Morphologic Study of the Lateral and Medial Collateral Ligaments of the Human Knee

By

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Summary: The collateral ligaments of the knee are important in maintaining knee stability. Numerous studies have been described the morphology and function of the ligaments of the knee. However, little data was given about the lateral and medial collateral ligaments simultaneously. The objective of the present study was to compare the morphology of the lateral (LCL) and medial (MCL) collateral ligaments in human knees. We dissected 34 cadaver knees and examined the size, attachment and inclination of the LCL and the MCL. In both of them, the posterior bundle was longer than that of the anterior bundle. The anterior and posterior bundles of the MCL were longer than that of the LCL. The proximal attachment of the MCL situated more anterior and superior than that of the LCL. As compared with the LCL, the distal attachment of the MCL located a little forward and inferior. The longitudinal diameter of the attachment of ligaments was longer than the transverse one, except for the proximal attachment of the MCL. The size of the attachments of the MCL was larger than that of the LCL except for the longitudinal diameter of the proximal attachment. At full extension of the knee, the inclination of the MCL was backward, while that of the LCL was forward. These data showed that the LCL and MCL had the different structural properties. It may provide a better understanding of the function of the collateral ligaments.

The human knee collateral ligaments play an important role in maintaining knee stability (Kapandji, 1983; Grood *et al.*, 1988; Liow *et al.*, 2003; Robinson *et al.*, 2004; Park *et al.*, 2005; Espregueira-Mendes and da Silva, 2006; Wymenga *et al.*, 2006). The medial collateral ligament (MCL) may be injured alone or in combination with the anterior cruciate ligament (ACL). Injury of the lateral collateral ligament (LCL) often accompanies ruptures of the posterior cruciate ligament (PCL). There have been a number of studies concerning the morphology and biomechanics of the LCL and MCL (Warren *et al.*, 1974; Bartel *et al.*, 1977; Nomura *et al.*, 1989; Sugita and Amis, 2001; Robinson *et al.*, 2004; Espregueira-Mendes and da Silva, 2006). Although the function of the LCL is somewhat complex, the primary role is to restrain abnormal motion. Many studies have shown that the LCL is the major restraint to primary varus rotation at all positions of knee flexion (Warren and Marshall, 1979; Grood *et al.*, 1988; Suda *et al.*, 1993; Shahne *et al.*, 1999; Meister *et al.*, 2000; Sugita

and Amis, 2001; Espregueira-Mendes and da Silva, 2006). The MCL complex has recently been divided into three main structures: the longitudinal fibers of the superficial MCL, the deep MCL (Fetto and Marshall, 1978) and the posteromedial capsule (Robinson *et al.*, 2004). Previous studies have treated the MCL as a whole and did not distinguish the different parts of the ligament. Some anatomical studies, however, identified them (Kennedy *et al.*, 1976; Murase *et al.*, 1985; Robinson *et al.*, 2005). They reported the structural properties of these three individual structures (Robinson *et al.*, 2005). In the present study, we examined the size, attachment and inclination of the superficial MCL, not deep one. The MCL has been shown to resist valgus moments and anterior loads beyond 60° of flexion (Robinson *et al.*, 2004). The MCL has also been considered to stabilize the knee in response to anterior tibial loads after ACL injury. It was described that the length of the MCL and LCL changed with knee flexion (Bartel *et al.*, 1977; Park *et al.*, 2005). There are few reports concerning the

Fig. 1. Attachment site of the LCL of the left knee joint. Fig. 1a: Photograph. Fig. 1b: Schematic drawing. A: the anterior margin of the lateral condyle; B: the center of the proximal attachment; C: the posterior margin of the lateral condyle; D: the inferior margin of the lateral condyle; E: the anterior margin of the lateral condyle; F: the anterior margin of the fibular head; G: the center of the distal attachment; H: the anterior margin of the tibia; I: the posterior margin of the fibular head; J: the superior margin of the lateral tibial plateau; θ : the inclination of the longitudinal axis of the LCL.

LCL and MCL simultaneously the same knee. The purpose of the present study was to investigate and compare the structural properties of the LCL and MCL of the same knee.

Materials and Methods

We used 18 right and 16 left knees from 6 male and 17 female cadavers. They showed no particular pathologic findings on the bone and joint. The average age of cadavers was 79.5 ± 9.5 years (age range 64–98 years old). The bones were cut about 150 mm above and below the knee joint. The muscles were removed from the femur, tibia and fibula, preserving the ligaments and joint capsule intact. When the LCL and MCL were identified, the pattern and definition of the structures were examined. At full extension of the knee joint, we measured and recorded the position and the size of the at-

tachments and the length of the LCL (Fig. 1a) and MCL (Fig. 2a) by using a slide caliper, as followed. In the sagittal plane, we measured (i); the anteroposterior distance of the lateral femoral condyle (Fig. 1a, AC), and (ii); the distance of the center of proximal attachment of the LCL from the anterior margin of the lateral femoral condyle (Fig. 1a, AB). The center of the proximal attachment was shown as the percentage (ii/i). We measured (iii); the superoinferior distance of the lateral femoral condyle from the inferior margin (Fig. 1a, DE) and (iv); the distance of the center of proximal attachment of the LCL from the inferior margin of the lateral femoral condyle (Fig. 1a, DB). The center of the proximal attachment was shown as the percentage (iv/iii). We measured (v); the anteroposterior distance of the fibular head (Fig. 1a, FI) and (vi); the distance of the center of distal attachment of the LCL from the anterior margin of the fibular head (Fig. 1a, FG). Furthermore, we measured (vii); the ante-

Fig. 2. Attachment site of the MCL of the left knee joint. Fig. 2a: Photograph. Fig. 2b: Schematic drawing. a: the anterior margin of the medial condyle; b: the center of the proximal attachment; c: the posterior margin of the medial condyle; d: the inferior margin of the medial condyle; e: the anterior margin of the medial condyle; f: the anterior margin of the tibia; g: the center of the distal attachment; h: the superior margin of the medial tibial plateau; ϕ : the inclination of the longitudinal axis of the MCL.

roposterior distance between anterior margin of the tibia and posterior margin of the fibular head (Fig. 1a, HI) and (viii); the distance of the center of distal attachment of the LCL from the anterior margin of the tibia (Fig. 1a, HG). The center of the distal attachment was shown as the percentage (vi/v), (viii/vii). We measured the superoinferior distance of the center of distal attachment of the LCL from the lateral plateau of tibia (Fig. 1a, JG). We measured and calculated them about the MCL by the same way (Fig. 2a). We measured the length of the anterior and posterior bundles of the LCL and MCL (Figs. 3, 4) and the size of the attachment area of the LCL and MCL (Figs. 5, 6). We measured the longitudinal and transverse diameters of the proximal attachment of the LCL and MCL respectively. The angle between the longitudinal axis of the collateral ligaments and the long axis of the tibia (inclination of the longitudinal axis of the LCL, MCL) was measured. Furthermore, the angle between the attachment bundles and the frontal plane or the long axis of the tibia (inclination of the proximal

and distal attachment bundle of the LCL, MCL) was evaluated with a protractor.

All data were presented as means $\pm$ SD. The statistical analysis was performed using unpaired t-test (Microsoft Office Excel). P values of <0.05 in the analyses were considered as statistically significant.

Results

1) The shape of the proximal and distal attachments of the LCL and MCL

The LCL was a cord-like ligament, extending inferiorly from the lateral epicondyle of the femur to the lateral surface of the fibular head. It had a semicircular-shaped attachment on the femoral condyle, with well-defined limits. The fibular attachment of the LCL had a fan-like shape. Its most lateral fibers continued distally as a reinforcement of the fascia over the peroneus longus muscle of the lateral compartment of the leg (Fig. 1a). The MCL

Fig. 3. The length of the LCL of the left knee joint. KP: the anterior length of the bundle; MR: the posterior length of the bundle.

Fig. 4. The length of the MCL of the left knee joint. in: the anterior length of the bundle; kp: the posterior length of the bundle.

Fig. 5. The size of the LCL attachment area of the left knee joint. MN: longitudinal diameter of the femoral attachment; LN: transverse diameter of the proximal attachment; QR: longitudinal diameter of the distal attachment; OQ: transverse diameter of the distal attachment; KLMN: proximal attachment area; B: the center of the proximal attachment; OPRQ: distal attachment area; G: the center of the distal attachment; θ_1 : the inclination of the proximal attachment bundle of the LCL; θ_2 : the inclination of the distal attachment bundle of the LCL.

was a flat band that extended from the medial epicondyle of the femur to the medial condyle and the superior part of the medial surface of the tibia. The proximal attachment of the MCL was oval in shape and the distal attachment had a trapezoid shape (Fig. 2a).

2) The proximal and distal attachments of the LCL (Fig. 1)

The mean distance between the anterior and posterior margins of the lateral femoral condyle was 59.9 ± 5.0 mm (range 50.2–69.0 mm, Fig. 1a, AC). The mean distance between the anterior margin of the lateral femoral condyle and the center of the proximal attachment of the LCL was 40.6 ± 3.7 mm (range 33.7–48.0 mm, Fig. 1b, AB). The center of the femoral attachment was $67.9 \pm 3.2\%$ posterior from the anterior margin of the lateral condyle (Fig. 1, AB).

Fig. 6. The size of the MCL attachment area of the left knee joint. kl: longitudinal diameter of the proximal attachment; jl: transverse diameter of the proximal attachment; op: longitudinal diameter of the distal attachment; mo: transverse diameter of the distal attachment; ijl: proximal attachment area; b: the center of the proximal attachment; mnpo: distal attachment area; g: the center of the distal attachment; $\phi 1$: the inclination of the proximal attachment bundle of the MCL; $\phi 2$: the inclination of the distal attachment bundle of the MCL.

The mean distance between the superior and inferior margin of the lateral femoral condyle was 38.9 ± 4.1 mm (range 33.0–47.0 mm, Fig. 1 β , DE). The mean distance between the inferior margin of the lateral femoral condyle and the center of the proximal attachment was 22.9 ± 3.2 mm (range 15.0–31.0 mm, Fig. 1 β , DB). The center of the proximal attachment was $59.1 \pm 7.5\%$ superior from the inferior margin of the lateral femoral condyle.

The mean distance between the anterior and posterior margin of the fibular head was 25.8 ± 2.8 mm (range 23.0–32.0 mm, Fig. 1 β , FI). The mean distance between the anterior margin of the fibular head and the center of the distal attachment was 13.0 ± 2.7 mm (range 8.0–20.0 mm, Fig. 1 β , FG). The center of the distal attachment was $50.5 \pm 9.6\%$ posterior from the anterior margin of the fibular head.

The mean distance between the anterior margin

of the tibia and the posterior margin of the fibular head was 59.5 ± 5.9 mm (range 48.0–70.0 mm, Fig. 1 β , HI). The mean distance between the anterior margin of the tibia and the center of the distal attachment was 44.5 ± 6.1 mm (range 31.0–59.0 mm, Fig. 1 β , HG). The center of the distal attachment was $74.7 \pm 6.8\%$ posterior from the anterior margin of the tibia. The mean distance between the superior margin of the lateral tibial plateau and the center of the distal attachment was 25.3 ± 3.6 mm (range 19.0–35.0 mm, Fig. 1 β , JG).

3) The proximal and distal attachments of the MCL (Fig. 2)

The mean distance between the anterior and posterior margin of the medial femoral condyle was 56.1 ± 6.5 mm (range 33.2–67.0 mm, Fig. 2 α , ac). The mean distance between the anterior margin of the medial femoral condyle and the center of the proximal attachment of the MCL was 27.7 ± 5.1 mm (range 18.4–39.7 mm, Fig. 2 β , ab). The center of the proximal attachment was $49.4 \pm 7.1\%$ posterior from the anterior margin of the medial femoral condyle.

The mean distance between the superior and inferior margin of the medial femoral condyle was 40.1 ± 3.2 mm (range 35.0–47.0 mm, Fig. 2 β , de). The mean distance between the inferior margin of the medial femoral condyle and the center of the proximal attachment was 27.7 ± 3.8 mm (range 21.0–38.0 mm, Fig. 2 β , db). The center of the proximal attachment was $69.1 \pm 6.5\%$ superior from the inferior margin of the medial femoral condyle.

The mean distance between the anterior and posterior margin of the tibia was 56.6 ± 4.8 mm (range 48.0–65.0 mm, Fig. 2 β , fq). The mean distance between the anterior margin of the tibia and the center of the distal attachment was 23.1 ± 2.8 mm (range 18.0–29.0 mm, Fig. 2 β , fg). The center of the distal attachment was $40.9 \pm 3.8\%$ posterior from the anterior margin of the tibia. The mean distance between the superior margin of the medial tibial plateau and the center of the distal attachment was 49.9 ± 4.8 mm (range 41.0–64.0 mm, Fig. 2 β , hg).

4) Comparison of the attachments of the LCL and MCL

The proximal attachment of the LCL was 67.9% posterior, while that of the MCL was 49.4% posterior from the anterior margin of the femoral condyle. The center of the proximal attachment of the MCL was more anterior than that of the LCL ($p < 0.05$). The proximal attachment of the LCL was 59.1% superior, while that of the MCL was 69.1% superior from the inferior margin of the

femoral condyle. The proximal attachment of the MCL was more superior than that of the LCL ($p < 0.05$).

The distal attachment of the LCL was 50.5% posterior from the anterior margin of the fibular head and 74.7% posterior from the anterior margin of the tibia. The distal attachment of the MCL was 40.9% posterior from the anterior margin of the tibia. The distal attachment of the LCL situated just at the center of the fibular head, while that of the MCL was a little forward.

The distal attachment of the LCL was 25.3 mm inferior, while that of the MCL was 49.9 mm inferior from the superior margin of the tibial plateau. The distal attachment of the MCL was more inferior than that of the LCL ($p < 0.05$).

5) The length of the anterior and posterior bundles of the LCL and MCL (Figs. 3, 4)

The mean length of the anterior and posterior bundles of the LCL was 52.9 ± 7.3 mm (range 35.6–70.0 mm) and 54.6 ± 7.2 mm (range 37.8–73.0 mm) respectively (Fig. 3). The mean length of the anterior and posterior bundles of the MCL was 80.1 ± 7.4 mm (range 70.0–100.0 mm) and 92.2 ± 8.0 mm (range 76.8–110.0 mm) respectively (Fig. 4). The length of the MCL was significantly longer than that of the LCL for both anterior and posterior bundles ($p < 0.05$). The length of the posterior bundle of the MCL was significantly longer than that of the anterior one ($p < 0.05$). There was no significant difference between the length of the anterior and posterior bundles of the LCL.

6) The size of the attachment area of the LCL and MCL (Figs. 5, 6)

The longitudinal and transverse diameters of the proximal attachment of the LCL were 11.0 ± 1.3 mm (range 8.0–13.0 mm) and 8.8 ± 0.9 mm (range 7.0–10.0 mm) respectively (Fig. 5, MN, LN). The longitudinal diameter of the LCL attachment was significantly longer than that of the transverse one ($p < 0.05$).

The longitudinal and transverse diameters of the proximal attachment of the MCL were 9.4 ± 1.6 mm (range 6.8–13.0 mm) and 11.3 ± 1.0 mm (range 9.7–14.0 mm) respectively (Fig. 6, kl, jl). The transverse diameter of the MCL attachment was significantly longer than that of the longitudinal one ($p < 0.05$).

The longitudinal and transverse diameters of the distal attachment of the LCL were 11.9 ± 1.3 mm (range 10.0–16.0 mm) and 6.8 ± 1.0 mm (range 5.0–10.0 mm) respectively (Fig. 5, QR, OQ). The longitudinal diameter of the LCL attachment was

significantly longer than that of the transverse one ($p < 0.05$).

The longitudinal and transverse diameters of the distal attachment of the MCL were 16.6 ± 3.7 mm (range 10.0–25.0 mm) and 9.5 ± 1.6 mm (range 7.0–15.0 mm) respectively (Fig. 6, op, mo). The longitudinal diameter of the MCL attachment was significantly longer than that of the transverse one ($p < 0.05$).

The size of the MCL attachment was larger than that of the LCL attachment, except for the longitudinal diameter of the femoral attachment.

7) The inclination of the LCL and MCL (Figs. 5, 6)

The angle between the proximal attachment of the LCL and the frontal plane (θ_1) was $18.1 \pm 4.6^\circ$ (range 5° – 30°) and the angle between the distal attachment of the LCL and the tibial longitudinal axis (θ_2) was $11.4 \pm 5.0^\circ$ (range 3° – 25°) in the sagittal plane (Fig. 5). The proximal and distal attachment bundles of the LCL showed the forward inclination. The angle between the longitudinal axis of the LCL and the tibial longitudinal axis was $16.7 \pm 4.6^\circ$ (range 10° – 27° , Fig. 1a, θ), showing the forward inclination.

The angle between the proximal attachment of the MCL and the frontal plane (ϕ_1) was $0.6 \pm 6.9^\circ$ (range forward 10° –backward 10°). The angle between the distal attachment of the MCL and the tibial longitudinal axis (ϕ_2) was $18.3 \pm 2.5^\circ$ (range 15° – 23° , Fig. 6), demonstrating the backward inclination. The angle between the longitudinal axis of the MCL and the tibial longitudinal axis was $19.1 \pm 3.6^\circ$ (range 10° – 23° , Fig. 2a, ϕ) and revealed the backward inclination.

Discussion

The anatomy of the lateral and medial aspects of the human knee is complex arrangement of static (ligaments) and dynamic (tendons and muscles) stabilizing structures (Warren *et al.*, 1979; Sugita *et al.*, 2001; Pasque *et al.*, 2003; Robinson *et al.*, 2004; Espreguieria-Mendes and da Silva, 2006). Few studies have compared the structural properties of the LCL and MCL (Park *et al.*, 2005). The present study examined and compared the morphology of the LCL and MCL in the same knee.

The LCL was a rounded bundle and extended from the lateral epicondyle of the femur to the lateral surface of the fibular head. It had a semicircular-shaped attachment on the femoral condyle. The distal attachment of the LCL had a fan-like shape (Espreguieria-Mendes and da Silva, 2006). The superficial MCL was a flat sheet and

extended from the medial epicondyle of the femur to the medial condyle and the superior part of the medial surface of the tibia. The proximal attachment of the MCL was oval in shape and the distal attachment had a trapezoid shape (Robinson *et al.*, 2004). These were similar to our result.

In the present study, the mean distance between the anterior and posterior margin of the lateral femoral condyle was about 60 mm and that of the medial femoral condyles was about 56 mm. We found that the proximal attachment of the LCL was 68% posterior from the anterior margin of the lateral femoral condyle. Similar results were found in the literatures (Suda *et al.*, 1992; Espregueira-Mendes and da Silva, 2006). The proximal attachment of the MCL was about 50% posterior from the anterior margin of the medial femoral condyle (Nomura *et al.*, 1989). The distal attachment of the LCL was about 50% posterior from the anterior margin of the fibular head, situated just at the center of the fibular head (Suda *et al.*, 1992). It was described that the proximal tibiofibular joint was variable and this could be correlated with the functions of the soft tissue structures attaching to the fibular head (Sugita and Amis, 2001).

In the present study, we found that the mean distance between the superior and inferior margin of the lateral and medial femoral condyles was almost the same, about 40 mm. The proximal attachment of the LCL was about 60% superior from the inferior margin of the lateral femoral condyle. The proximal attachment of the MCL was more superior than that of the LCL, at about 70% superior from the inferior margin of the medial femoral condyle. The mean distance between the superior margin of the lateral tibial plateau and the distal attachment of the LCL was 25 mm. The mean distance between the superior margin of the medial tibial plateau and the distal attachment of the MCL was 50 mm. The distal attachment of the MCL located more inferior than that of the LCL. We expect that these data are useful for localizing the center of the attachment of the LCL and MCL during surgical repair of these ligaments.

Esprequeira-Mendes and da Silva (2006) examined the histology of the LCL from 20 male cadavers with the mean age of 50 years. They reported that the length of the anterior bundle of the LCL was 63 mm. In the present study we used 6 male and 17 female cadavers with the mean age of 79.5 years. The length of the anterior bundle of the LCL was shorter than that of their report. The length depends on the sex and age of the cadavers. The length of the anterior and posterior bundle of the MCL was reported to be about 85 mm and 100 mm respectively (Nomura *et al.*, 1989; Manabe

et al., 1990). Similar results were found in the present study. From the above results, both anterior and posterior bundles of the MCL were longer than those of the LCL. The posterior bundle length was longer than the anterior one. This difference causes the movement variation of the anterior and posterior bundles at knee flexion (Bartel *et al.*, 1977). It was reported that the anterior bundle of the LCL became longer and the posterior one became shorter with the knee flexion (Wang *et al.*, 1974; Park *et al.*, 2005). The length of the anterior bundle of the MCL had no marked change and the posterior bundle became consistently shorter with the knee flexion, suggesting that the posterior bundle of the MCL might be tight in the full extension (Park *et al.*, 2005). Ries *et al.* (2003) stated that the medial and lateral soft tissue balance was dependent on the length of the collateral ligaments. The soft tissue constraint in flexion was dependent on the structural integrity of the collateral ligaments. When one of the collateral ligaments loosened, the soft tissue balance might not be achieved during the knee flexion.

As to the size of the proximal attachments, the longitudinal diameter of the LCL was longer than the transverse one (Esprequeira-Mendes and da Silva, 2006). However, the longitudinal diameter of the MCL was shorter than the transverse one (Suda *et al.*, 1992). For the distal attachment, the longitudinal diameter of the LCL and MCL was longer than that of the transverse one (Suda *et al.*, 1992; Esprequeira-Mendes and da Silva, 2006). The size of the distal attachment of the MCL was largest, and the size of the proximal attachment of the LCL was larger than that of the distal one. Ligamentous reconstruction might be performed by using autograft or allograft tendons for collateral ligamentous instability and the autograft or allograft should be fixed at the normal attachment sites to restore isometry (Nelson *et al.*, 2003). Our results may be beneficial in deciding the fixation point and size of the ligaments.

The proximal and the distal bundles of the LCL showed forward inclination same as the Suda's report (1992). The distal bundle of the MCL demonstrated the backward inclination. It was reported that the inclination of the LCL changed from forward to backward with the knee flexion, while the MCL showed backward inclination even though the knee was flexed (Kapandji, 1983; Meister *et al.*, 2000).

As for the LCL, the inclination of the proximal attachment bundle and the inclination of the distal attachment bundle and the inclination of the longitudinal axis of the LCL was almost same. As for the MCL, the inclination of the distal attachment bun-

dle was similar to the inclination of the longitudinal axis of the MCL. But the inclination of the proximal attachment bundle was different from the inclination of the distal attachment bundle and the inclination of the longitudinal axis of the MCL. Future examination is needed about this point.

In conclusion, the present study demonstrated that the MCL was longer than the LCL. The proximal attachment of the MCL was more anterior and superior than that of the LCL. As compared with the LCL, the distal attachment of the MCL located a little forward and inferior. The inclination of the MCL was backward, while that of the LCL was forward. The inclination of the proximal and distal attachment bundles of the LCL was similar to the inclination of the longitudinal axis of the LCL. The inclination of the proximal attachment bundle was different from both the inclination of the distal attachment bundle and the inclination of the longitudinal axis of the MCL. These results showed that the morphological properties of the LCL and MCL were different. It may provide a better understanding of the function of the collateral ligaments.

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