A Cadaver Study of the Structures and Positions of the Anterior Cruciate Ligament in Humans

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Date of Submission: May 17, 2012

Date of Acceptance: Sep 09, 2012

How to cite this article: Moghaddam AB, Torkaman A. A cadaver study of the structures and positions of the anterior cruciate ligament in humans. Int J Prev Med 2013; 4 (Suppl 1):S85-91.

ABSTRACT

Background: The anterior cruciate ligament (ACL) is one of the major knee structures. It consists of anteromedial bundle (AMB) and posterolateral bundle (PLB). Rupture of the ACL is one of the most prevalent traumas among athletes. There are two ways to reconstruct the rupture; Single–bundle and double–bundle (DB) reconstruction. Precise study on bundles anatomy, the exact number of attachments and knee flexion angle with an appropriate place of bundles and also choosing the best angle for the grafts are so important in successful reconstructing of the bundles. In this research, the general attempt was to assess anatomy and the act of the ACL is and bundles in Iranian population.

Methods: We obtained twelve fresh-frozen cadaver knees (two females, ten males). The average age of them was 30 years; they were mostly between 27 and 34 years old. Initially, skin, muscles, and patellar and articular capsule were removed. Then, bundle attachments, knee movements in flexion angle, extension and stiffness of both bundles were evaluated. Thereafter, on 0, 30, 60, 90, 120, and 180° angle knee flexion the bundles degree stiffness evaluated in different directions. During the process, to measure bundles size, digital camera for photography, oblique for measuring the angles, and micrometer were utilized. From all next of kin written consent testimonial form was obtained.

Results: In all knees, two bundles were identified as distinct. AMB attachment location in the anterior region observed as semi-lunate and in one case, it was rounded**.** In all cases, two bundles of full knee extension were paralleled, and the AMB was anterior to the PLB; with increasing flexion angle, femoral attachment location of AMB was in back direction and femoral attachment location of PLB moved toward the front direction. Two bundles were in the most amount of cross state, which the angle was 90°. From the stiffness point of view in all 6 samples, the PLB had the most tension in extension state, and the AMB had the most tension in 120° flexion.

Conclusion: In the current study, we realized that the ACL is a DB ligament in Iranian population. The AMB in full extension has the least stiffness and in 90° flexion has the most; the PLB also in full knee extension and in 160° flexion has the most and least stiffness, respectively.

Keywords: Anterior cruciate ligament, positions, athletes

Original Article

INTRODUCTION

Anterior cruciate ligament (ACL) is one of the frequent sites of injury in sport,[1] which have been managed by surgical procedure preferably.[2-4] The purpose of ACL reconstruction techniques is the renovation of native anatomy and function of ligament.[5,6] Single bundle ACL reconstruction is one of the established surgical methods, although, 30% of patients have not returned to normal level of function[2] and osteoarthritic changes were developed in 60-90% of them in long-term follow-up,[7-9] which increase the attentions toward double bundle (DB) reconstruction method. A technique resulted in more native anatomy.[10] It was shown that in DB ACL reconstruction, the rotational instability of the knee was restricted by posterolateral bundle (PLB).[11-14] Different factors determine outcome of DB ACL reconstruction such as graft materials, graft fixation, initial graft tensioning, and especially the tibial and femoral tunnel positions of both the anteromedial bundle (AMB) and PLB.[15] As a result, complete information about the normal arrangement of ligament is critical for appropriate anatomic tunnel placement for the two bundles.[16] The normal anatomy or ACL have been studied during recent years, although, there are some controversies among them, especially number of bundles. While Odensten and Gillquist described one bundle,[17,18] Girgis *et al*. and Arnoczky presented two bundles,[19-21] the anteromedial and the PLBs. The variation of biomechanic of ACL in different studies can be related to factors such as age,[22] gender,[23,24] ethical background[25] and so on. So, anatomical knowledge about normal ACL ligament is necessary in our population to increase restoration of normal function during operation.

In order to, address this we described the anatomy of bundles, the femoral and tibial attachment sites, anatomical position as well as the tension pattern of each bundle in cadaver.

METHODS

We obtained twelve fresh-frozen cadaver knees (two females, ten males). The average age of them was 30 years; they were mostly between 27 and 34 years old. ACL torn knees, history of previous surgery, injury, and degenerative disease to the knees were excluded from the study. There were six left and six right knees. Ethical approval of this study was obtained from the Ethics Committee of Tehran University of Medical Science. Skin, muscles, patella, and the joint capsule were observed and documents were recorded then except the ACL, PCL, medial, and lateral meniscus and the collateral ligaments, all soft tissues were removed. Identifying the AM and PL bundle were done according to tension pattern of them during joint motion, AMB was tighten during flexion, and the PLB was tighten during extension. The two bundles were remarked by wrapping a string. After that the PCL ligament was excised and to expose the femoral attachment of the ACL the medial femoral condyle was removed with a spots Tension pattern and anatomical position change of each bundle were evaluated at 0, 30, 60, 90, 120, and 180°of knee flexion.

Following that, femoral and tibial attachment sites were marked with ink. After removal of the AM and PL bundle, the center of the femoral insertion site of each bundle was also marked. The anatomical position of femoral and tibial insertion site of two bundles was described three planes (sagital, frontal, transvers). We determined the angle formed between a horizontal line and a line connecting the center of the femoral insertion of each bundle at 90 knee flexion and full extension. Then, the length and width of the length of the ACL tibial insertion was measured as the distance between the anterior and the posterior edge of the tibial insertion and the width was measured at its widest part between tibial condyle [Figure 1]. The length and the width of the insertion on the femur were measured in maximal flexion of the knee joint. The length of the femoral insertion was measured from the most proximal to the most distal point of ACL insertion in the direction of posterior femoral cortex [Figure 2]. The width of the femoral insertion was measured as the greatest perpendicular distance between the line of femoral insertion length and the beginning of the joint surface at the point of outer femoral condyle's greatest convexity. Attachments were measured by digital photographs or micrometer. The length of the AMB of the ACL was measured from the anterior edge of the tibial insertion to the medial part of femoral insertion along frontal portion of the AMB. The length of PLB was measured from the posterior edge of tibial insertion to the lateral

part of femoral insertion, along back portion of the PLB were measured by a standard micrometer. The ranges along with the mean of our measurements were reported.

RESULTS

In all cadavers we verified two separate anatomical bundles in ACL ligament, an observation in accordance to some previous studies. The femoral insertion area of the AM bundle was ovally shape at the posterior-inferior part of the inner surface of the lateral condyle with attachment area of 63.83 mm^2 [Figure 3].

The PL bundle was located in anterior aspect of AM attachment site with semilunar shape except one cadaver with round shape attachment. The insertion site of PL bundle was about 49 mm^2. The tibial insertion area of the AM bundle with semilunar shape in ten cadavers and oval in two cadavers was originated from anteromedian of tibial plateau and medial to the tibial spine with attachment area of 63.87 mm^2. The PL bundle area was also located at the anteromedian of tibial plateau but lateral to the tibial spine with attachment site of 51 mm^2. In fact, the tibial spine separated the tibial origin of these two bundles [Figure 4]. The length and width of AM and PL bundles were reported in Table 1.

The anatomical position change of two bundles was evaluated from full extension to 120° of knee flexion [Table 2]. AM and PL was parallel in the sagittal plane with full extended knee and the AM bundle was located in the anterior proximal aspect of the PL bundle, however, the bundles twisted around each other with increasing degrees of knee

Figure 1: Measurement the width of the PL bundle on tibial insertion

Figure 2: measurement the lenght of the AM bundle

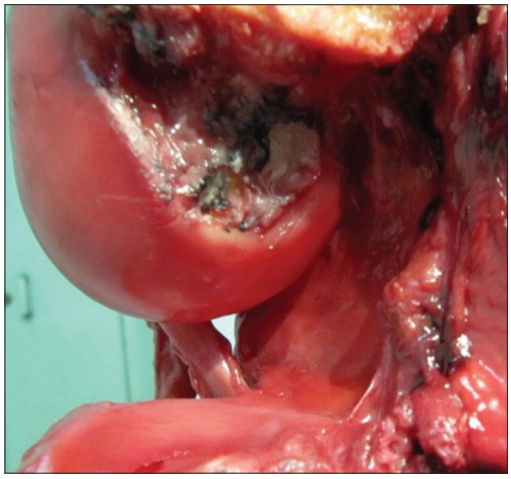

Figure 3: The femoral insertion area of the AM bundle

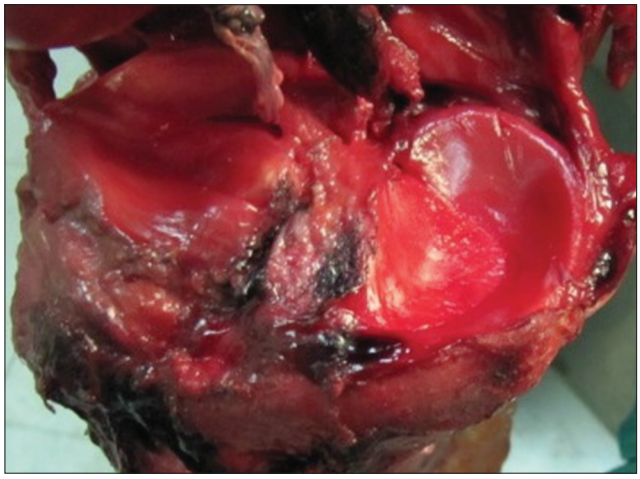

Figure 4: the tibial origin of AL and PL bundles

Table 1: Anteromedial bundle size

Width (mm)	Length (mm)	Side	Age	Sex	row
6	38	Right	33	Male	1
8	40	Right	32	Male	2
6	35	Left	28	Female	3
8	37	Right	36	Male	4
7	38	Left	34	Male	5
6	34	Right	27	Female	6
7	40	Right	24	Male	7
8	38	Left	41	Male	8
6	38	Left	34	Male	9
7	39	Right	28	Male	10
8	41	Left	30	Male	11
5	36	Left	27	Male	12
8-5	41-36	Range			
6/66	66/38	Average			

Table 2: Postero lateral bundle size

Width (mm)	Length (mm)	Side	Age	Sex	row
4	25	Right	33	Male	1
5	26	Right	32	Male	2
4	24	Left	28	Female	3
5	26	Right	36	Male	4
5	27	Left	34	Male	5
4	26	Right	27	Female	6
4	29	Right	24	Male	7
5	27	Left	41	Male	8
5	25	Left	34	Male	9
5	28	Right	28	Male	10
4	28	Left	30	Male	11
4	26	Left	27	Male	12
4-5	23-26	Range			
4.66	24.5	Average			

flexion and femoral insertion site of AM and PL bundles were displaced to posterior and anterior respectively [Figures 5 and 6].

Tension pattern observation of the AM and PL bundle were revealed AM bundle was tighten as the knee was flexed toward 120, and PL bundle was tighten at full extension.

The angle between a horizontal line parallel to tibial plateau surface and a line connecting the center of the femoral insertion of each bundle at 90 knee flexion and full extension is demonstrated in Table 3.

DISCUSSION

In all cadavers we distinguished two separate bundles in the ACL ligament, anteromedial and

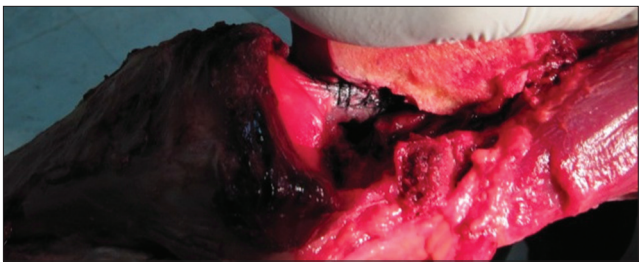

Figure 5: The bundles was parallel with full extended knee

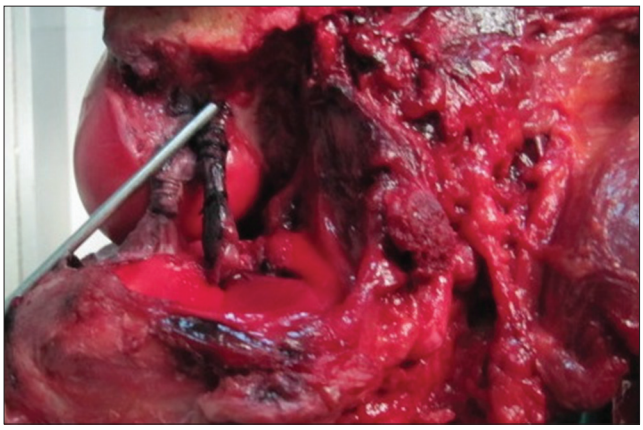

Figure 6: The bundles twisted with knee flexion

posterolateral bundle, which was consistent with some previous studies.[20,26] As revealed in literature, the Odensten *et al*. and Heming *et al*. described one structure [17,18] and Aims *et al*. and Hollis *et al*. found three bundles in ACL anatomy.[27,28]

One of the essential factors predicting success in DB ACL reconstruction technique is graft tunnel placement,[29] which requires accurate description of the bundle attachment on femur and tibia.[30] In our study, the femoral attachment of AM bundle was in the posterior-inferior part of the inner surface of the lateral condyle and PL bundle in anterior aspect of it. The posterior part of the inner surface of the lateral condyle has been described by some previous studies as the femoral ACL origin.[17,19,20] Hefzy and Zavras[31,32] have revealed that minor change in the femoral insertion site of ligament had resulted in the length and tensioning patterns difference of the ACL. The tibial insertion area of the AM and PL bundles were anteromedian of tibial plateau where tibial spine separated their origins. Tibial attachment area of AM and PL were 63.87 mm^2 and 51 mm^2 in our samples, which were in range of other studies, 56 mm^2[33] to136 mm^2[34] for AM and 52 mm^2[24] to 93 mm^2[34] for the PL bundle. Furthermore, Femoral attachment area

Table 3: The angle between a horizontal line parallel to tibial plateau surface

The angle between a horizontal line parallel to tibial plateau surface	Knee angle	Row
25	0	1
42	90	
23	0	2
45	90	
25	0	3
40	90	
26	0	4
41	90	
24	0	5
43	90	
28	0	6
43	90	
25	0	7
41	90	
26	0	8
42	90	
23	0	9
42	90	
25	0	10
44	90	
27	0	11
41	90	
28	0	12
42	90	

of AM and PL were 63.83 mm^2 and 49 mm^2 in our samples, which were in range of other studies, 44 mm^2[23] to120 mm^2[35] for AM and 40 mm^2[23] to 103 mm^2[34] for the PL bundle.

In other observation, AM and PL was parallel in the sagittal plane with full extended knee and the AM bundle was located in the anterior proximal aspect of the PL bundle, however, the bundles twisted around each other with increasing degrees of knee flexion toward 90° and femoral insertion site of AM and PL bundles were displaced to posterior and anterior respectively. Hollis *et al*.,[28] Duthon *et al*.,[36] Takashi *et al*.[25] and Steckel *et al*.[2] approved the parallel and twisted orientation in full extension and 90° flexion respectively.[12] Another study showed the PL bundle lies behind the AM bundle in an anteroposterior direction.[37-39] Moreover, it was revealed that the femoral origin of the PL bundle is posterior and inferior of the AM bundle when knee is extended, although, in flexion it placed anterior the origin of AM bundle on the lateral femoral condyle.[37] Considering this position is essential especially in arthroscopic surgery in which the knee is flexed.

The initial tension of grafts significantly affected the values of each graft tension at each knee flexion in DB ACL reconstruction, although there is no consensus regarding bundle-tensioning protocols.[36,37]

CONCLUSION

In our survey, tension pattern study of the AM and PL bundle demonstrated AM bundle tighten as the knee was flexed toward 120°, and PL bundle was tighten at full extension. In accordance to our findings, in previous studies the AM bundle tightened at 90° knee flexion and the PL bundle tightened in the full extended knee [2,28,34,37] or about 0-15° flexion.[13] In biomechanical evaluation of ACL by Takai *et al*.[36] and Hollis *et al*.[28] 3.3 mm and 3.6 mm increasing of AM bundle length were reported in 90° knee flexion in order and in both study decreasing of PL bundle length was shown in full extension knee which indicate that the tension of bundles should be considered in DB ACL reconstruction.

The average angle between the tibial plateau surface and a line connecting the center of the femoral insertion of each bundle at 90 knee flexion and full extension was 42.33 and 25.16° respectively. The only study in literature review was measured the angle between a horizontal line and the line connecting the center of the femoral insertion of the AM and PL bundle in the sagittal plane in 0, 30, 60, 90, 120, and 150° which was 55.2, 79.2, 105.7, 136.8, 170.2, and 205.8 in order.[2]

During recent years surgeons are more interested in DB reconstruction of ACL to restore the normal function of ligament [5,34,36] so, knowledge of ACL anatomy is essential to the success of double-tunnel reconstructions. As there is wide variety in anatomical structure of ligament in different population,[22] study of our population was one of the priority, which assists to better outcome of our surgeries. Although, some limitations are noticeable in our study such as small sample size, lack of enough female cadaver to compare the effect of sex in ACL anatomy. More surveys are needed to elaborate more details of ACL anatomy in future.

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Source of Support: Nil, **Conflict of Interest:** None declared.