patients in the 6-strand hamstring group, the authors increased the tendon-bone tunnel interface with the larger diameter graft compared to 4-strand hamstring tendon.

Limitation of study: All clinical test of stability were performed by investigators and objective study using an arthrometer is not done. Patients were consecutively selected and no randomization was done. Follow up is short with at least a two year follow up needed for comment on knee osteoarthritis.

In conclusion, the present results show that increasing cross-sectional area of hamstring tendons by using 6-strand graft can improve knee stability and reflected by the patient's activity in the early clinical outcomes. Anterior cruciate ligament reconstruction with hamstring tendons have less donor-site morbidity resulting in less difficulty in kneeling, which is more compatible to Asian life-style. However, there are no differences in terms of subjective assessment.

REFERENCES:

1 Johnson RJ: The anterior cruciate ligament: A dilemma in sports medicine. Int J Sports Med 3: 71–79, 1982

2. Miyasaka KC, Daniel DM, Stone ML, et al: The incidence of knee ligament injuries in the general population. Am J Knee Surg 4: 3–8, 1991.
3. Fauno P, Kaalund S (2005) Tunnel widening after hamstring anterior cruciate ligament reconstruction is influenced by the type of graft fixation used: a prospective randomized study. Arthroscopy 21:1337–1341
4. Lee Y, Kim SK, Park JH, Park JW, Wang JH, Jung YB, Ahn JH (2007) Double-bundle anterior cruciate ligament reconstruction using two different suspensory femoral fixation: a technical note. Knee Surg Sports Traumatol Arthrosc 15:1023–1027
5. Steiner ME, Hecker AT, Brown CH Jr, Hayes WC (1994) Anterior cruciate ligament graft fixation. Comparison of hamstring and patellar tendon grafts. Am J Sports Med 22:240–246
6. Aglietti P, Buzzi R, Menchetti PM, Giron F. Arthroscopically assisted semitendinosus and gracilis tendon graft in reconstruction for acute anterior cruciate ligament injuries in athletes. Am J Sports Med 1996; 24: 726-31.
7. Salmon LJ, Russell VJ, Refshauge K, et al. Long-term outcome of endoscopic anterior cruciate ligament reconstruction with patellar tendon autograft: minimum 13-year review. Am J Sports Med. 2006; 34(5):721-32.
8. Pinczewski LA, Lyman J, Salmon LJ, Russell VJ, Roe J, Linklater J. A 10-year comparison of anterior cruciate ligament reconstructions with hamstring tendon and patellar tendon autograft: a controlled, prospective trial. Am J Sports Med. 2007 Apr; 35(4):564-74.
9. Sherman OH, Banffy MB. Anterior cruciate ligament reconstruction: which graft is best? Arthroscopy. 2004; 20(9):974-80.
10. Eriksson E. Auto- or allograft for ACL-reconstruction? Knee Surgery Sports Traumatology Arthroscopy. 2007; 15(6):689.

11. Barber FA. Should allografts be used for routine anterior cruciate ligament reconstructions? Arthroscopy.2003: 19(4): 421.
12. West RV, Harner CD. Graft selection in anterior cruciate ligament reconstruction. J Am Acad Orthop Surg. 2005; 13(3):197-207.
13. Lebel B, Hulet C, Galaud B, Burdin G, Locker B, Vielpeau C. Arthroscopic reconstruction of the anterior cruciate ligament using bone-patellar tendon-bone autograft: a minimum 10-year follow-up. Am J Sports Med. 2008 Jul; 36(7):1275-82.
14. Mauro CS, Irrgang JJ, Williams BA, Harner CD. Loss of extension following anterior cruciate ligament reconstruction: analysis of incidence and aetiology using IKDC criteria.Arthroscopy. 2008; 24(2):146-53.
15. Breitfuss H, Frohlich R, Povacz P, Resch H, Wicker A. The tendon defect after anterior cruciate ligament reconstruction using the mid third patellar tendon: a problem for the patellofemoral joint? Knee Surgery Sports Traumatolgy Arthroscopy. 1996;3(4):194-8.
16. Brown, C. H., Jr.; Steiner, M. E.; and Carson, E. W.: The use of hamstring tendons for anterior cruciate ligament reconstruction. Clin. Sports Med., 12: 723-756, 1993.
17. Goldblatt JP, Fitzsimmons SE, Balk E, and Richmond JC: Reconstruction of the anterior cruciate ligament: meta-analysis of patellar tendon versus hamstring tendon autograft. Arthroscopy 2005;21: 791–803.
18. Aglietti P, Buzzi R, Zaccherotti G, De Biase P. Patellar tendon versus doubled semitendinosus and gracilis tendons for anterior cruciate ligament reconstruction. Am J Sports Med. 1994 Mar-Apr; 22(2):211-7; discussion 217-8.
19. Aune AK, Holm I, Risberg MA, Jensen HK, Steen H. Fourstrand hamstring tendon autograft compared with patellar tendon-bone autograft for anterior cruciate ligament reconstruction: a randomized study with two-year follow-up. Am J Sports Med. 2001;29 (6):722-8.
20. Aglietti P, Giron F, Buzzi R, Biddau F, Sasso F. Anterior cruciate ligament reconstruction: bone-patellar tendon-bone compared with double semitendinosus and gracilis tendon grafts. A prospective, randomized clinical trial. J Bone Joint Surgery Am. 2004 Oct; 86-A (10):2143-55.
21. Kartus J, Movin T, Karlsson J. Donor-site morbidity and anterior knee problems after anterior cruciate ligament reconstruction using autografts. Arthroscopy.2001 Nov-Dec; 17(9):971-80.
22. Yasuda K, Tsujino J, Ohkoshi Y, Tanabe Y, Kaneda K. Graft site morbidity with autogenous semitendinosus and gracilis tendons. Am J Sports Med. 1995 Nov-Dec; 23(6):706-14.
23. Fahey M, Indelicato PA. Bone tunnel enlargement after anterior Cruciate ligament replacement. Am J Sports Med. 1994 May-Jun; 22(3):410-4.
24. Christen, B., and Jakob, R. P.: Fractures associated with patellar ligament grafts in cruciate ligament surgery. J. Bone and Joint Surg., 74-B (4): 617-619, 1992.
25. Otero AL, Hutcheson L. A comparison of the doubled semitendinosus/gracilis and central third of the patellar tendon autografts in arthroscopic anterior cruciate ligament reconstruction. Arthroscopy. 1993;9(2):143-8.
26. Sachs, R. A.; Daniel, D. M.; Stone, M. L.; and Garfein, R. F.: Patellofemoral problems after anterior cruciate ligament reconstruction. Am. J. Sports Med., 17: 760-765, 1989.
27. Höher J, Möller HD, Fu FH. Bone tunnel enlargement after anterior cruciate ligament reconstruction: fact or fiction. Knee Surg Sports Traumatol Arthrosc. 1998;6:231-240.
28. Höher J, Withrow JD, Livesay GA, et al. Early stress causes grafttunnel motion in hamstring grafts. Trans Orthop Res Soc. 1998;23:44.
29. Insalata JC, Klatt B, Fu FH, et al. Tunnel expansion following anterior cruciate ligament reconstruction: a comparison of hamstring and patellar tendon autografts. Knee Surg Sports Traumatol Arthrosc. 1997;5:234-238.
30. Campbell's text book of operative orthopaedics; eleventh edition, volume 3 page no. 2526
31. Markolf KL, Burchfield DM, Shapiro MM, Cha CW, Finerman GA, Slauterbeck JL. Biomechanical consequences of replacement of the anterior cruciate ligament with a patellar ligament allograft. Part II: forces in the graft compared with forces in the intact ligament. J Bone Joint Surg Am 1996; 78: 1728-34.
32. Hamner DL, Brown CH Jr, Steiner ME, Hecker AT, Hayes WC. Hamstring tendon grafts for reconstruction of the anterior cruciate ligament: biomechanical evaluation of the use of multiple strands and tensioning techniques. J Bone Joint Surgery Am 1999; 81: 549-57.
33. Wilson TW, Zafuta MP, Zobitz M. A biomechanical analysis of matched bone patellar tendon-bone and double-looped semitendinosus and gracilis tendon grafts. Am J Sports Med 1999; 27: 202-7.
34. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. Clinical Orthopaedics. 1985; 198:43-9.
35. Hefti F, Muller W, Jakob RP, Staubli HU. Evaluation of knee ligament injuries with the IKDC form. Knee Surgery Sports Traumatolgy Arthroscopy. 1993; 1: 226-34.
36. Karlson, J. A.; Steiner, M. E.; Brown, C. H.; and Johnston, J.: Anterior cruciate ligament reconstruction using gracilis and semitendinosus tendons. Am. J. Sports Med., 22: 659-666, 1994.
37. McKernan, D. J., and Paulos, L. E.: Graft selection. In Knee Surgery, pp. 667-678. Edited by F. H. Fu, C. D. Harner, and K. G. Vince. Baltimore, Williams and Wilkins, 1994.
38. Marder RA, Raskind JR, Carroll M. Prospective evaluation of arthroscopically assisted anterior cruciate ligament reconstruction. Patellar tendon versus semitendinosus and gracilis tendons. Am J Sports Med. 1991 Sep-Oct;19(5):478-84.
39. Steiner, M. E.; Hecker, A. T.; Brown, C. H., Jr.; and Hayes, W. C.: Anterior cruciate ligament graft fixation. Comparison of hamstring and patellar tendon grafts. Am. J. Sports Med. 22: 240-247, 1994.
40. Chen CH, Chang CH, Su CI, Wang KC, Liu HT, Yu CM, Wong CB, Wang IC. Arthroscopic single-bundle anterior cruciate ligament reconstruction with periosteum-enveloping hamstring tendon graft: clinical outcome at 2 to 7 years. Arthroscopy. 2010 Jul; 26(7):907-17.
41. Drogset JO, Strand T, Uppheim G, Odegard B, Boe A, Grontvedt T. Autologous patellar tendon and quadrupled hamstring grafts in anterior cruciate ligament reconstruction: a prospective randomized multicenter review of different fixation methods. Knee Surg Sports Traumatol Arthrosc. 2010 Aug;18(8):1085-93.
42. Barenius B, Nordlander M, Ponzer S, Tidermark J, Eriksson K. Quality of life and clinical outcome after anterior cruciate ligament reconstruction using patellar tendon graft or quadrupled semitendinosus graft: an 8-year follow-up of a randomized controlled trial. Am J Sports Med. 2010 Aug; 38(8):1533-41.
43. Noyes FR, Butler DL, Grood ES, et al. Biochemical analysis of human ligament graft used in knee ligament repairs and reconstruction. J Bone Joint Surg Am 1984; 66; 344-52
44. The orthopaedic clinics of North America (OCNA); Anterior Cruciate Ligament Reconstruction Part I (page 605-606) and Part II (page 10). 2002 & 2003
45. Laoruengthana A, Pattayakorn S, Chotanaputhi T, Kosiyatrakul A. Clinical comparison between six-strand hamstring tendon and patellar tendon autograft in arthroscopic anterior cruciate ligament reconstruction: a prospective, randomized clinical trial. J Med Assoc Thai. 2009 Apr; 92(4):491-7.
46. Lipscomb AB, Johnston RK, Snyder RB, Warburton MJ, Gilbert PP. Evaluation of hamstring strength following use of semitendinosus and gracilis tendons to reconstruct the anterior cruciate ligament. Am J Sports Med. 1982 Nov-Dec; 10(6):340-2
47. Cross MJ, Roger G, Kujawa P, Anderson IF. Regeneration of the semitendinosus and gracilis tendons following their transection for repair of the anterior cruciate ligament. Am J Sports Med. 1992 Mar-Apr; 20(2):221-3.

48. Prodromos, Chadwick M.D.; Joyce, Brian B.A, Five-Strand Hamstring Anterior Cruciate Ligament Reconstruction: Presentation of a New Technique with Better Stability at 7 to 9-Year Follow Up Than 4 Strand.Techniques in Orthopaedics: September 2005 - Volume 20 - Issue 3 - pp 192-193
49. Heijne A, Werner S. A 2-year follow-up of rehabilitation after ACL reconstruction using patellar tendon or hamstring tendon grafts: a prospective randomised outcome study. Knee Surg Sports Traumatol Arthrosc. 2010 Jun;18(6):805-13.
50. Hamner DL, Brown CH Jr, Steiner ME, Hecker AT, Hayes WC. Hamstring tendon grafts for reconstruction of the anterior cruciate ligament: biomechanical evaluation of the use of multiple strands and tensioning techniques. J Bone Joint Surg Am 1999; 81: 549-57.
51 Markolf KL, Burchfield DM, Shapiro MM, Cha CW, Finerman GA, Slauterbeck JL. Biomechanical consequences of replacement of the anterior cruciate ligament with a patellar ligament allograft. Part II: forces in the graft compared with forces in the intact ligament. J Bone Joint Surg Am 1996; 78: 1728-34.
52. Noyes FR, Butler DL, Grood ES, Zernicke RF, Hefzy MS. Biomechanical analysis of human ligament grafts used in knee-ligament repairs and reconstructions. J Bone Joint Surg Am 1984; 66: 344-52.
53. Aglietti P, Giron F, Buzzi R, Biddau F, Sasso F. Anterior cruciate ligament reconstruction: bonepatellar tendon-bone compared with double semitendinosus and gracilis tendon grafts. A prospective, randomized clinical trial. J Bone Joint Surg Am 2004; 86-A: 2143-55.
54. Rodeo SA, Arnoczky SP, Torzilli PA, Hidaka C, Warren RF. Tendon-healing in a bone tunnel. A biomechanical and histological study in the dog. J Bone Joint Surg Am 1993; 75: 1795-803.
55. Greis PE, Burks RT, Bachus K, Luker MG. The influence of tendon length and fit on the strength of a tendon-bone tunnel complex. A biomechanical and histologic study in the dog. Am J Sports Med 2001; 29: 493-7.
56. Giurea M, Zorilla P, Amis AA, Aichroth P. Comparative pull-out and cyclic-loading strength tests of anchorage of hamstring tendon grafts in anterior cruciate ligament reconstruction. Am J Sports Med 1999; 27: 621-5.
57. Pinczewski LA, Clingeleffer AJ, Otto DD, Bonar SF, Corry IS. Integration of hamstring tendon graft with bone in reconstruction of the anterior cruciate ligament. Arthroscopy 1997; 13: 641-3.
58. Robert H, Es-Sayeh J, Heymann D, Passuti N, Eloit S, Vaneenoge E. Hamstring insertion site healing after anterior cruciate ligament reconstruction in patients with symptomatic hardware or repeat rupture: a histologic study in 12 patients. Arthroscopy 2003; 19: 948-54.
59. Proceedings from the 16th Annual Fall Course of the arthroscopic association of North America (AANA) – Nov 1997
60. Sajovic M, Strahovnik A, Komadina R, Dernovsek MZ. The effect of graft choice on functional outcome in anterior cruciate ligament reconstruction. Int Orthop. 2008 Aug;32(4):473-8. Epub 2007 Mar 13. Retraction in: Int Orthop. 2009 Oct;33(5):1471
61. Laxdal G, Sernert N, Ejerhed L, Karlsson J, Kartus JT. A prospective comparison of bone-patellar tendon-bone and hamstring tendon grafts for anterior cruciate ligament reconstruction in male patients. Knee Surg Sports Traumatol Arthrosc. 2007 Feb;15(2):115-25.
62. Ahldén M, Kartus J, Ejerhed L, Karlsson J, Sernert N. Knee laxity measurements after anterior cruciate ligament reconstruction, using either bone-patellar-tendon-bone or hamstring tendon autografts, with special emphasis on comparison over time. Knee Surg Sports Traumatol Arthrosc. 2009 Sep;17(9):1117-24.
63. Drogset JO, Strand T, Uppheim G, Odegård B, Bøe A, Grøntvedt T. Autologous patellar tendon and quadrupled hamstring grafts in anterior cruciate ligament reconstruction: a prospective randomized multicenter review of different fixation methods. Knee Surg Sports Traumatol Arthrosc. 2010 Aug;18(8):1085-93.

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