

Research Article

Comparing Dimensions of Four-Strand Hamstring Tendon Grafts with Native Anterior and Posterior Cruciate Ligaments

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Background. The aim of the study was to evaluate whether or not there was any incompatibility between four-strand hamstring tendons taken from the same knee and the dimensions of the ACL and PCL. **Methods.** 15 fresh frozen cadaver hamstrings were prepared as four-strand grafts and measurements made of the ACL and PCL circumferences in the midsection were made in the narrowest part of the midsection. The cross-section areas and diameters were calculated with geometric calculations used to measure the cross-sectional area of cylinders. Accepting that the geometric insertions were elliptical, the length, width, and area were calculated for entry areas. **Results.** A significant relationship at 96.2% was determined between the ACL mid and the hamstring diameter. A significant relationship at 96.7% was determined between the ACL and the hamstring mid area. A significant relationship at 96.4% was determined between the PCL mid and the hamstring diameter. A significant relationship at 95.7% was determined between the PCL and the hamstring mid area. **Conclusion.** For the reconstruction of ACL and PCL, it was determined that there is less incompatibility between the four-strand hamstring tendons taken from the same knee and the dimensions of the midsection PCL compared to the ACL dimensions.

1. Introduction

The bone structure which forms the knee joint is a stable structure due to the ligaments of the knee. The two important ligaments providing this stability are the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL), the anatomy of which are becoming increasingly known [1–4]. As a result of studies which have focused on the equivalence of the ACL and PCL projections, there has been extensive research on the anatomic dimensions of the ACL and PCL and variations have been determined in various individuals [5].

The use of a hamstring tendon autograft is a widely preferred method in the treatment of injuries of these ligaments. Some previous anatomic studies have been conducted to

evaluate the appropriate dimensions of hamstring tendons compared with the natural ACL, particularly in the form of the midsection and the entry area [6]. However, to the best of our knowledge, there has not yet been any study related to the PCL.

In one such previous study, it was reported that increased graft size did not improve the time zero biomechanical stability of the knee after ACL reconstruction (ACLR). It is found that increased graft size did not compensate for biomechanical instability resulting in a nonanatomic tunnel position [7]. There are also the potential risks that an oversized graft will disturb the healing process and kinematics [6]. Using arthroscopic second looks, Marzo et al. and Toritsuka et al. demonstrated that graft deterioration occurred mainly in the midsubstance zone [8, 9]. Thus size matching of

graft midsubstance with native ACL and PCL becomes increasingly important assuming anatomic tunnel position restoration. Therefore, the compatibility of the dimensions of four-strand hamstring tendon grafts with native ACL and PCL will provide additional knowledge for the application of hamstring autograft.

The aim of this study was to evaluate whether or not there was any incompatibility between four-strand hamstring tendons taken from the same knee and the dimensions of the ACL and particularly the PCL, which has not been previously investigated.

2. Material and Methods

In this anatomic study, evaluation was made of 15 knees of fresh frozen cadavers which had been stored at +4°C. The cadavers were 6 (60%) males and 4 (40%) females. The knees used were 5 right side and 4 left side from the male cadavers and 3 right and 3 left from the female cadavers. Exclusion criteria were knees with evident osteoarthritis (>Outerbridge Grade 3), those with osteophytes on the intercondylar notch (femur and/or tibia), or those with torn ACL or PCL or damaged hamstring tendons. None of the knees which were included for evaluation had any previous surgical scar or any sign of clinical deformation. The age of the cadavers at death was 51, 60, 63, 64, 69, 76, 78, 81, 82, and 94 years, respectively, and mean BMI was $25.2 \pm 5.76 \text{ kg/m}^2$ (range, 18–34 kg/m^2). The mean time from death to dissection was 1 month (range 0–3 months). The knee movements measured with a goniometer showed minimum 120° flexion and full extension.

To harvest the hamstring grafts, a standard open antero-medial approach was used. The gracilis and semitendinosus tendons were identified in the tibial entry region and after the standard opening procedure, the grafts were taken separately using a closed stripper. Then the grafts were prepared and cleaned. Manual measurements were taken of the surroundings of the four-strand tendons with a digital goniometer.

The knee joint was opened for later removal of the ACL and PCL. Before taking the measurements, the soft tissues including the synovial membrane were carefully removed. The manual measurements of the ACL and PCL circumference were taken at approximately 1.5 cm proximal to the tibial entry area, which is the narrowest part of the midsection [6] (Figure 1). To preserve the natural tension of the graft, these measurements were made before cutting the ACL and PCL. When taking the measurements, first the ACL was measured; then to be able to measure the PCL, the ACL was cut and cleaned. At the same time, to be able to better expose the posterior region of the PCL, the structures in the posterior of the knee joint were carefully cleaned. Thus by fully exposing the PCL, the measurements were taken. The ACL and PCL were then completely removed. The cross-sectional areas and diameters were calculated with the geometric calculations which are used to measure the cross-sectional area of a cylinder. As the ACL and PCL resemble simple cylinders, the midsection was used to estimate the smallest cross-sectional area in both the ACL and PCL. The femoral and tibial entry

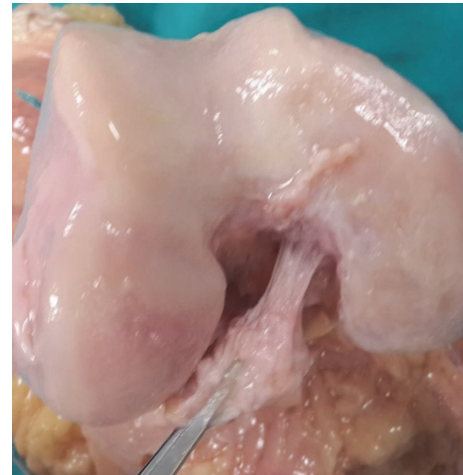


FIGURE 1: PCL circumference measurements made in the midsection 1.5 cm proximal to the tibial entry area after removal of the synovial membrane.

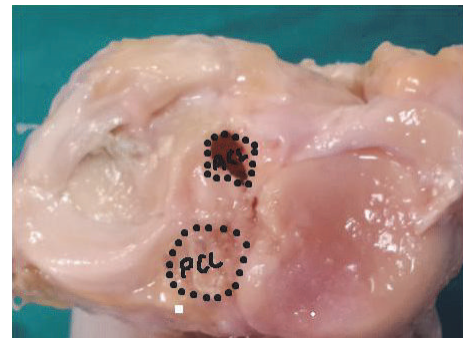


FIGURE 2: Measurements of the surface area of the tibial entry area without the synovial membrane.

areas of the ACL and PCL were then measured. Accepting that the insertions were geometrically elliptical, calculations were made of the length, width, and areas for both the ACL and the PCL. The length measurements were taken from the major axis of the entry areas and the width was measured perpendicular to the long axis at the widest point [6] (Figures 2 and 3).

Statistical analyses of the findings obtained in the study were made using IBM SPSS v. 22 (IBM, SPSS, Turkey) software. When evaluating the study data, conformity to normal distribution was tested with the Shapiro Wilk test. In the evaluation of the relationship between parameters, Pearson correlation analysis was applied in addition to descriptive statistics. A value of $p < 0.05$ was accepted as statistically significant.

3. Results

All the results are summarised in Tables 1 and 2.

A correlation was determined between the hamstring tendon dimensions and the ACL and PCL (diameter, cross-section area, $p < 0.01$). The mean diameter of the hamstring

TABLE 1: Summary of results.

Measurements	Mean	Left knee	Right knee	Male	Female
Hamstring diameter (mm)	7.01 ± 0.64	6.82 ± 0.74	7.17 ± 0.54	7.45 ± 0.3	6.34 ± 0.33
Hamstring mid area (mm ²)	38.02 ± 6.83	37.49 ± 7.14	38.49 ± 7.01	43.35 ± 1.32	30.03 ± 0.34
ACL mid diameter (mm)	6.2 ± 0.59	5.98 ± 0.63	6.39 ± 0.5	6.6 ± 0.27	5.59 ± 0.34
ACL mid area (mm ²)	29.69 ± 3.87	28.86 ± 4.43	30.42 ± 3.44	32.57 ± 1.35	25.37 ± 1.31
PCL mid diameter (mm)	7.16 ± 0.7	6.91 ± 0.76	7.39 ± 0.61	7.65 ± 0.31	6.43 ± 0.39
PCL mid area (mm ²)	34.28 ± 4.64	33 ± 5.03	35.4 ± 4.28	37.72 ± 1.53	29.12 ± 1.77
ACL-tibial insertion length (mm)	13.75 ± 1.21	13.59 ± 1.21	13.9 ± 1.28	14.58 ± 0.79	12.51 ± 0.14
ACL-tibial insertion width (mm)	10.74 ± 0.77	10.62 ± 0.76	10.84 ± 0.82	11.23 ± 0.61	10.01 ± 0.11
ACL-femoral insertion length (mm)	13.21 ± 1.19	13.05 ± 1.19	13.36 ± 1.24	14.03 ± 0.76	11.99 ± 0.14
ACL-femoral insertion width (mm)	9.37 ± 1.33	9.72 ± 1.54	9.06 ± 1.14	10.05 ± 1.3	8.34 ± 0.4
ACL-tibial footprint area (mm ²)	118.2 ± 18.43	122.64 ± 21.5	114.31 ± 15.69	128.6 ± 16.6	102.6 ± 4.86
ACL-femoral footprint area (mm ²)	99.6 ± 19.41	103.53 ± 22.27	96.16 ± 17.31	112.2 ± 14.43	80.7 ± 2.75
PCL-tibial insertion length (mm)	15.9 ± 1.46	15.71 ± 1.47	16.07 ± 1.54	16.91 ± 0.92	14.38 ± 0.16
PCL-tibial insertion width (mm)	12.55 ± 1.04	12.4 ± 1.03	12.67 ± 1.1	13.24 ± 0.72	11.51 ± 0.13
PCL-femoral insertion length (mm)	15.23 ± 1.48	15.03 ± 1.5	15.4 ± 1.55	16.27 ± 0.89	13.67 ± 0.16
PCL-femoral insertion width (mm)	11.12 ± 1.81	11.44 ± 2.07	10.8 ± 1.6	12.08 ± 1.53	9.4 ± 0.42
PCL-tibial footprint area (mm ²)	135.26 ± 21.13	141.8 ± 25.38	129.54 ± 16.13	146.78 ± 19.71	117.98 ± 5.58
PCL-femoral footprint area (mm ²)	120.69 ± 29.17	121.09 ± 27.47	120.35 ± 32.48	139.3 ± 22.56	92.78 ± 3.15

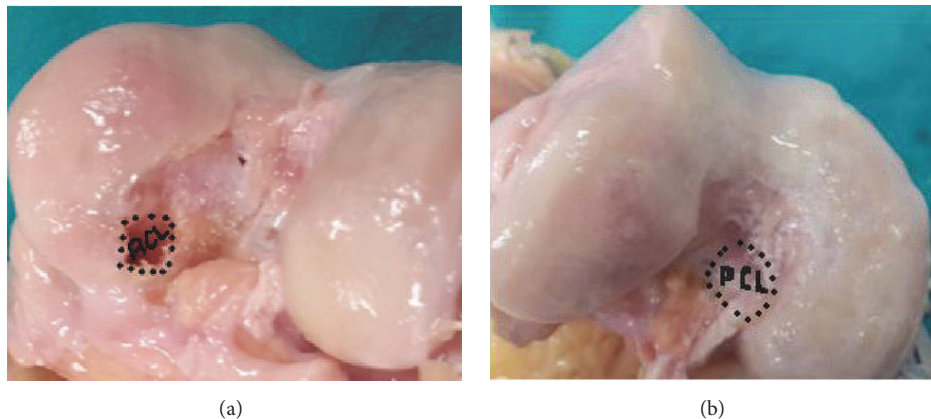


FIGURE 3: Measurements of the surface area of the femoral entry area without the synovial membrane.

tendons was found to be significantly larger than the diameter of the ACL in the midsection (mean 13.06%). A positive statistically significant relationship at 96.2% was determined between the ACL mid diameters and the hamstring diameters ($p < 0.01$). The mean cross-section area of the hamstring tendons was found to be significantly larger than the area of the ACL in the midsection (mean 28.05%). A positive statistically significant relationship at 96.7% was determined between the ACL mid areas and the hamstring mid areas ($p < 0.01$).

The diameter of the hamstring tendons was significantly smaller than the PCL diameter in the midsection (mean 2.13%). A positive statistically significant relationship at 96.4% was determined between the PCL mid diameters and the hamstring diameters ($p < 0.01$). The cross-section area of the hamstring tendons was significantly greater than the PCL area in the midsection (mean 10.91%). A positive statistically

significant relationship at 95.7% was determined between the PCL mid areas and the hamstring mid areas ($p < 0.01$).

The dimensions of the hamstring tendons, ACL, and PCL were determined to be smaller in females than in males. The statistically significant positive relationship between ACL mid diameters and hamstring diameters was higher in females (89.1%, $p = 0.011$) than in males (79.8%, $p = 0.017$) ($p < 0.05$). Similarly, the statistically significant positive relationship between PCL mid diameters and hamstring diameters was higher in females (89.1%, $p = 0.011$) than in males (79.5%, $p = 0.017$) ($p < 0.05$).

4. Discussion

The most significant finding of this study was that, despite the good correlation between the midsection cross-sectional area of both ACL and PCL, for the reconstruction of these

TABLE 2: Correlations of the hamstring diameter and areas with the ACL and PCL diameter and areas.

	<i>r</i>	<i>p</i>
ACL mid diameter (mm)		
Mean	0.962	0.001**
Left knee	0.983	0.001**
Right knee	0.933	0.001**
Male	0.798	0.011*
Female	0.891	0.017*
PCL mid diameter (mm)		
Mean	0.964	0.001**
Left knee	0.984	0.001**
Right knee	0.933	0.001**
Male	0.795	0.011*
Female	0.891	0.017*
ACL mid area (mm ²)		
Mean	0.967	0.001**
Left knee	0.980	0.001**
Right knee	0.985	0.001**
Male	0.801	0.011*
Female	0.630	0.180
PCL mid area (mm ²)		
Mean	0.957	0.001**
Left knee	0.978	0.001**
Right knee	0.976	0.001**
Male	0.608	0.083
Female	0.583	0.225

Pearson correlation analysis **p* < 0.05 ***p* < 0.01.

ligaments, there was determined to be less incompatibility between the four-strand hamstring tendons taken from the same knee and the dimensions of the midsection PCL compared to the ACL dimensions. Such a correlation for the PCL in particular is revealed for the first time in this study.

Injuries of the knee ligaments have been reported at the rate of 60.9 per 100,000 people and ACL injuries are seen more than PCL injuries [10, 11]. The general approach in surgery for the incapacity created by these ligament injuries is intra-articular anatomic reconstruction of the ligaments rather than primary repair. However, there is as yet no consensus on subjects such as graft selection, placement, and fixation in both ACL and PCL reconstruction [12–14]. In addition, graft selection depends on the surgeon's experience, preference, tissue status, the age and activity level of the patient, concomitant diseases, the preoperative status, and the patient's wishes [12, 15, 16]. Hamstring tendons are known to still be the most commonly used grafts in ACL and PCL reconstruction [17, 18]. However, the correlations of ACL and PCL dimensions with hamstring grafts have a very small place in recent literature [6].

In comparison with other cadaver studies which have defined ACL and PCL dimensions, the mean age of the cadavers, the mean BMI measurements, and the waiting time of the cadavers on which the measurements were made to evaluate the correlations have been reported to be similar to

those of the current study [6]. While some researchers have used a micrometer or digital calipers to manually measure the width and length for the evaluation of this correlation, others have used different methods such as digital picture analysis, radiographs, or MRI [19–22]. In the current study, measurements were made manually using digital calipers. Therefore, the results of this study can be considered to be more sensitive and more reliable.

There are various measurement techniques with different results for ACL and PCL [23–25]. Different results have been obtained in particular when measurements have been made before and after the removal of synovial membrane [26]. This was taken into consideration for the current study and in the belief of being able to make a more accurate correlation evaluation, cleaning of the synovial membrane was preferred. The results obtained were seen to be similar to the results obtained in other studies where the synovial membrane was removed [27–29].

When anatomic placement of the ligaments was examined, it was seen that the ACL is wider in the entry area and has a biconcave shape with the narrowest part in the midsection. The width in the entry area is generally in the anteroposterior direction. In other words, the midsection of the ligament is approximately 3.5 times smaller than the ACL projection [22]. Similarly, when the PCL was examined, the tibial attachment point of the ligament is more inferior and posterior compared to the tibial joint surface and is a trapezoidal area. The femoral attachment point is anteromedial to the intercondylar notch wall when the knee is in extension. With this structure, one of the most important ligaments providing stability of the knee joint is the PCL, the main function of which is to prevent posterior translation of the tibia below the femur. A secondary function is to aid rotational and varus-valgus stability of the knee. If it is considered that the tensile strength of the PCL is approximately twice that of the ACL, it is accepted as the primary stabiliser of the knee [29, 30]. Due to this structure, the PCL has always been evaluated within all the knee ligaments as the “central pivot” [31]. Therefore, in the last 10 years there have been studies which have reported improvements in functional results after isolated PCL reconstruction and indicated the potential benefits of surgery in certain cases [32].

Although the anatomic structure of both the ACL and PCL is well understood, the question arises of how compatible hamstring tendons are, which are currently often used as the most appropriate graft, in place of these ligaments. The compatibility of hamstring grafts with both ACL and PCL may vary according to gender and the individual's body structure. While extremely intense debate on surgical reconstruction techniques continues, the use of sufficiently robust grafts is recommended for both ligaments. Second-look arthroscopic examinations have shown that generally deterioration of the graft has occurred in the midsection [8, 9, 33]. One condition which could cause this is the compatibility of the graft used for reconstruction in place of both ACL and PCL. Studies in literature showing that it is not correct to think that, as the graft thickness increases, stability increases have brought this consideration to the fore [7, 34].

It is well known that the anatomic restoration of native foot print anatomy in ACLR is of paramount importance regardless of graft size and source. However, oversizing of the graft has a negative effect on the healing process and kinematics [6]. Therefore, the goals of ACL/PCL reconstruction should be the anatomic reconstruction of foot prints with an appropriate size of graft which should match the native ACL/PCL. In this study, both ACL/PCL cross-sectional area measurements were found to match with four-strand hamstring tendon grafts. However, the particular contribution of this study to literature is that PCL midsubstance cross-sectional area measurements matched the four-strand hamstring tendon grafts, and this point has not been previously studied.

Together with these evaluations, there were some limitations to this study, primarily the number of cadavers and the fact that the mean age of the cadavers was significantly higher than that of most patients who undergo ACL and PCL reconstruction. Even if the number of cadavers can be increased with further studies, the advanced age of the cadavers could affect the structure and morphology of the ACL and PCL. Furthermore, the cross-sectional geometric forms of both the ACL and PCL were found to be irregular in that they were not purely circular or purely elliptical. Therefore, the calculations can only reflect approximate results, not exact results [12].

5. Conclusion

Compared with current ACL reconstruction techniques, grafting has a greater diameter despite the good correlation between four-strand hamstring tendons and the midsection cross-sectional areas, especially of the ACL. Moreover, compared with current PCL reconstruction techniques, there is a good correlation between four-strand hamstring tendons and the midsection cross-sectional areas in particular of the PCL. Therefore, compared to ACL reconstruction, in the anatomic reconstruction of PCL, four-strand hamstring tendons could be more compatible with the footprint of these ligaments or could be considered to mimic the midsection of the ligament.

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

Barış Yılmaz, Güzelali Özdemir, Elif N. Keskinöz, Gamze Tümentemur, Kemal Gökkuş, and Bahtiyar Demiralp designed the study, collected data, assessed the results, and wrote the manuscript.

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