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Characterization of the orientation and isometry of Humphrey's ligament

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ABSTRACT

Objectives/purpose: The purpose of this study was to examine the effect of flexion angle on isometry and fiber obliquity of the anterior meniscofemoral ligament (Humphrey's ligament (HL)).
Methods: Following a medial parapatellar arthrotomy on 7 fresh frozen cadavers, the insertion points of the anterolateral (AL) and posteromedial (PM) bundles of the PCL, and HL were identified. Using a 9 mm circular software tool, virtual fibers were created. Within each virtual graft, a central fiber was calculated and used to generate anisometry profiles for the AL and PM bundles and HL at flexion angles of 0°, 30°, 60°, 90°, and 120°. Previously validated computer navigation software was used to re-create three dimensional bundles to measure fiber obliquity in the sagittal, frontal, and axial planes.
Results: HL length increased with knee flexion from 0 to 120°, and underwent similar length changes as the PCL bundles. In full extension and at 90°, the average length of the PM and AL bundles were not statistically different ($p = 0.13$ and $p = 0.85$ respectively). From 0 to 120°, the PM bundle was the most isometric, but the anisometry profile was statistically similar to the AL bundle and HL. In general, HL and the PM bundle had similar graphic trends in terms of fiber obliquity in all planes.
Conclusions: Using computer navigation, we have demonstrated that HL has similar isometry profiles as the PM and AL bundles of the PCL, and "mirrored" the obliquity of the PM bundle in all planes throughout flexion to 120°.

1. Background

Examining the biomechanical properties of the posterior cruciate ligament (PCL) has recently been emphasized [5,9,11,16,17]. The PCL is composed of two bundles, the anterolateral (AL) and posteromedial (PM), with distinct insertion sites on the tibia and femur. The anterior meniscofemoral ligament (Humphrey's ligament (HL)) originates anterior to the PCL attachment on the femur and is oriented with the PCL on the tibia where it attaches to the posterior horn of the lateral meniscus. The importance of Humphrey's ligament is unknown, with varying reports of incidence [12,21]. Historically, it has been thought that the stronger anterolateral bundle is tight in flexion while the posteromedial bundle is more taught in extension, with little biomechanical data available regarding the anterior meniscofemoral ligament [1,12]. Treatment of PCL injuries remains a controversial topic. There has been recent debate as to whether one or both of the bundles need to be reconstructed to recreate necessary constraint. The anterolateral bundle has been shown to be stronger and stouter, leading many investigators to make the AL the focus of reconstructive surgery [4,20]. Still, other studies have described the biomechanical necessity of both bundles in PCL reconstruction by showing reciprocal importance of each bundle throughout knee flexion [14,15,18]. However, this theory of reciprocal bundle kinematics has recently been challenged [19].

Recent studies have validated the use of computer reconstruction to evaluate ligament biomechanics and anatomy [3,6]. Surgical navigation offers a quantitative means of defining the anisometry, bundle length, and the three-dimensional obliquity of the posterior cruciate ligament and the meniscofemoral ligament at different flexion angles. Thus, the purpose of this study was to 1) record the prevalence of an intact meniscofemoral ligament (Humphrey's ligament) in a cadaveric sample, 2) define the anisometry and bundle length of Humphrey's ligament, AL, and PM bundles of the PCL from 0 to 120° of knee flexion and 3) quantify the three dimensional obliquity (frontal, sagittal, and axial planes) of HL, AL and PM bundles throughout knee flexion. We hypothesized that the anterior meniscofemoral ligament will have similar anisometry profiles and fiber obliquity to the posterior cruciate ligament.

2. Methods

An institutional review board approved this controlled laboratory study. Seven fresh frozen cadavers without PCL injury or severe arthritis were utilized for this study (age range 25–93). Exclusion criteria included previous surgery, gross malalignment, and ligamentous pathology. Specimens were bench mounted, secured using a vise around the proximal femur and positioned to allow for a free flexion cycle from 0 to 120°.

The Praxim Surgetics surgical navigation system (Praxim Medivision, Grenoble, France) was used for kinematic data acquisition. This

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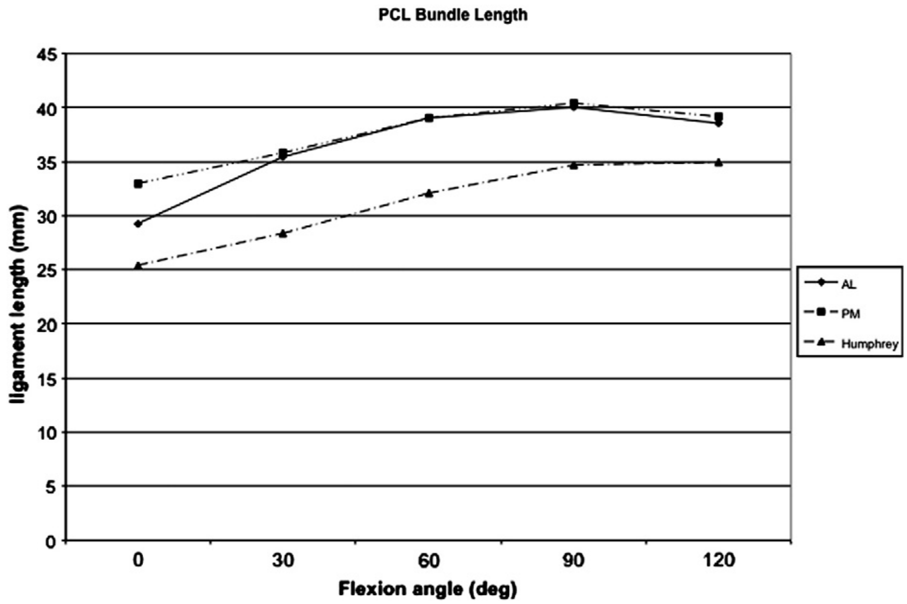


Fig. 1. Fiber length of the posteromedial (PM — square) and anterolateral (AL — circle) bundles of the PCL and Humphrey's ligament (HL — triangle) from 0 to 120° of flexion.

"imageless" technology generates a three-dimensional (3-D) image of the patient's articular anatomy by acquiring points directly on the bone surface and then forming a statistical model to fit these points. This system has been shown to be statistically accurate to 1° or 1 mm and to be highly reliable compared with an industrial robotic sensor [7,12]. Steinmann pins secured in both the distal femur and proximal tibia were mounted with reflective markers. Surface landmarks were recorded, intra-articular surface geometry was mapped and the 3-D model was created. The knee was manually cycled from full extension to 120° of flexion. The flexion angle and kinematics were tracked with the navigation system. Care was taken to prevent the application of a rotational load to the tibia, and the navigation system monitored the kinematics of the motion to confirm that a complete flexion/extension cycle was achieved.

A medial parapatellar arthrotomy and posterior dissection was performed to identify insertion points of the anterolateral, posteromedial and anterior meniscofemoral ligament (Humphrey's ligament) on both the tibia and femur. They were bluntly dissected with a probe to help distinguish the individual bundles, and were tagged with sutures. Using traction the bundles were then removed from their insertions and labeled with acrylic outlines to identify individual footprints. The entire PCL footprint was then carefully morphed using the navigation software and the borders of the bundle footprints were delineated.

Individual bundle length was measured using computer navigation software at different flexion angles of 0°, 30°, 60°, 90°, and 120°.

2.1. Creation of virtual fibers

Using a 9 mm circular software tool, virtual fibers were created in the center of the AL bundle, PM bundle, and HL on both the femoral and tibial footprints. Within each virtual graft, a central fiber was calculated and used to generate anisometric profiles and three-dimensional obliquities for the 3 ligaments at all flexion angles.

2.2. Three dimensional obliquity

The three dimensional obliquity of the 3 virtual grafts was determined with the knee in full extension, 30°, 60°, 90°, and 120° of flexion. The coordinate system used to compute the obliquity was determined using the references acquired by the navigation system. Specifically, tracking of the flexion/extension cycle determined in the sagittal plane, and the orthogonal axial and coronal planes were resolved from this plane. The obliquity angles were then determined by projecting the fiber insertion points on these three orthogonal reference planes at the various knee flexion angles.

2.3. Anisometry profiles

Virtual fiber lengths were normalized to zero at full extension for the flexion/extension cycles.

For each flexion angle from 0 to 120°, the change in length between the fiber length at full extension and the fiber length at the respective flexion angle was computed. Changes in length were graphed to demonstrate the anisometry "profile" of the fiber from 0 to 120°. The total length of change in each fibre when the knee was ranged from 0 to 120° was also computed and defined as the absolute anisometry.

2.4. Statistical analysis

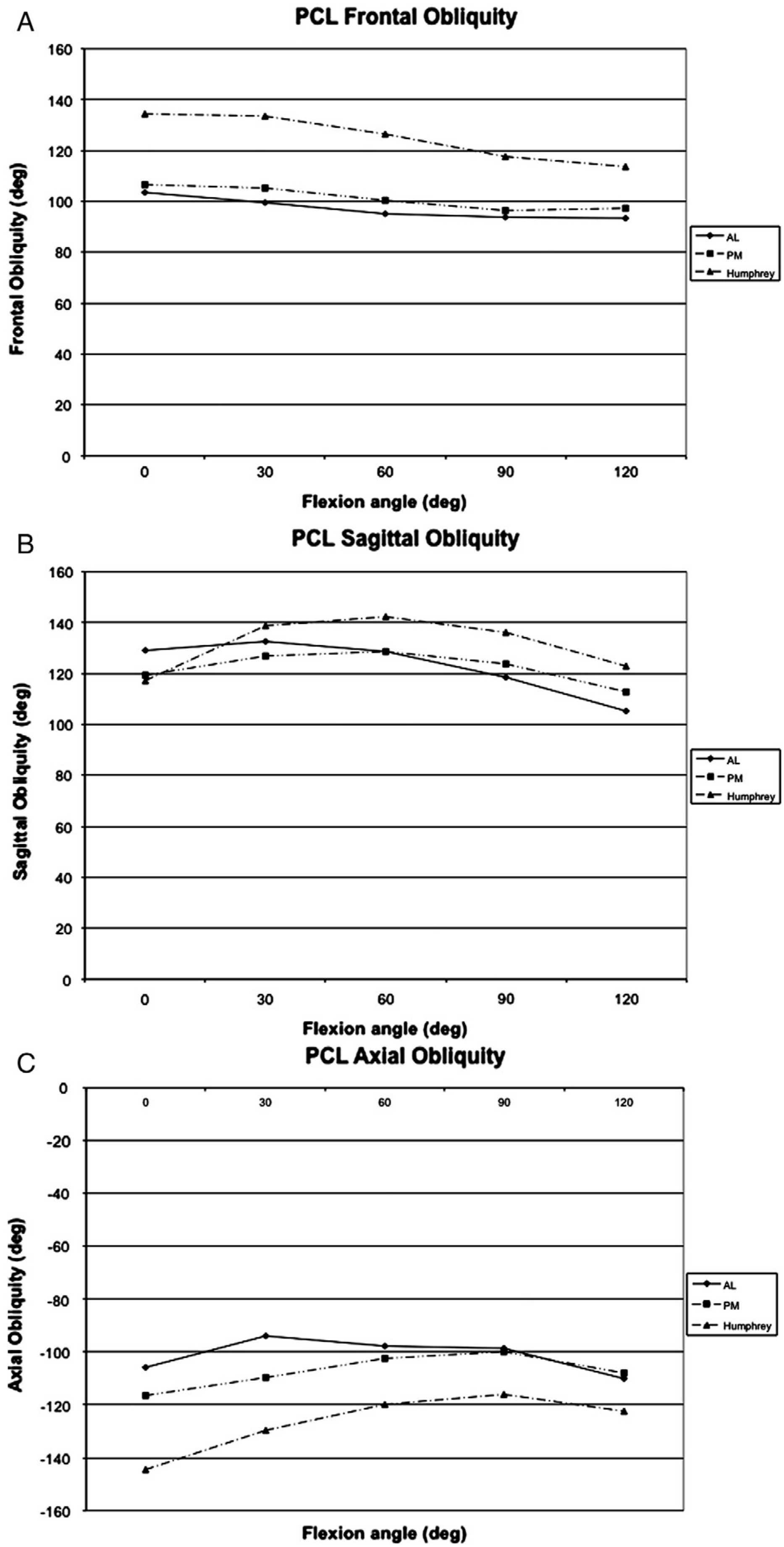
Repeated measures ANOVA with a post hoc Bonferroni correction was used using SPSS software to compare the obliquity of the various fibre types in each plane at each flexion angle. Repeated measures ANOVA with a Tukey's Multiple Comparison test was performed using Microsoft Excel to compare the anisometry of the grafts at 0°, 30°, 60°, 90°, and 120°. Significance was initially set at $p < 0.05$, but adjusted p values based on the post hoc correction were used to determine statistical significance. The study was powered a priori to detect less than 2 mm difference in the anisometry values at each flexion angle (alpha = 0.05).

3. Results

3.1. Anisometry and bundle length

A distinct, intact Humphrey's ligament was identified in all 7 specimens. The PM bundle was the most isometric throughout the full range of knee flexion. However, the absolute anisometric ranges of the AL bundle (9.1 ± 4.5 mm), PM bundle (5.9 ± 2.73), and HL (9.3 ± 3.7 mm) throughout the 0–120° flexion cycle were not

Fig. 2. Fiber obliquity of the posteromedial (PM — square) and anterolateral (AL — diamond) bundles of the PCL and Humphrey's ligament (HL — triangle) from 0 to 120° of flexion in the frontal (A), sagittal (B), and the axial (C) planes.


A
PCL Frontal Obliquity
Frontal Obliquity (deg)
160
140
120
100
80
60
40
20
0
0
30
60
90
120
Flexion angle (deg)
AL
PM
Humphrey
B
PCL Sagittal Obliquity
Sagittal Obliquity (deg)
160
140
120
100
80
60
40
20
0
0
30
60
90
120
Flexion angle (deg)
AL
PM
Humphrey
C
PCL Axial Obliquity
Axial Obliquity (deg)
0
-20
-40
-60
-80
-100
-120
-140
-160
0
30
60
90
120
Flexion angle (deg)
AL
PM
Humphrey

statistically different ($p = 0.18$). In full extension, the average length of the PM bundle (33.0 ± 4.9 mm) and the AL bundle (29.3 ± 3.6 mm) were not significantly different ($p = 0.13$); however, length of the PM bundle and HL (25.4 ± 5.0 mm) were statistically different ($p = 0.01$). In 90° of flexion, again, the average length of the PM bundle (40.4 ± 2.9 mm) and AL bundle (40.0 mm ± 5.3 mm) were not statistically different ($p = 0.85$). Similar to our findings in full extension, the length of the HL (34.7 ± 4.2 mm) was statistically different from the PM bundle at 90° of flexion ($p = 0.01$) but not significantly different than the AL bundle ($p = 0.06$) (Fig. 1).

The length of the AL bundle and PM bundle increased with knee flexion from 0 to 90°, and then decreased in length from 90 to 120°; however, HL steadily increased in length throughout knee flexion up to 120° (Fig. 1). Compared to their relative bundle length in full extension, the AL bundle was significantly longer at 60° ($p = 0.002$), 90° ($p < 0.001$), and 120° ($p = 0.001$) of knee flexion, whereas the PM was only significantly longer at 90° ($p = 0.005$).

3.2. Obliquity

No significant difference was seen in the obliquity of the AL and PM bundles in the frontal, sagittal, or axial planes at any degree of flexion ($p > 0.05$). In general, HL and the PM bundle had similar graphic trends (Fig. 2A–C) in obliquity in all planes, whereas the obliquity of HL was often significantly different than the AL bundle, especially in the axial and frontal planes. The obliquity of the AL, PM and HL in the frontal plane followed the same graphic trends up to 90° of flexion, with the obliquity of the HL being significantly higher than the AL at all flexion angles ($p < 0.05$) and PM bundles at all flexion angles except for 120° ($p < 0.05$ up to 90°; $p = 0.079$ at 120°) (Fig. 2A). In the sagittal plane, the obliquity of the HL and PM followed the same graphic trend, increasing in obliquity up to 60° of flexion and then decreasing up to 120°; however, the obliquity of the AL bundle began to steadily decrease starting at 30° of flexion. Significant differences in obliquity in the sagittal plane between the AL, PM and HL were only seen at 60°, 90°, and 120° with the HL having significantly higher obliquity than the AL at 60°, 90°, and 120° and PM bundles at 60° and 90° (Fig. 2B) In regard to the axial obliquity, the AL and HL were significantly different up to 60° of knee flexion ($p < 0.05$), and the PM bundle steadily became more oblique in the axial plane up to 90° of flexion (Fig. 2C).

4. Conclusions

The anterolateral and posteromedial bundles were not significantly different from each other in anisometry, bundle length, and obliquity throughout knee flexion from 0 to 120°. The posteromedial bundle was the most isometric, but both the AL bundle and the PM bundle increased in length up to 90° of knee flexion and then shortened with hyperflexion. Further, the anterior meniscofemoral ligament (Humphrey's ligament) was universally present in all the cadaveric specimens, and the obliquity profile mirrored the PM bundle at a different level of magnitude.

The small sample size is a limitation of the current study. However, the study was powered a priori to determine a 2 mm difference in anisometry at each flexion angle. The PM bundle was in fact more isometric by more than 2 mm, and was not significant; thus, we feel confident concluding that sample size was sufficient, at least to assess anisometry. Further, multiple statistical comparisons were made; however, a post hoc Bonferroni correction and a Tukey's multiple comparison test were used in all of the analyses, and the lower, adjusted alpha value was used determine significance. In contradiction with prior a publication, [10] a distinct HL was present in all of the cadaveric specimens. Given the universal presence, its role in controlling posterior tibial translation, rotation and contact pressures across the knee may be underappreciated [2,13]; however, the published literature is limited on the biomechanical properties of the anterior meniscofemoral ligament. As a result of the lack of knowledge, it is widely believed not to play a significant role in knee function and is in fact often removed during knee arthroscopy to improve visualization. The obliquity trends of HL mirrored the PM bundle; thus, a hypothesis for future studies assessing the biomechanical properties of the HL could logically be that the HL works in conjunction and plays a similar biomechanical role as the PM bundle of the PCL. The AL and PM bundles have similar isometry and obliquity profiles throughout knee range of motion. The AL bundle has traditionally thought to be important for preventing tibial translation in flexion, whereas the PM bundle inhibits tibial translation in extension [1,8]. Contradictory to this belief, we found that both bundles increase in length as the knee flexes to 90°, and then begin to shorten with hyperflexion, suggesting a co-dominance in restraining posterior tibial translation throughout knee range of motion. Thus, perhaps tensioning of both bundles should be performed at 90° to avoid over-constraint in a double bundle PCL reconstruction.

In the frontal plane, the AL and PM bundles are virtually indistinguishable with similar orientations. Although the obliquity of the HL graphically mirrored the PM bundle, HL was significantly more oblique in the frontal plane than both the AL and PM bundles suggesting a distinct biomechanical role from the AL and PM bundles of the PCL. Although not statistically significant, examining the sagittal obliquity at 0 and 90° suggests bundle orientation may rotate throughout flexion as the PM bundle is more oblique at full extension, while the AL bundle is more oblique at 90° of flexion. Thus, graft position and rotation may be important for graft tensioning at 90° of flexion.

In summary, contrary to traditional teaching, the AL and PM bundles had similar anisometry, bundle lengths, and obliquity in all planes throughout knee flexion; further, the anterior meniscofemoral ligament was universally present in all specimens, concurring with the published literature suggesting that Humphrey's ligament may be more prevalent and important than traditionally believed.

5. Conflict of interest statement

Dr. Anrew Pearle is board member of Bluebelt technologies. All other authors have nothing to disclose.

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