Ultrasonographic assessment of the anterolateral ligament of the knee in healthy subjects

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Summary

Objective: **The aim of our study was to determine inter-observer agreement in the ultrasonographic identification of the anterolateral ligament (ALL) and in the evaluation of its length and thickness in healthy subjects.**
Methods: **80 healthy volunteers (160 knees) (42 males and 38 females) were enrolled in the study. All subjects underwent ultrasound (US) examination of both knees, performed by two physicians with over ten years of musculoskeletal US experience. In order to keep the ALL under optimal tension, the knee was flexed at approximately 30-35°, slightly internally rotated and length and thickness of the ligament were measured.**
Results: **ALL was identified in 93.8% (150 out of 160) and in 92.5% (148 out of 160) of the knees by Evaluator 1 and Evaluator 2, respectively. Inter-observer agreement was substantial to almost perfect for the visualization of the ALL (=0.90) and for measurements of its length (ICC = 0.83), and strong for measurements of its thickness (ICC = 0.75).**
Conclusion: **In our study on healthy subjects, ALL has been visualized with a high rate of reproducibility. Further studies are needed to see if US may be a reliable and reproducible diagnostic tool in patients with traumatic or degenerative knee disorders.**
Level of evidence*:* II, evidence obtained from cohort study.

KEY WORDS: anatomy, anterolateral ligament, knee, ultrasound.

Introduction

In the last few years, the anterolateral ligament (ALL) of the knee has been investigated by several Authors. This structure, described by Segond in 1879 as "a pearly, resistant, fibrous band"[1], recognized by Campos et al. in 2001 as "anterior oblique band"[2], and subsequently defined by Vieira et al. and Claes et al. as "anterolateral ligament" (ALL)[3,4], appears to play a role in rotational stability of knee[5-8]. In particular, Parsons et al. identified the ALL as an important stabilizer of the knee internal rotation at a flexion angle greater than 35°[7].
The identification and description of this ligament, was carried out with magnetic resonance imaging (MRI) *in vivo* and in anatomic dissection with different percentages of sensitivity[9-13].
At present only three studies identify the ALL on ultrasound (US) imaging. In 2014, Cianca et al. reported an ultrasonographic description of the ALL in a case report[14]; in 2015, Cavaignac et al. studied US sensitivity in the detection of the ALL in 18 cadaveric knees[15]; lastly, in a recently published study, Oshima et al. evaluated the efficacy of US in demonstrating ALL in 9 healthy subjects[16].
Therefore, the aim of this study was to determine inter-observer agreement of the ultrasonography in the identification of the ALL and in the evaluation of its length and thickness in healthy subjects.

Materials and methods

Subject recruitment
Between March and October 2015, 80 healthy volunteers (160 knees) (42 males and 38 females) were

Table I. Characteristics of subjects.

Characteristic	(no.= 80)
Age, mean ± SD (range), y	31.4 ± 5.6 (19 - 40)
Sex, no. (%)	
Men	42 (52.5)
Women	38 (47.5)
Height, mean ± SD (range), cm	171.1 ± 9.5 (152 - 192)
BMI, mean ± SD (range), kg/m^2	24.2 ± 4.3 (16.3 - 36.5)

Legenda: no., number; SD, standard deviation; y, years; cm, centimeters; BMI, Body Mass Index; kg/m^2, weight(kilograms)/$height^2$($meters^2$).

enrolled in the study after having previously signed an informed consent[17]. The characteristics of the study sample are shown in Table I.

Exclusion criteria were: concomitant knee disorders or history of knee injuries with or without capsulo-ligament lesion, and previous knee surgery. For every subject, we recorded clinical data included age (years), gender (male, female), height (m), and body mass index (kg/m^2).

This study was approved by the Review Board of our Institution.

Ultrasound evaluations

All US examinations were performed independently and separately by two medical doctors with at least ten years' experiences in musculoskeletal US, A.G. (Evaluator 1; musculoskeletal radiologist) and M.V. (Evaluator 2; Physical Medicine and Rehabilitation Specialist and sonographer), using a state of the art sonographic unit (MyLab™ Twice, Esaote, Genova, Italy) with a 3-13 MHz linear array probe suitable for musculoskeletal tissues (LA533, Esaote, Genova, Italy).

Subjects were lying on the lateral decubitus on the opposite hip. For an optimal evaluation of the ALL, knees were flexed at approximately 30-35° and slightly internally rotated, in order to keep the ligament un.der optimal tension[7].

The ultrasonographic evaluation started by recognizing the Gerdy's tubercle on the anterolateral margin of the tibia, where the iliotibial band has its distal insertion. When using a longitudinal view, the ALL appeared as a hyperechoic structure localized deeply and posteriorly to the iliotibial band (Fig. 1). A second reference anatomical identification point at the distal portion of the ALL, near to its insertion on the tibia, was the recognition of the lateral inferior branch of the geniculate artery (LIGA)[4,16]; this small artery was identified using color-doppler or power Doppler settings. Once the distal portion of the ligament was visualized, ALL relationship with the lateral meniscal body was evaluated[4,16,18]. Then the proximal portion of the ALL was followed until its origin on the lateral femoral condyle above the popliteal fossa.

After having identified an optimal US orientation for the entire visualization of the ALL, its length and thickness were quantified in millimeters on both knees. As a standardized reference, ligament thickness was measured at the level of its distal portion just below the lateral meniscus and above the hyperechoic line drown by the tibial proximal epiphysis.

Each evaluator stored his images and measurements on a PACS – picture archiving and communication

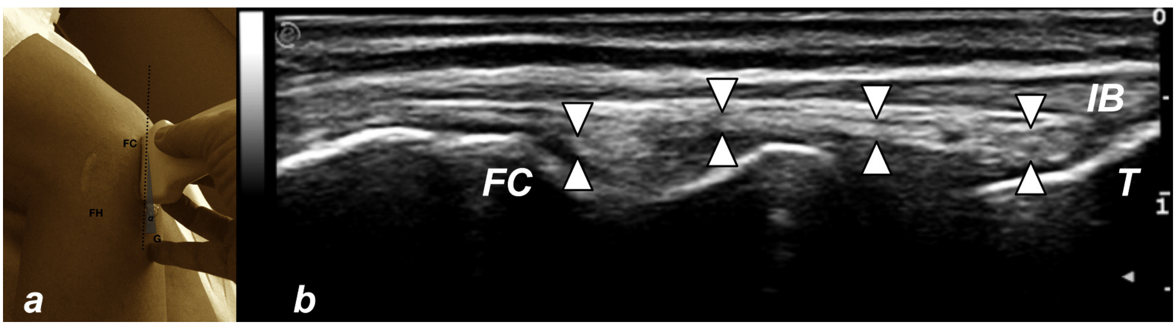

Figure 1 a, b. a. Photograph showing the correct position of the patient for an optimal evaluation of the ALL (lateral decubitus on the opposite hip, with knee flexed at approximately 30-35°s and slightly internally rotated).
Legenda: FC, femoral condyle; FH, fibular head; G, Gerdy tubercle; alfa, inclination angle from the Gerdy tubercle. b. Male, 27y. US longitudinal scan showing the ALL (arrowheads) as a hyperechoic structure localized deeply and posteriorly to the iliotibial band. Legenda: FC, femoral condyle; T, tibial insertion; IB, iliotibial band.

system – (Centricity PACS RA1000 Workstation, GE Healthcare Integrated). IT Solutions, Barrington, IL, USA) using its Advanced Windows Suite for measurements and imaging evaluations. All the stored US images were jointly reviewed by both evaluators together with an orthopedic surgeon (M.C.V), who has decades of experience in musculoskeletal US, and with two musculoskeletal radiologists (L.C. and A.B.) with experience in ultrasound imaging, in order to obtain a consensus opinion regarding ALL identification and its meniscal relationship.

Statistical analyses

US identification (complete, partial or absent visualization) of the ALL by both evaluators was chosen as primary outcome, whereas measurable quantification of the length and thickness of ALL was defined as secondary outcome.

Cohen's kappa coefficient (κ) was used to determine inter-observer agreement on the visibility of the ALL, and intraclass correlation coefficient (ICC) with 95% confidence interval (CI) for the assessment of consistency and reproducibility of quantitative measurements (ALL length and thickness). Coefficient values were interpreted as follows: 0-0.20 indicates poor agreement: 0.21-0.40 indicates fair agreement; 0.41-0.60 indicates moderate agreement; 0.61-0.80 indicates strong agreement; and >0.8 indicates almost perfect agreement[19].

Logistic regression models were performed for both evaluators independently to correlate the visibility of the ALL *vs* age, gender, height, BMI, and knee side. P-value was calculated for each coefficient, and a p-value <0.05 suggested a significant relationship between the two variables.

All statistical analyzes were performed using the IBM SPSS Statistics for Macintosh, Version 21.0 (Armonk, NY: IBM Corp).

Results

ALL was identified in 150 out of 160 patients by Evaluator 1, whereas Evaluator 2 was able to identify the ALL in 148 out of 160 patients. Evaluator 2, in fact, did not identify ALL in two knees that Evaluator 1 did visualize. Data from both evaluators are shown in Table II.

Once the distal part of the ligament had been identified, a complete visualization of the ALL was obtained by both operators; there were no cases of partial visualization of the ALL. Inter-observer agreement was substantial to almost perfect for the visualization of the ALL (κ=0.90). There was no correlation between ALL visibility with regard to age, gender, height, BMI, or knee side (P>0.05) for each evaluator.

A close relationship between the body of the lateral meniscus and the distal band of the ALL could be seen in all visualized cases. Nevertheless, it was not possible to clearly define fibers connecting the ALL and the lateral meniscus by using the long axis plane. The LIGA was detected in all the cases, in 84% of the cases (123 out of 148 of the ALL identified by both evaluators) it was superficial to the ALL; in 3.8% of the knees (7 out of 148) the LIGA was crossing ALL having a deeper anatomical situation, and in 12.2% (18 out of 148 of the ALL) it was identified having a direct relation with its distal band, crossing it approximately at its half-length between the meniscus and its distal attachment.

Quantitative measurements of length and thickness obtained by both evaluators are shown in Table II. The inter-observer reliabilities for the measurements of length and thickness were almost perfect (ICC = 0.83; 95% CI, 0.75 to 0.88) and strong (ICC = 0.75; 95% CI, 0.65 to 0.82), respectively.

Discussion

Recently, the ALL of the knee was identified by MRI studies, cadaveric anatomical dissections and finally by ultrasonographic evaluations[6,16,18].

The ALL shares its origin on the lateral femoral condyle with the lateral collateral ligament (LCL). Two anatomic variations of the ALL femoral insertion have

Table II. Results data from both evaluators.

Data	Evaluator 1	Evaluator 2	Inter-observer agreement
ALL visualization, no. (%)			*0.902*[a]
Complete	150 (93.8)	148 (92.5)	
Partial	-	-	
Not visible	10 (6.2)	12 (7.5)	
ALL length mean ± SD (range), mm	33.0 ± 2.1 (28.5 – 36.1)	33.4 ± 1.7 (29.2 – 35.9)	*0.826*[b]
ALL thickness mean ± SD (range), mm	2.2 ± 0.4 (1.5 – 3)	2.2 ± 0.3 (1.7 – 2.8)	*0.748*[b]

Legenda: ALL, anterolateral ligament of the knee; no., number; SD, standard deviation; mm, millimeters; [a] Cohen's kappa coefficient (κ); [b] Intraclass Correlation Coefficient (ICC).

been described[7,20]. Caterine et al.[9] and Helito et al.[10,18] have described the ALL femoral insertion as anterior or antero-distal to that of the LCL. Dodds et al.[21] and Cavaignac et al.[15] have found the ALL to be posterior to the LCL at its femoral insertion. ALL runs obliquely parallel but deep to the iliotibial band (ITB). Dodds et al. described the ALL as an extracapsular ligamentous structure superficial to the LCL and the joint capsule, with branching attachments to the lateral meniscus[21]. Claes et al.[4], Caterine et al.[9] and Helito et al.[11] confirmed that this ligament had attachments to the lateral meniscus. The distal insertion site of the ALL was described to be midway between the Gerdy tubercle and the fibular head, on the anterolateral proximal tibia[3,4,9,10,12,14-16,18,21,22].

Several studies have analyzed the ALL length at different knee range of motion: Caterine et al. have found that the mean length in extension was 40.3 ± 6.2 mm[9], Claes et al. have measured it at 90° of flexion as 41.5 ± 6.7 mm and in extension as 38.5 ± 6.1 mm[4], and Vincent et al. found it to be 34.1 ± 3.4 mm at 90° of flexion[22].

In our study, ALL was recognized using US in healthy subjects and an appropriate technical procedure was described for its recognition. A 30-35° of knee flexion was used as previously suggested by Parson's biomechanical essay[7], and recently adopted in Oshima's study[16]. Cianca et al. described a different approach in the identification of the ALL using 90° flexion of the knee[14]. To better visualize the ALL, we applied a slight internal rotation of the tibia as described by Cianca in his case report[14], and used by Cavaignac et al. in their cadaveric study on 20 knees[15].

In our experience, the visualization of the ALL is possible if all landmarks are recognized (Fig. 2). With this technical approach, in our study an almost perfect inter-observer agreement for the visualization of the ALL was obtained by both evaluators, with a Cohen's kappa coefficient of 0.90. Observer 1 was able to identify ALL in 150/160 knees, while Observer 2 did not visualize ALL in 12 knees, the same 10 of Observer 1 and two others more. We are not able to surely affirm that the ALL was not present in 6.25% of all 160 knees (10/160) because knee MRI or surgical exploration were not performed in our cohort of healthy subjects.

US, with its dynamic real time evaluation, has a pivotal advantage in the clear distinction of the ALL. In agreement with Cavaignac et al., in our ultrasound procedure, US identification of the distal tract of the iliotibial band has been used as a first targeting point in our ALL evaluation method, and it has proved to be a very easy technique to reproduce both in the single observer and among the two of them[15]. In fact, the ALL distal tract, running between the body of the lateral meniscus and its tibial insertion, is easier to identify once it has been distinguished from the iliotibial band. The distal part of the ALL appears as a hyperechoic band and the LIGA (lateral inferior geniculate artery) can be used as a second easy anatomical reference landmark (Fig. 3). In our sample, the LIGA could be detected in all the cases, and we could observe a certain degree of anatomical variation of its actual relationship with the ALL. In most cases LIGA was identified in a superficial situation, but in 3.8% of the knees in our series LIGA was crossing ALL, and in 12.2% (18 out of 148 of the ALL identified by both evaluators) it could be identified having a direct relation with its distal band. In our study, no clear demonstration of fibers directly connecting the body of the lateral meniscus with the ALL was possible, as Oshima stated in his work[16].

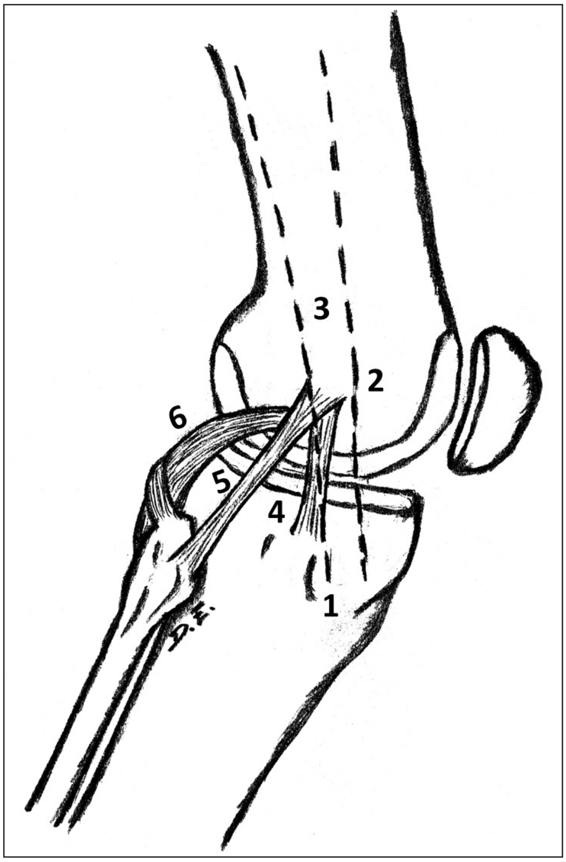

Figure 2. Drawing illustrating the lateral structures of the knee used as anatomic landmarks, at 35° of flexion. Legenda: 1 - Gerdy tubercle; 2 - Lateral femoral epicondyle; 3 - Iliotibial band; 4 - Anterolateral ligament; 5 - Lateral collateral ligament; 6 - Popliteus tendon.

The ALL proximal band seems to be in some cases difficult to recognize, because this band could be found to be always thinner, but, anyway, if the ALL could be identified, its proximal end could also be identified above the popliteal fossa (Fig. 4). Anisotropy artifacts may reduce echogenity of ALL at the middle tract of the proximal band, due its arcuate morphology, often determining a different angle of insonation.

Oshima et al. also report, in their recent study with real-time virtual sonography (RVS) on 9 healthy patients, severe problems in visualizing the proximal part of the ALL at its femoral portion, in fact this portion of the ligament, could not be identified in two

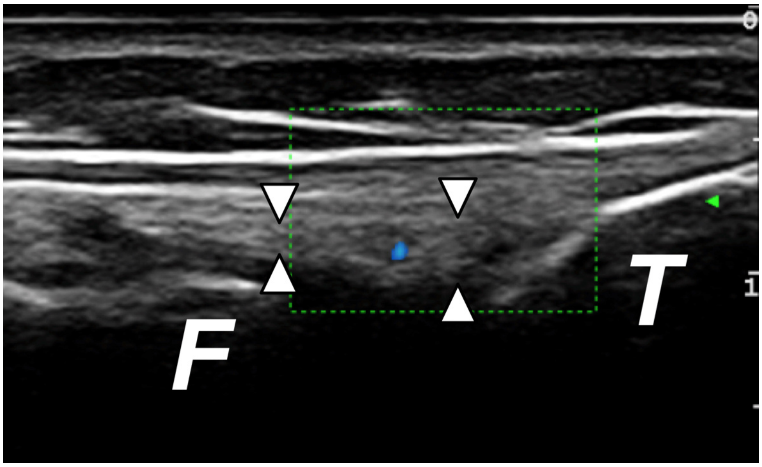

Figure 3. Female 33y. US longitudinal image showing the distal part of the ALL (arrowheads) as a hyperechoic band, between the distal femoral epiphysis (F) and the anterolateral margin of the tibia (T). The lateral inferior branch of the geniculate artery (LIGA) - used as anatomical reference landmark - appears as a roundish structure, crossing the ligament at its half-length.

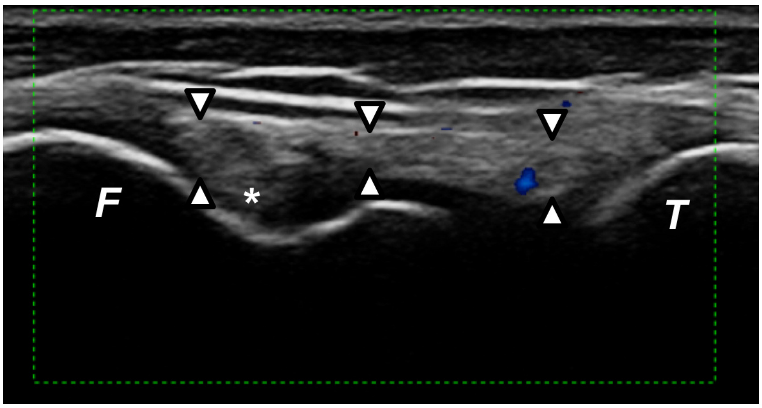

Figure 4. Male 31y. US longitudinal image showing the ALL (arrowheads) as a thin hyperechoic structure, running between the lateral meniscus and the femoral condyle, above the popliteal fossa and popliteal tendon (asterisk). Anisotropy artifact slightly diminishes echogenity of ALL at the middle tract of the proximal band. Legenda: F, lateral femoral condyle; T, anterolateral margin of the tibia.

subjects by the first observer and in three subjects by the second observer[16].
The different rate of reproducibility in the identification of the ligament, between our study and Oshima's, is probably due to the fact that in our study MRI was not previously used to identify the ligament, so we have not been influenced in our approach.
In subjects with an irregular or particularly prominent profile of the lateral side of the knee, mostly in males, in which the surface was less adherent to US linear probes, gel pads were used in order to get a more regular and linear lying surface for the probe: the gel pad allowed a quicker survey of the whole ALL but it didn't improve its anatomical detailed depiction.
In our study, US quantification of length and thickness of ALL was strongly, almost perfectly, reproducible among observers. The average length of the ALL reported in literature differs from ours[6], probably depending on the different positioning in tibial internal rotation and knee flexion used in our study. In an MRI study on living subjects by Taneja[13], average length was reported as 33.2 mm (range 24.1-39.9 mm) and these values are similar to the average measures we obtained.
As regards ligament's length, our measurements are very close to ones reported by Oshima[16]; the slight difference recorded, could be due to the different number of patients enrolled in the two studies.
Thickness of ALL has never been reported in previous US studies on living subjects. Thickness has been measured on previous cadaveric or MRI studies. We measured ALL at the level of its distal portion just below the lateral meniscus and above the hyperechoic line drown by the tibial proximal epiphysis. Our choice depended on the fact that both tibial epiphysis and lateral meniscus are easy to reproduce as anatomical land marks. Nevertheless, it is well known that US assessments highly depend on operator skills and on US technology available. For this kind of specific detailed anatomical evaluation, both experienced and skilled musculoskeletal US operators and high performance up-to-date US equipment are necessary. For all these reasons, even though in healthy and young subjects US may have a high rate of reproducibility, at present we cannot say if US may become in the near future a gold standard examination in the assessment of ALL injury.
The greatest limitation of our study was the lack of a standard reference confirming the presence and length of the ALL in our cohort of patients. Neither

MRI nor dissection were, in fact, performed on the 160 knees included in our study (considering surgical dissection as the actual gold standard).
In conclusion, in our study on young and healthy subjects, ALL has been visualized with a good rate of reproducibility. Our future advance in US ALL evaluation will be to see if it may be validated as a reliable and reproducible diagnostic tool in a cohort of patients affected by traumatic or degenerative knee disorders.

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References

1. Segond P. Recherches cliniques et expérimentales sur les épanchements sanguins du genou par entorse. Progres Med. 1879;7:297-341.
2. Campos JC, Chung CB, Lektrakul N, Pedowitz R, Trudell D, Yu J, et al. Pathogenesis of the Segond fracture: anatomic and MR imaging evidence of an iliotibial tract or anterior oblique band avulsion. Radiology. 2001;219(2):381-386.
3. Vieira EL, Vieira EA, da Silva RT, Berlfein PA, Abdalla RJ, Cohen M. An anatomic study of the iliotibial tract. Arthroscopy. 2007;23(3):269-274.
4. Claes S, Vereecke E, Maes M, Victor J, Verdonk P, Bellemans J. Anatomy of the anterolateral ligament of the knee. J Anat. 2013;223(4):321-328.
5. Pomajzl R, Maerz T, Shams C, Guettler J, Bicos J. A review of the anterolateral ligament of the knee: current knowledge regarding its incidence, anatomy, biomechanics, and surgical dissection. Arthroscopy. 2015;31(3):583-591.
6. Van der Watt L, Khan M, Rothrauff BB, Ayeni OR, Musahl V, Getgood A, et al. The structure and function of the anterolateral ligament of the knee: a systematic review. Arthroscopy. 2015;31(3):569-582 e3.
7. Parsons EM, Gee AO, Spiekerman C, Cavanagh PR. The biomechanical function of the anterolateral ligament of the knee. Am J Sports Med. 2015;43(3):669-674.
8. Bonasia DE, D'Amelio A, Pellegrino P, Rosso F, Rossi R. Anterolateral Ligament of the Knee: Back to the Future in Anterior Cruciate Ligament Reconstruction. Orthop Rev (Pavia). 2015;7(2):5773.
9. Caterine S, Litchfield R, Johnson M, Chronik B, Getgood A. A cadaveric study of the anterolateral ligament: re-introducing the lateral capsular ligament. Knee Surg Sports Traumatol Arthrosc. 2015;23(11):3186-3195.
10. Helito CP, Helito PV, Costa HP, Bordalo-Rodrigues M, Pecora JR, Camanho GL, et al. MRI evaluation of the anterolateral ligament of the knee: assessment in routine 1.5-T scans. Skeletal Radiol. 2014;43(10):1421-1427.
11. Helito CP, Demange MK, Bonadio MB, Tirico LE, Gobbi RG, Pecora JR, et al. Anatomy and Histology of the Knee Anterolateral Ligament. Orthop J Sports Med. 2013;1(7):2325967113513546.
12. Claes S, Bartholomeeusen S, Bellemans J. High prevalence of anterolateral ligament abnormalities in magnetic resonance images of anterior cruciate ligament-injured knees. Acta Orthop Belg. 2014;80(1):45-49.
13. Taneja AK, Miranda FC, Braga CA, Gill CM, Hartmann LG, Santos DC, et al. MRI features of the anterolateral ligament of the knee. Skeletal Radiol. 2015;44(3):403-410.
14. Cianca J, John J, Pandit S, Chiou-Tan FY. Musculoskeletal ultrasound imaging of the recently described anterolateral ligament of the knee. Am J Phys Med Rehabil. 2014;93(2):186.
15. Cavaignac E, Wytrykowski K, Reina N, Pailhe R, Murgier J, Faruch M, et al. Ultrasonographic Identification of the Anterolateral Ligament of the Knee. Arthroscopy. 2016;32(1):120-126.
16. Oshima T, Nakase J, Numata H, Takata Y, Tsuchiya H. Ultrasonography imaging of the anterolateral ligament using real-time virtual sonography. Knee. 2016;23(2):198-202.
17. Padulo J, Oliva F, Frizziero A, Maffulli N. Muscles, Ligaments and Tendons Journal - Basic principles and recommendations in clinical and field science research: 2016 update. MLTJ. 2016;6(1):1-5.
18. Helito CP, Demange MK, Bonadio MB, Tirico LE, Gobbi RG, Pecora JR, et al. Radiographic landmarks for locating the femoral origin and tibial insertion of the knee anterolateral ligament. Am J Sports Med. 2014;42(10):2356-2362.
19. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159-174.
20. Rezansoff AJ, Caterine S, Spencer L, Tran MN, Litchfield RB, Getgood AM. Radiographic landmarks for surgical reconstruction of the anterolateral ligament of the knee. Knee Surg Sports Traumatol Arthrosc. 2015;23(11):3196-3201.
21. Dodds AL, Halewood C, Gupte CM, Williams A, Amis AA. The anterolateral ligament: Anatomy, length changes and association with the Segond fracture. Bone Joint J. 2014;96-B(3):325-331.
22. Vincent JP, Magnussen RA, Gezmez F, Uguen A, Jacobi M, Weppe F, et al. The anterolateral ligament of the human knee: an anatomic and histologic study. Knee Surg Sports Traumatol Arthrosc. 2012;20(1):147-152.