Anatomic and Flexion-Dependent Differences Between the Fibular Collateral Ligament, Anterolateral Ligament, and Iliotibial Band Fibers: Guiding Graft Fixation in Lateral Knee Reconstruction

Edouard J Augustin, Zachary R Oppenheim, Jose Francisco Vega, Fernando Gómez Verdejo, Felipe Jose Casanova, German Escribano, Andrew Bi, Jorge A Chahla, Adam Blair Yanke

INTRODUCTION: The lateral knee contains several ligamentous structures that contribute to varus and rotational stability, including the fibular collateral ligament (FCL), anterolateral ligament (ALL), and iliotibial band (ITB) fibers extending from Gerdy's tubercle to the proximal and distal Kaplan fibers. A detailed understanding of the native anatomic insertion points and flexion-dependent behavior of these structures is essential for guiding graft fixation during reconstructive surgery. This study aimed to characterize the native location and length changes of the FCL, ALL, and ITB fibers across knee flexion using a cadaveric model.

METHODS: Fellowship-trained orthopedic surgeons dissected fresh-frozen cadaveric knees, preserving the tendon and ligament attachments of the lateral knee (Figure 1A). Bony landmarks on the femur, tibia, and fibula were marked with pins, including the footprint centers of the FCL (n=10), ALL (n=7), gastrocnemius tendon, popliteus tendon, iliotibial band tibial insertion (Gerdy's tubercle), and anterior biceps femoris (Figure 1B). Using a MicroScribe system (MicroScribe; Solution Technologies), 3D coordinates of each landmark were recorded at 0°, 15°, 30°, 45°, 60°, and 90° of flexion (Figure 1C). We calculated the ALL and FCL lengths as the 3D distance between footprint centers. ITB fiber lengths from Gerdy's tubercle to the distal Kaplan fibers (n = 10) and proximal Kaplan fibers (n = 9) were analyzed independently. We used paired t-tests to compare ligament lengths between full extension (0°) and deep flexion (90°). We also measured distances from ligament attachment sites to surrounding landmarks.

RESULTS: The FCL femoral attachment is generally more anterior and distal compared to the ALL, as the FCL is farther from key proximal landmarks like the Kaplan fiber ridges (proximal ridge $p = 0.041$, distal ridge $p = 0.089$) and closer to distal landmarks such as the popliteus sulcus ($p = 0.005$) and tibial plateau ($p=0.003$) (Table 1A). The FCL inserts distally onto the fibular head, while the ALL inserts more anteriorly and proximally onto the tibia, often in closer proximity to Gerdy's tubercle ($p = 0.001$) and the tibial plateau ($p = 0.0005$) (Table 1B). The FCL and ALL demonstrated statistically significant shortening from 0° to 90° of knee flexion (FCL: 7.59 mm, $p = 0.004$; ALL: 6.44 mm, $p = 0.020$), supporting their dynamic length-dependent function (Figure 3C). In contrast, length changes from Gerdy's tubercle to the distal Kaplan fibers (0.78 mm, $p = 0.853$) and proximal Kaplan fibers (3.99 mm, $p = 0.506$) were not statistically significant, indicating minimal length variation across the arc of flexion (Figure 3C).

DISCUSSION AND CONCLUSION: The FCL and ALL have anatomically distinct femoral and tibial attachment sites with different spatial relationships to surgical landmarks, reinforcing the importance of individualized tunnel placement to avoid convergence. The FCL and ALL shorten with knee flexion and should be fixated at angles that preserve native length to avoid graft over-constraint. Fixing the FCL in near-full extension and the ALL before 60° of flexion may better reproduce native biomechanics. In contrast, the ITB fibers from Gerdy's tubercle to the Kaplan fibers remain relatively isometric throughout flexion and may not require precise tensioning during reconstruction. These findings offer nuanced insight into lateral knee anatomy and inform surgical decision-making for anatomic graft placement.

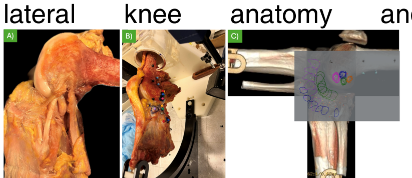


Figure 1: A) Representative depiction of the dissected tendon and ligament attachments of the lateral knee at 90º, namely the anterolateral ligament (ALL), fibular collateral ligament (FCL), popliteus tendon (PLT), lateral gastrocnemius (LGT), and iliotibial band (ITB), to the femur, tibia, and fibula respectively. B) Representative image of the same specimen after removing the lateral knee structure attachments and marking all attachment points and surrounding landmarks with colored pins (green for ALL femur and tibia attachment, dark blue for FCL femur and fibula attachment, pink for PLT femur attachment, orange for LGT femur attachment, purple for Gerdy's tubercle on the tibia, light blue for proximal and distal kaplan fiber ridges on the femur.). The knee is depicted in the flexion jig at 0º, next to the Microscribe. C) Representative image of Microscribe 3D coordinate system mapping of points using Rhino 6 software (McNeel North America, Seattle, WA, USA) in 6 angles of flexion (0°, 15°, 30°, 45°, 60°, and 90°) overlayed over two 3D CT images of the same dissected knee, at 0º and 90º of flexion, normalized to the femur position.

A) Ligament Attachment Distances to Femur Landmarks

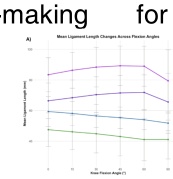
Landmark	FCL Attachment Femur		ALL Attachment Femur		
	Average	SD	Average	SD	p value
Kaplan Fibers Proximal Ridge	47.34	8.11	37.25	10.06	**0.041***
Kaplan Fibers Distal Ridge	28.82	7.81	23.00	9.95	0.089
Lateral Gastrocnemius Tubercle	11.18	4.30	7.54	3.49	0.052
Lateral Epicondyle	7.41	2.20	10.76	5.57	0.12
Popliteus Sulcus	11.19	3.78	20.44	6.44	**0.005****
ALL Attachment Femur	12.52	5.89			
Tibial Plateu Lateral (Joint Line)†	27.46	6.39	38.26	8.46	**0.003****

B) Ligament Attachment Distances to Tibia and Fibula Landmarks

Landmark	FCL Attachment Fibula		ALL Attachment Tibia		
	Average	SD	Average	SD	p value
Gerdy'S Tubercle Center Point	41.10	5.48	18.53	7.62	**0.001****
Proximal Fibular Styloid Process	17.84	4.98	27.71	7.34	**0.026***
Anterior Margin Fibular Head	11.89	3.10	22.02	6.17	**0.037***
Anterior Arm Biceps Femoris	26.00	5.37	10.56	3.22	**0.002****
All Attachment Tibia	29.10	6.01			
Tibial Plateu Lateral (Joint Line)†	27.32	4.92	7.51	2.72	**0.0005*****

Table 1: Average 3-dimensional distances (using x, y, and z coordinate system) were calculated from the ALL and FCL femur attachment points to femoral landmarks, and from the ALL tibia and FCL fibula attachments to landmarks on the tibia and fibula, respectively, at 0º of flexion (*$p < 0.05$, **$p < 0.01$,***$p<0.001$).

†2-dimensional distance (on x axis) from the lateral tibial plateau was also calculated for each of the ligament attachment points on the femur, tibia, or fibula, at 0º as measurement of distance to the joint line.



B) Summary of ligament lengths (mean ± SD, in mm) at each flexion angle.

Ligament	0° (mm)	15° (mm)	30° (mm)	45° (mm)	60° (mm)	90° (mm)
ALL	47.51 ± 10.97	46.13 ± 11.55	44.86 ± 12.52	43.04 ± 12.65	41.07 ± 13.89	41.08 ± 12.7
FCL	59.38 ± 9.7	58.14 ± 7.87	56.49 ± 7.5	55.33 ± 7.01	54.02 ± 6.5	51.79 ± 6.56
Gerdy to Distal Kaplan Fibers	66.38 ± 11.66	68.39 ± 11.59	70.39 ± 11.66	71.51 ± 11.38	71.84 ± 11.5	65.6 ± 18.72
Gerdy to Proximal Kaplan Fibers	83.41 ± 11.1	86.31 ± 11.71	88.37 ± 12.93	89.24 ± 12.89	88.99 ± 13.04	79.42 ± 20.28

C) Comparison of mean ligament lengths at 0° and 90° of flexion with paired t-test results.

Ligament	Mean 0°	Mean 90°	Mean Difference	p.value
FCL	59.38	51.79	7.59	**0.004**
ALL	47.51	41.08	6.44	**0.02**
Gerdy to Distal Kaplan Fibers	66.38	65.60	0.78	0.853
Gerdy to Proximal Kaplan Fibers	83.41	79.42	3.99	0.506

Figure 2: A&B) Lengths were calculated as the 3D distance between anatomical insertion points for the anterolateral ligament (ALL), fibular collateral ligament (FCL), and iliotibial band (ITB) fibers extending from Gerdy's tubercle to the proximal and distal Kaplan fibers. Measurements were taken at 0°, 15°, 30°, 45°, 60°, and 90° of knee flexion. While the FCL and ALL demonstrated progressive shortening with increased flexion, the Gerdy-to-Kaplan fiber distances remained relatively stable across angles. C) Both the FCL and ALL exhibited statistically significant reductions in length between full extension and deep flexion, while no significant length changes were observed for the Gerdy-to-Kaplan fiber distances.