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DEPARTAMENTO DE MEDICINA

LUCAS NOGUEIRA DE OLIVEIRA

O LIGAMENTO ANTEROLATERAL DO JOELHO FETAL: UM ESTUDO ANATÔMICO E HISTOLÓGICO.

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O LIGAMENTO ANTEROLATERAL DO JOELHO FETAL: UM ESTUDO ANATÔMICO E HISTOLÓGICO.

Monografia apresentada à Universidade Federal de Sergipe como requisito parcial à conclusão da graduação de Medicina do Centro de Ciências Biológicas e da Saúde.

Orientador: Prof. Dr. José Aderval Aragão

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LISTA DE ABREVIATURAS E SIGLAS

LCL	Ligamento Colateral Lateral
LAL	Ligamento AnteroLateral
TIT	Trato IlioTibial
ATJ	Artroplastia Total do Joelho
EFL	Epicôndilo Femoral Lateral
TG	Tubérculo de Gerdy
CAL	Complexo AnteroLateral do Joelho
CF	Cabeça da Fíbula
MP	Músculo Poplíteo
LCA	Ligamento Cruzado Anterior
RNM	Ressonância Magnética
TC	Tomografia Computadorizada
CFL	Côndilo Femora Lateral

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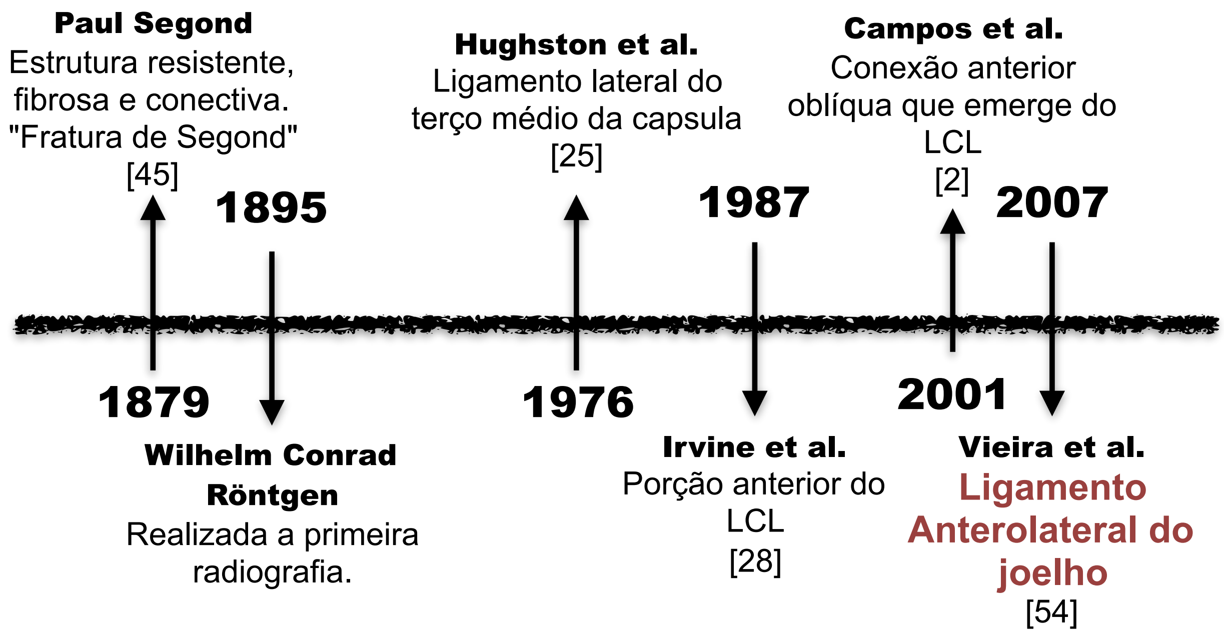
1. REVISÃO DA LITERATURA

1.1. NOVO LIGAMENTO

1.1.1. Linha do tempo

Figura 1. Linha do tempo das descrições do Ligamento Anterolateral.



Dr. Paul Segond, em 1879, percebeu um padrão de fratura na região anterolateral da porção proximal da tíbia. Pacientes que passaram por lesões traumáticas com rotação interna do joelho apresentaram uma fratura com avulsão de fragmento na topografia do tubérculo de Gerdy (TG), mais especificamente, anteriormente e acima desse, acidente anatômico que ocorre devido inserção do trato iliotibial (TIT). Após o delimitado, Dr. Paul descreveu uma estrutura resistente, fibrosa e conectiva que recebia muita força de tensão ao ocorrer a rotação interna forçada do joelho. Surgiu então o epônimo fratura de Segond, entretanto a estrutura no compartimento anterolateral do joelho por ele visualizada continuou em situação obscura (Segond, 1879).

Nos anos seguintes, a literatura, por vezes, descreveu essa mesma estrutura de outras formas, como porção anterior do ligamento colateral lateral (LCL)

(Irvine; Dias; Finlay, 1987), ligamento lateral do terço médio da capsula (Haims et al., 2003; Hughston et al., 1976; Johnson, 1979; Moorman; LaPrade, 2005) e de conexão anterior oblíqua que emerge do LCL (Campos et al., 2001). As descrições, entretanto, sempre foram vagas e os estudos possuíam outros focos. Somente em 2007 esse acidente anatômico recebeu o nome de Ligamento Anterolateral (LAL) por Vieira et al. (2007), pois perceberam que na camada cápsular-óssea do trato iliotibial (TIT) havia uma estrutura anatômica funcional bem delimitada e, que devido a sua localização estratégica e espessura, poderia ser chamada de o verdadeiro LAL do joelho, contudo esse estudo detinha foco no TIT e pouco descreveu o LAL (Vieira et al., 2007).

Em 2012, um estudo fez a primeira descrição anatômica e histológica focada no LAL. Vincent et al. dissecaram 10 joelhos de humanos adultos além de checar a existência desse em 30 cirurgias de artroplastia total de joelho (ATJ) para tratamento de osteoartrose de compartimento medial. Determinou-se que, nos 40 joelhos avaliados, o LAL apresentou origem próxima da inserção do tendão do músculo poplíteo (MP) e se inseria no menisco lateral e no planalto tibial com 5 mm de distância da superfície articular e posteriormente ao tubérculo de Gerdy. Além disso, foi descrito histologicamente como uma estrutura de cerne fibroso envolta de líquido sinovial (Vincent et al., 2012).

Claes et al. em 2013 buscaram encontrar uma forma padrão de dissecar joelho de cadáveres humanos para encontrar o LAL. Avaliaram 41 joelhos não pareados, embalsamados, com média de idade de 79 anos. As dissecações iniciaram-se com a criação de uma grande aba cutânea retangular centrada na parte lateral dos joelhos flexionados. O TIT foi cortado transversalmente 6 centímetros proximalmente ao epicôndilo femoral lateral (EFL) e cuidadosamente liberado de sua inserção tibial no TG, precisamente cortando a camada profunda do TIT que é aderida ao septo inter-muscular lateral e ao retináculo lateral. Com o TIT rebatido, visualizou-se a lâmina superficial da capsula do joelho. O LCL foi palpado com o joelho em delicado varo e o tecido que envolve esse foi cuidadosamente incisado posteriormente e paralelamente (Claes et al., 2013).

Flexionou-se o joelho a 60°, aplicou-se um torque no pé o que revelou as fibras distintas as quais percorrem a região lateral femoral até a porção proximal da tÍbia posteriormente ao TG. Subsequentemente todas as fibras dessa estrutura ligamentar foram cuidadosamente isoladas em sua inserção até a tíbia. Cuidado foi tido para não lesionar fibras que interceptavam a parte proximal do LCL. Ao fim, o menisco lateral, a artéria geniculada inferior, o LCL e o tendão do MP foram isolados para estudar a relação com o LAL. As origens e inserções do LAL, LCL, TIT e tendão do MP foram mostradas *in situ* usando pequenos marcadores de metal. Por essa técnica, encontrou-se o LAL em 97% dos espécimes dissecados. Relacionou-se o papel das lesões desse ligamento com instabilidade rotatória do joelho em testes de *pivot-shift* (Claes et al., 2013).

Recentemente, em 2018, formou-se o grupo de consenso do complexo anterolateral (CAL) do joelho. Esse deteve a função de elucidar os fatos diante da nova descrição dessa região, o que gerou divergências nos trabalhos científicos entre o período de 2013 a 2018 (Getgood et al., 2018).

1.2.ANATOMIA

1.2.1.Consenso

Ficou determinado pelo grupo de consenso do Complexo Anterolateral do joelho (CAL) em 2018 que o ligamento anterolateral é uma estrutura anatômica que se encontra no CAL. As estruturas do complexo anterolateral de superficial a profunda são: bandas superficiais do TIT e do trato iliopatelar, a banda profunda do TIT a qual incorpora o sistema de fibras de Kaplan — este apresenta inserções supracondilares (proximal e distal) e condilares (continua com a camada capsular-óssea do TIT) — o LAL e a capsula articular do joelho. O LAL é uma estrutura que está na terceira camada de Seebacher da capsula anterolateral do joelho (Seebacher et al., 1982), possui uma ampla variedade de tamanhos e espessuras dentre indivíduos, tem origem posterior e proximal ao EFL e ao LCL, percorre superficialmente ao LCL e se insere no ponto médio da reta que passa pela borda anterior da cabeça da fíbula (CF) e da borda posterior do TG e também existe uma inserção do LAL no menisco lateral (Getgood et al., 2018).

1.2.2.Descrição

A origem do ligamento anterolateral é descrita como sendo anterior e proximal ao EFL. As inserções são descritas uma no menisco lateral e outra, na tíbia (Claes et al., 2013; Helito et al., 2013).

Segundo Helito et al. em um estudo conduzido com 20 joelhos de cadáveres não pareados em 2013, o LAL foi observado em todos espécimes e sua origem e inserção coincidem com o descrito pelo consenso de 2018. Observou-se neste trabalho uma bifurcação do ligamento que ocorreu em aproximadamente 52.5% ± 8.1% de seu comprimento, com duas inserções, uma proximal ao menisco lateral na transição entre o corno anterior e o corpo desse e outra na tíbia distalmente entre o TG e a CF. A inserção tibial foi encontrada aproximadamente a 4.4 ± 1.1 mm da porção mais distal da cartilagem articular da tíbia. Já a inserção meniscal se encontrou a aproximadamente 19.4 ± 3.5 mm anterior ao tendão do MP. A analise histológica dos ligamentos comprovou existência de tecido conjuntivo denso modelado e pouco material celular foi encontrado em todos espécimes (Helito et al., 2013).

Apesar dessa descrição ter sido observada nesses casos, a literatura demonstra variação frequente nas descrições. A origem do LAL, por exemplo, é descrita como anterior e distal ao LCL, próximo ao epicôndilo lateral (Claes et al., 2013; Helito et al., 2013), porém alguns autores observaram origem posterior e proximal ao epicôndilo lateral também (Dodds et al., 2014; Kennedy et al., 2015; Lutz et al., 2015). Um estudo em 2016 propôs com 8 espécimes pediátricos com média de idade de 3 anos e 5 meses encontrar o LAL, entretanto somente encontraram em um espécime (sexo feminino, 1 ano de idade) o ligamento (Shea et al., 2016).

1.3.BIOMECÂNICA

1.3.1.Consenso

A estrutura responsável pela estabilização primaria de ambas translação anterior e rotação interna próxima da extensão é o ligamento cruzado anterior (LCA). Os estabilizadores secundários são o TIT, as fibras de Kaplan, o menisco lateral, o LAL e a capsula anterolateral. O LAL é uma estrutura anisométrica (Getgood et al., 2018).

1.3.2.Descrição

O LAL foi reportado como importante na estabilização rotatória em testes biomecânicos. Simularam o teste *pivot-shift* em 10 joelhos de cadáveres em um sistema robótico que aplicava torques de 10 N.m em valgo e 5 N.m de rotação interna em ângulos de 0º a 60º de flexão. Também aplicava torque de 5 N.m em rotação interna, além de 88 N de carga anterior à tíbia, ambos de 0º a 120º de flexão do joelho. As diferenças cinéticas foram medidas e comparadas com joelhos intactos para secção isolada do LCA e secção combinada do LCA com o LAL. Durante o movimento de flexão com torque de rotação interna em joelhos com LCA deficientes, o LAL provou-se como estabilizador secundário (Rasmussen et al., 2016; Spencer et al., 2015). Outros estudos descreveram que o LAL funciona como estabilizador secundário também, entretanto só inicia sua função após a translação da tíbia além dos limites fisiológicos de movimento de um joelho com o LCA intacto (Huser et al., 2017; Thein et al., 2016). Demonstrou-se, contudo, que quando combinadas lesões de LCA e do LAL, reconstrução isolada do LCA não restaura a cinética normal do joelho, mas a reconstrução combinada o faz (Inderhaug et al., 2017).

Por fim, o consenso de 2018 concluiu que a reconstrução do LAL produz benefício no controle do *pivot-shift*, além disso, afirmou o ponto de origem para reconstrução posterior e proximal ao LCL, ou seja, posteriormente ao centro de rotação do joelho, para que o enxerto fique firme na extensão (Getgood et al., 2018).

1.4.EXAMES DE IMAGEM

1.4.1.Radiografia e Tomografia computadorizada

As radiografias ficam limitadas a detectar o sinal patognomônico de lesão de LCA e de LAL que é a fratura com avulsão de fragmento no TG, ou seja, a fratura de Segond. Um estudo utilizou a Tomografia computadorizada (TC) para avaliar a isometria do LAL. Esse concluiu como que há um aumento médio de 16,7% do comprimento quando há flexão de 90º (Helito et al., 2014b). Na prática clínica a aplicação da TC se restringe à mesma da Radiografia.

1.4.2.Ressonância magnética

Caracterizou-se o LAL em joelhos normais de pacientes menores de 18 anos com ressonância magnética (RNM) para determinar a partir de qual idade é possível visualizar essa estrutura. Em RNM de 363 joelhos, 200 eram do sexo feminino e 163 do sexo masculino. O LAL foi visualizado em 69.4% dos casos, em maiores de 6 anos em pacientes masculinos e maiores de 7 anos nos femininos. Já nos casos entre 17 e 18 anos, visualizou-se os ligamentos em todos independentemente do sexo. A partir dos 13 anos no caso da mulheres e homens a partir dos 15 anos a freqüência de visualização do ligamento é aproximadamente 70%. Abaixo dessas idades a caracterização do LAL encontra-se imprecisa via os protocolos convencionais (Helito et al., 2014c).

Em RNM, espera-se baixo sinal do LAL em todas sequencias. O melhor protocolo para se visualizar a estrutura com boa correlação anatômica é manter sem espaços, espessura de cortes com aproximadamente 1 a 2 mm e geralmente os vasos geniculados são úteis para acesso ao LAL. Outro fato importante é que, em pacientes vivos, comumente não se distinguem a origem do LAL da origem do LCL. (Helito, 2017b; Helito et al., 2014c, Helito et al., 2018c). Uma possível explicação para isso é o pequeno tamanho desse ligamento (espessura de 1.5±0.5 mm largura de 5.2±0.7 mm) o que o torna suscetível a efeitos de volume parcial (Helito et al., 2018a).

Apesar de já se descrever bem a anatomia do LAL normal em RNM, poucos estudos focaram em descrever lesões, tampouco há correlação entre as descobertas em imagens e aquelas em procedimentos cirúrgicos (Helito et al., 2018a).

1.5.TRATAMENTO

1.5.1.Consenso

Deve-se reconstruir as estruturas extra-capsulares associado a reconstrução do LCA quando houver uma cirurgia de revisão de enxerto de LCA, *pivot-shift* de alto grau, frouxidão ligamentar generalizada, *Genu recurvatum* e pacientes jovens que retornarão a atividades físicas com movimentos pivotantes (Getgood et al., 2018).

1.5.2.Indicação

Foi demonstrado o potencial benéfico em se realizar a reconstrução combinada de LCA com o LAL em um estudo com acompanhamento de 92 pacientes em 2 anos. As indicações para o procedimento são (deve-se apresentar no mínimo 1): fratura de Segond, lesão crônica de LCA, *pivot-shift* grau 3, alto índice de praticas esportivas, esportes pivotantes e sinal radiográfico de incisura femoral lateral. Uma vez indicado o procedimento, o paciente é conduzido a avaliação préoperatória (Sonnery-Cottet et al., 2015).

1.5.3.Técnica

A técnica recebe o nome de reconstrução combinada de LCA e LAL e inicia-se com a coleta e preparação de enxertos de tendão. Pode-se utilizar tendões autólogos ou de bancos de tecidos. O primeiro tendão a ser escolhido é o semitendíneo o qual é preparado como um enxerto de três camadas (dobra-se a extensão do ligamento em três camadas) e o tendão do músculo grácil utilizado em uma só camada. Dessa forma, une-se os dois enxertos com suturas formando-se um único enxerto de 4 camadas em sua porção que servirá de LCA, e a parte restante, com uma camada que servirá de LAL (Helito et al., 2015; Helito et al., 2018b).

A reconstrução do LAL é então iniciada com acesso cirúrgico a parte lateral do joelho. Após separação do TIT através de suas fibras na altura do epicôndilo lateral, com abertura de aproximadamente 3 cm de comprimento, uma ancora de metal é inserida no ponto de origem do LAL (Helito et al., 2015).

1.5.3.1.Artroscopia

Após a inserção da âncora, inicia-se a artroscopia. O espaço intra-articular é inspecionado e lesões de cartilagem e meniscos são tratadas. A área intercondilar é preparada com o desbridamento da parede interna do côndilo femoral lateral. Utiliza-se a técnica *outside-in* para fazer o túnel femoral, que começa fora do côndilo femora lateral (CFL) e sai na parede medial desse mesmo côndilo. Deve-se respeitar o mesmo *footprint* do LCA. O cirurgião deve ter cuidado para não atingir a âncora de metal que foi inserida para fixação do LAL no CFL. O túnel tibial é feito através da topografia natural do LCA (Helito et al., 2015).

Para a perfuração dos túneis insere-se fios guias nos trajetos, e então perfuram-se os túneis. É utilizado guia tibial de LCA padrão apenas ajustando as angulações para alcançar os *footprints* corretos. Os diâmetros dos túneis são iguais aos diâmetros dos enxertos. O enxerto é passado pela tÍbia ao femur após a preparação dos túneis. A porção restante de enxerto composta pelo grácil sai pelo CFL (Helito et al., 2015; Helito et al., 2018b).

1.5.3.2.Reconstrução do LAL

Insere-se o restante de enxerto do grácil na âncora que havia sido posicionada no início do procedimento. Outra âncora de 5 mm é colocada na inserção anatômica do LAL na tíbia. Escolhe-se um ponto entre a CF e o TG aproximadamente 5 a 10 mm a baixo da linha articular do platô tibial lateral. O enxerto é então passado entre o TIT até sua inserção tibial ser assegurada por sutura com ancora (Helito et al., 2015; Helito et al., 2018b).

2. IMPACTO DO ARTIGO

O artigo foi publicado na revista American Journal of Sports Medicine que apresenta fator de impacto JCR de 6,057 e o sistema Qualis-periódicos a classifica como A1. Até o presente momento, o estudo foi citado 18 vezes em outros trabalhos científicos.

2.1. REVISÃO DAS CITAÇÕES

Em 2017, Toro Ibargen et al. citou o nosso artigo mencionando a prevalência de 100% da presença do ligamento anterolateral nas 20 peças anatômicas conservadas em solução de formol. Esse relato concordou com os resultados deles que obtiveram o mesmo valor de prevalência em 40 espécimes frescos congelados. Além disso levantaram o contraste com o trabalho de Shea et al. em 2016, os quais referiram somente um caso em oito espécimes pediátricos (Shea et al., 2016; Toro-Ibarguen et al., 2017).

Adversamente ao nosso estudo e ao de Toro Ibargen et al. (2017), Sabzevari et al. (2017) referiram falha em identificar o LAL em 21 joelhos de cadáveres frescos com 18 a 22 semanas de idade gestacionais. Afirmaram que a frequência de 100% de aparecimento em nosso artigo poderia ser devido ao uso de solução de formol para conservação dos espécimes (Sabzevari et al., 2017). Toro-Ibargen et al. (2017), contudo, utilizaram cadáveres frescos e técnica padronizada similar a nossa chegando a resultados semelhantes.

Em confronto aos dados de Sabzevari et al. (2017), uma revisão sistemática de 2019 mostrou que o LAL aparece em 74.07% de todas dissecações de fetos publicadas na literatura até aquele período (Ariel de Lima et al., 2019). Essa discussão também foi abordada por outros autores citando o nosso estudo como uma forma correta de encontrar o LAL no estagio fetal (Helito C.P., Helito P.V.P., 2018a; Sonnery-Cottet, 2017).

Quanto a descrição anatômica e histológica, estudos mencionam nosso artigo fazendo parte dos trabalhos que descrevem o LAL na fase fetal como estrutura discreta que apresenta origem e inserção ósseas além de ser extra-capsular (Dagget et al., 2018; Helito et al., 2018b; Helito et al., 2017b; Helito et al., 2018c; Patel et al., 2018). Estudos utilizaram a nossa descrição histológica para suportar a hipótese de que as fibras do LAL são de fato similares a de um ligamento verdadeiro (Neri et al., 2018; Weber et al., 2019).

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4. REGRAS DE PUBLICACÃO

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5. ARTIGO PUBLICADO

Anterolateral Ligament of the Fetal Knee

An Anatomic and Histological Study

Camilo Partezani Helito,*† MD, Julio Augusto do Prado Torres,† MD,
Marcelo Batista Bonadio,† MD, José Aderval Aragão,‡ MD, PhD, Lucas Nogueira de Oliveira,‡
Renato José Mendonça Natalino,† MD, José Ricardo Pécora,† MD, PhD,
Gilberto Luis Camanho,† MD, PhD, and Marco Kawamura Demange,† MD, PhD
Investigation performed at the University of São Paulo, São Paulo, Brazil

Background: The anterolateral ligament (ALL) of the knee has recently been described in detail. Most studies of the ALL have been conducted in adults; therefore, little is known about the anatomy and histology of the ALL in younger patients, and nothing is known about the fetal presence of the ALL.

Purpose: To evaluate the ALL in human fetuses to determine its presence or absence and to describe its microscopic anatomy and histological features compared with the findings of studies conducted in adults.

Study Design: Descriptive laboratory study.

Methods: Twenty human fetal cadaveric specimens were used. The mean age of the fetuses was 28.64 ± 3.20 weeks. The ALL was dissected in the anterolateral region of the knee, and its anatomic parameters, including its origin, insertion, and path in relation to known adjacent anatomic landmarks, in addition to its length, width, and thickness over the path toward the tibia, were measured. After dissection, the ALL was removed en bloc with a portion of the lateral meniscus for histological analysis of 4-μm sections, hematoxylin and eosin staining, and immunohistochemical staining for type I collagen.

Results: The ALL was located in all dissected knees. Its origin was located at a mean distance of 1.87 mm from the origin of the lateral collateral ligament, with variations from the center of the lateral epicondyle to posterior and proximal to it, and it exhibited an anterior-inferior path toward the tibia, an insertion in the lateral meniscus approximately 2.08 mm anterior to the popliteal tendon, and another insertion in the tibia between the Gerdy tubercle and the fibular head at 2.46 mm below the articular cartilage. The histological sections of the ALL showed well-organized, dense collagenous tissue fibers with elongated fibroblasts (mean, 1631 fibroblasts/mm^2) and a predominance of type I collagen.

Conclusion: The ALL is present during fetal development, with anatomic and histological features similar to those of the adult ALL.

Clinical Relevance: The findings of this study help to better understand the ALL's anatomy and histology from the fetal period to adulthood. The study presents the existence of the ALL since fetal development, emphasizes the characterization of the ALL, and brings important information to future pediatric ALL lesion studies.

Keywords: knee ligaments; anatomy; anterolateral ligament; ACL; fetal anatomy; histology

The anterolateral ligament (ALL) of the knee has recently been studied in detail,[1,2,9,10,25] despite having been described several years earlier by Segond.[20] Although most researchers have been able to locate this anatomic structure in cadaveric dissection studies, some groups have been unable to differentiate this ligament from the anterolateral capsule of the knee.[4] Histological studies of the anterolateral portion of the joint capsule have demonstrated the presence of well-organized, dense connective tissue, similar to ligament tissue.[1,9]

The ALL originates near the lateral epicondyle, but there is some controversy regarding its exact point of origin. Some anatomic descriptions place it anterior and distal to the lateral collateral ligament (LCL), near the center of the lateral epicondyle, while others place it posterior and proximal to the LCL.[1-3,9,14,16,25] The tibial insertion point is more constant, between the fibular head and

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the Gerdy tubercle, approximately 5 to 10 mm distal to the lateral plateau in adults. In addition to this tibial insertion point, several researchers have found an insertion of the ALL in the lateral meniscus, described in detail in a study by Helito et al.[8]

The ALL is biomechanically important in the control of rotational stability of the knee, functioning as a secondary restrictor to the anterolateral rotation of the tibia in relation to the femur, especially in cases of associated injuries to the anterior cruciate ligament (ACL).[17-19] There is also controversy regarding the level of knee flexion at which the ALL has more tension and therefore produces greater action.[2,3,12,26]

Most studies of the ALL have been performed on adults and, because of the availability of anatomic specimens, have most involved elderly patients; thus, little is known about the anatomy and histology of the ALL in younger patients, and nothing is known about fetal ALL development. A single study conducted by Shea et al[21] attempted to describe the ALL in patients with an immature skeleton, but the authors only managed to isolate this structure in 1 of the 8 cases studied. These researchers suggested that the ALL may not be fully developed in the immature skeleton.

The anatomy of the ACL in developing fetuses was described in detail by Ferretti et al[5] using 40 anatomic specimens with a mean age of 20 weeks. That study was important because it described the development of the ACL, the presence of its 2 anatomic bands, and the similarities and differences to the adult ACL.

Therefore, the main objective of the present study was to evaluate the ALL in human fetuses to determine its presence or absence and describe its macroscopic anatomy and histological features relative to the findings obtained in studies of adults. The secondary objective was to assess its behavior during knee flexion and extension.

METHODS

In this study, 20 human fetal cadaveric specimens were used. The fetuses were obtained from preserved cadaveric specimens of the Department of Anatomy of our institutions. The study was approved by the Committee of Research and Education of the University of São Paulo. The age of the fetuses varied from 25.5 to 37.3 weeks, with a mean of 28.64 ± 3.20 weeks, and the mean fetal length was 39.69 ± 4.33 cm. Specimens with malformations were excluded from the study. The fetuses were preserved in 10% formalin. Ten right knees and 10 left knees were used, of which 10 were from male specimens and 10 were from female specimens.

Basic dissection materials were used to dissect the fetuses. First, the skin of the thigh and leg was circumferentially incised approximately 4 cm proximal and 4 cm distal to the knee joint line. A transverse midline incision connecting the 2 initial incisions was then performed in the anterior region of the knee. A subfascial dissection plane was followed, detaching all skin circumferentially. Next, the fascia lata and femoral biceps tendon were dissected and incised approximately 3 cm proximal to the joint line. These structures were carefully dissected up to their distal insertions to maintain their insertion in the Gerdy tubercle and the fibular head, which served as anatomic landmarks for subsequent measurements. Then, the LCL was carefully dissected. When all bone parameters were easily visible, the ALL was carefully dissected. The ALL was observed more easily during knee flexion and internal rotation of the tibia, a position in which it had apparently more tension. All dissections followed the same protocol. After isolating the ALL, measurements were performed using a digital caliper with 0.01-mm precision and a 10× magnifying glass for precise viewing and measurement of the structures of interest. The measurements (in mm) were performed separately by 2 authors (J.A.P.T. and J.A.A.).

The length of the ALL was measured with the knee in full extension and at 30°, 60°, and 90° of flexion, always with neutral rotation of the knee. The width and thickness of the ALL were also measured at its origin, at the level of the joint line, and at the tibial insertion. The femoral origin of the ALL was measured in relation to the lateral epicondyle and LCL. The tibial insertion of the ALL was measured in relation to the Gerdy tubercle, the fibular head, and the lateral plateau. The meniscal insertion of the ALL was measured in relation to the popliteus muscle tendon at the height of the joint line. The size and macroscopic shape of the ALL insertion sites in the femur and tibia were also evaluated.

After dissection and measurement of anatomic parameters, the ALL was removed en bloc along with a portion of the lateral meniscus because of difficulty in totally isolating the structure resulting from the small size of the fetal structures. The ligaments were removed and used for histological analysis.

Histological analysis was performed by placing the dissected material in 10% formalin for tissue fixation. After standard processing, 4-μm histological sections were cut and stained with hematoxylin and eosin, and immunohistochemical staining was performed for type I collagen (1:1000 dilution; Clone ab34710; Abcam). The fibroblast count was determined in the fetal structure and then compared with the count of previously dissected adult anatomic specimens.

Statistical Analysis

Statistical analysis was performed to evaluate the interobserver agreement between the anatomic measurements performed by the 2 evaluators and to evaluate the alteration in length between different degrees of knee flexion. The intraclass correlation coefficient (ICC) was used for the interobserver agreement, and the Student t test was performed to analyze the change in length between different degrees of flexion.

RESULTS

Results are reported as means ± SDs. The ALL was observed clearly in all of the 20 dissected knees. At the time of dissection, with internal rotation of the tibia and knee flexion, the ALL was observed below the iliotibial tract, immediately anterior to the LCL.

The femoral point of origin of the ALL exhibited a close relationship to the origin of the LCL, located at a mean of 1.87 ± 0.81 mm from the central point of origin of the LCL

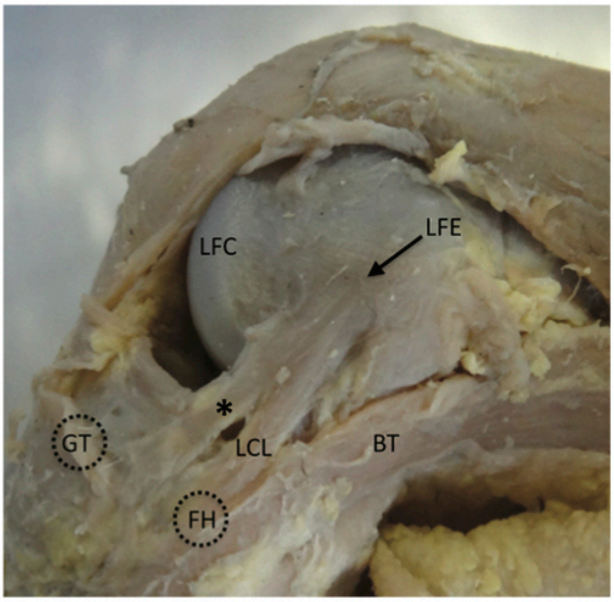

Figure 1. Anatomic image of a 26.6-week-old fetal left knee showing the anterolateral ligament (ALL) (asterisk), anterior to the lateral collateral ligament (LCL), with an origin near the center of the lateral epicondyle (LFE) and an anterior-inferior path toward the tibia, with the tibial insertion between the Gerdy tubercle (GT) and the fibular head (FH). BT, biceps tendon; LFC, lateral femoral condyle.

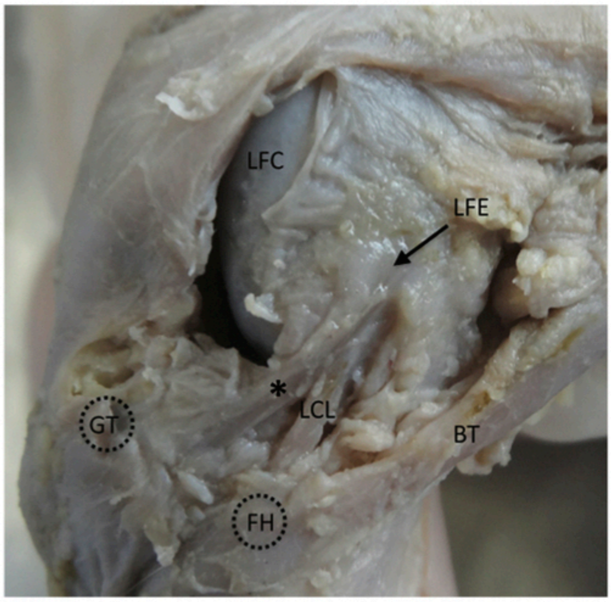

Figure 2. Anatomic image of a 28.4-week-old fetal left knee showing fibers of the origin of the anterolateral ligament (ALL) (asterisk), near the origin of the lateral collateral ligament (LCL), passing over its origin toward the tibia. BT, biceps tendon; FH, fibular head; GT, Gerdy tubercle; LFC, lateral femoral condyle; LFE, lateral epicondyle.

(Figure 1). Some variation was found in the point of origin of the ALL. Because the origin of the LCL is located at the posterior and proximal portion of the lateral epicondyle, according to the findings of LaPrade et al,[15] the ALL was located near the center of the lateral epicondyle or slightly posterior and proximal to it in most knees. In 7 knees, the ALL was anterior and distal to the LCL origin, close to the lateral epicondyle center; in 11 knees, it was immediately anterior to the LCL or slightly proximal to the lateral epicondyle center; and in 2 knees, it was immediately proximal to the LCL or posterior and proximal to the lateral epicondyle center (Figure 2). In this region of the femur, because of the size of the fetuses and the inferior path of the popliteal tendon in relation to the ALL, on many occasions, only after ALL resection was it possible to clearly observe the popliteal tendon path, located immediately below the ALL.

Following its origin in the femur, the ALL followed an anterior-inferior path toward the tibia. At a mean point of 57.7% ± 15.4% of its path, the ALL exhibited a bifurcation toward the lateral meniscus, with an insertion in the transition between its body and the anterior horn. The meniscal insertion occurred at a mean of 2.08 ± 0.80 mm anterior to the popliteal tendon at the joint level, when the latter was intra-articular (Figure 3). The main portion of the ALL continued along a path toward the tibia, with mean insertions of 6.29 ± 1.62 mm posterior to the posterior edge of the Gerdy tubercle, 6.61 ± 2.13 mm anterior to the anterior edge of the fibular head, and approximately 2.46 ± 0.78 mm below the lateral articular cartilage.

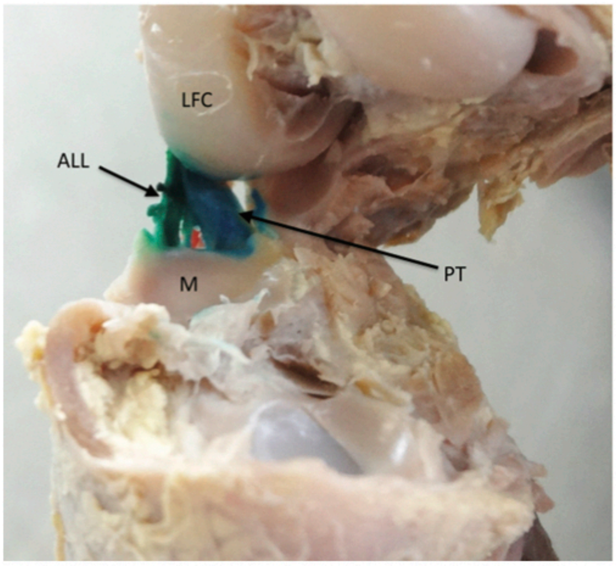

Figure 3. Anatomic image (internal view) of the lateral portion of a 25.5-week-old fetal right knee showing the relationship of the anterolateral ligament (ALL) to the popliteal tendon (PT), forming a triangle with a base at the lateral meniscus and a vertex at the lateral epicondyle. LFC, lateral femoral condyle; M, lateral meniscus.

TABLE 1
Length of the Anterolateral Ligament in Different Degrees of Knee Flexion

	Anterolateral Ligament Length, mm		
Flexion, deg	Mean ± SD	Median	Range
0°	7.19 ± 1.86	6.90	4.90-12.16
30°	7.60 ± 1.79	7.33	5.34-12.21
60°	8.52 ± 1.55	8.20	6.13-12.24
90°	9.11 ± 1.60	8.89	6.84-13.32

The mean lengths of the ALL were 7.19 ± 1.86, 7.60 ± 1.79, 8.52 ± 1.55, and 9.11 ± 1.60 mm with the knee in full extension and at 30°, 60°, and 90° of flexion, respectively (Table 1). Therefore, an increase in the ALL length was observed with knee flexion. The mean increase from extension to 30°, 30° to 60°, and 60° to 90° of flexion was 0.41, 0.92, and 0.59 mm, respectively ($P < .05$ for all) (Table 2).

The mean ALL widths were 2.14 ± 0.57, 2.12 ± 0.47, and 2.67 ± 0.68 mm at the origin, joint line, and tibial insertion, respectively. The mean thicknesses of the ALL were 0.45 ± 0.16, 0.39 ± 0.16, and 0.56 ± 0.18 mm at the origin, joint line, and tibial insertion, respectively. After en bloc resection of the ALL, a mean circular femoral footprint of 3.85 ± 1.91 mm^2 and a mean band-shaped tibial footprint of 1.83 ± 1.42 mm^2 were observed (Figure 4). The ICCs for the variables studied ranged from 0.87 to 0.97.

The histological sections of the ALL showed dense, well-organized collagenous fibers with elongated fibroblasts (mean, 1631 fibroblasts/mm^2). The fetal ALL had an increased cell concentration compared with the adult ALL (mean, 121 fibroblasts/mm^2) and was formed predominantly of type I collagen (Figure 5). Differences between male and female specimens are shown in the Appendix (available online at http://ajsm.sagepub.com/supplemental).

DISCUSSION

The main finding of this study was that the ALL is a structure that is present during fetal development, with anatomic and histological features similar to the ALL of adults. The ALL was found in all of the 20 cadaveric specimens used in this study, similar to recent studies that clearly identified the ALL in most of the specimens studied. In a recent systematic review, the ALL was characterized in 96% of the cases studied in 16 articles.[24] Nevertheless, studies such as that conducted by Dombrowski et al[4] found well-defined lateral capsular thickening in only 40% of the cases.

The position and path of the ALL in relation to the neighboring structures observed in the fetuses were consistent with the recent literature regarding this structure. The most controversial anatomic parameter was the correct femoral point of origin of the ALL. While Helito et al[9] and Claes et al[2] located the ALL anterior and distal to the LCL, near the center of the lateral epicondyle, Dodds et al,[3] Kennedy et al,[14] and Lutz et al[16] observed the ALL posterior and proximal to the lateral epicondyle. Caterine

TABLE 2
Difference in the Length of the Anterolateral Ligament Between Different Degrees of Knee Flexion

Change in Flexion, deg	Mean Difference in Length, mm	*P* Value
0°-30°	0.41	<.01
0°-60°	1.33	<.01
0°-90°	1.92	<.01
30°-60°	0.92	<.01
30°-90°	1.51	<.01
60°-90°	0.59	<.01

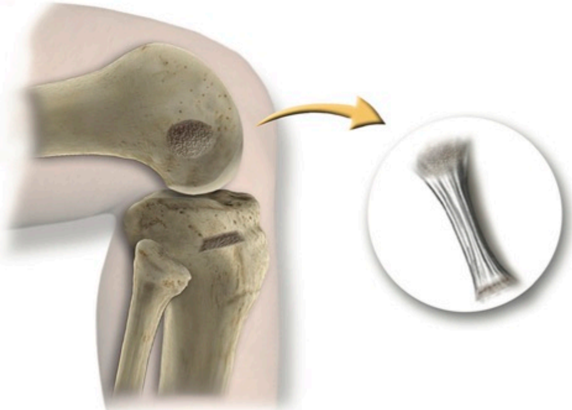

Figure 4. Schematic drawing showing the anterolateral ligament (ALL) femoral footprint and the band-shaped ALL tibial footprint.

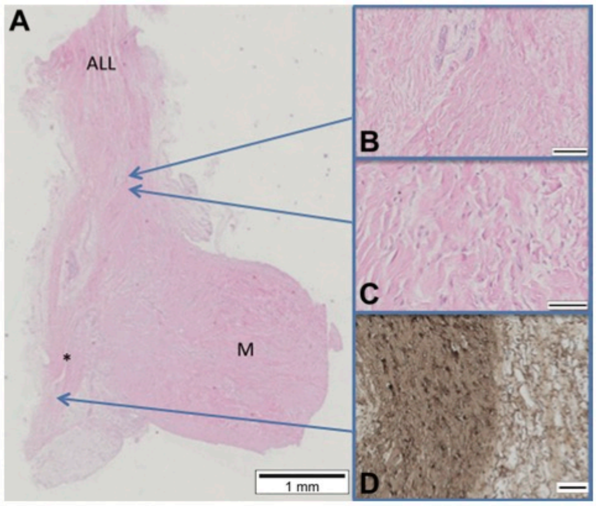

Figure 5. Histological images of (A) the anterolateral ligament (ALL) and its relationship to the lateral meniscus (M) in a 37.3-week-old fetus, showing (B) the presence of intrasubstantial blood vessels (scale bar = 100 μm), (C) well-organized and dense connective tissue with high fibroblast cellularity (scale bar = 50 μm), and (D) an abundant presence of type I collagen (scale bar = 50 μm). The asterisk in (A) indicates the distal portion of the fetal ALL.

et al[1] found both variations. Vincent et al[25] were the only investigators to determine a closer relationship of the ALL to the popliteal tendon. In a different anatomic study, Helito et al[7] were unable to differentiate the origin of the ALL and LCL in 2 cases and found posterior and proximal variation in a minority of the dissected knees (6.2%). In our study, the ALL was found anterior to the LCL in most knees, near the center of the lateral epicondyle or slightly posterior and proximal to it and not anterior to it, although we also observed anatomic variations. We propose that the variations among studies may be related to the difficulty of dissecting the lateral region of the knee, which includes the possible removal of a small amount of tissue that may be proximal to the origin of the LCL, and the possibility that the origin of the ALL has extensions that may have greater or lesser anatomic and biomechanical significance. Kawaguchi et al[13] and Smigielski et al[22] showed that even the ACL can have a main insertion, which is more central, and extensions around it that do not always play an important biomechanical role. The same may apply to the ALL.

The path of the ALL was also similar to that described in the literature.[2,9,14] Insertions in the tibia and between the body and anterior horn of the meniscus were observed. All specimens exhibited a tibial insertion between the Gerdy tubercle and the fibular head, immediately below the lateral plateau. Among the existing studies, only 1 case described by Caterine et al[1] showed a distal insertion in the fibular head, which is considered an anatomic variation.

The relative length measurements between flexion angles found in this study are consistent with the findings of biomechanical studies conducted by Helito et al[12] and Zens et al,[26] showing an increase in the ALL length during knee flexion. Dodds et al[3] observed the opposite results, with increased length upon knee extension. These differences may be related to the point of origin of the ALL in the femur. However, Kennedy et al[14] found a femoral point similar to Dodds et al,[3] but with behavior similar to that of studies showing greater length during knee flexion, indicating a lack of consensus in the literature regarding ALL behavior. Theoretically, a proximal and posterior point of origin would produce ALL behavior opposite to that of a distal and anterior origin. We believe that a greater length during flexion suggests ALL tensioning during flexion. Even though some structures were removed to isolate the ALL, we do not believe it to have significantly altered the physiological joint mechanics. A biomechanical study by Parsons et al[19] showed that the action of the ALL is more significant in flexion angles greater than 35°, although a pivot shift, attributed to ALL failure, occurs at angles closer to extension. Understanding the behavior of the ALL throughout the range of motion is important for defining the ideal position for tensioning the structure during reconstruction techniques. Currently, there is no consensus in the literature regarding how possible fixation should be performed.[6,23] The main variations of the structure include the main point of origin of the ligament in the femur and the degree of knee flexion during ligament tensioning and fixation.

The fetal ALL was 6 times shorter, 4 times narrower, and approximately 4 times thinner than the adult ALL dimensions reported in the literature. This variation was slightly lower than the variation found in a study of the fetal ACL; however, Ferretti et al[5] used fetuses with mean age of 20 weeks, whereas the fetuses used in our study had a mean age of 28.64 weeks, which may explain this difference. The differences in measurements found between male and female specimens can also be explained by the differences in fetal age and length. Female specimens were a mean of 1.20 weeks older and 2.18 cm taller than male specimens; that is probably why most of the measurements presented higher values in female specimens.

Regarding histological analysis, the studied structure consisted of dense, well-organized connective tissue, similar to the ligament structure found in adults, but with increased cellularity. The cell count (per mm^2) in this study was lower than that found by Ferretti et al[5] in their study of the fetal ACL (5600×1631 per mm^2), which may also be explained by the difference in the mean age of the fetuses between the studies. An alternative hypothesis is that the ALL may contain fewer cells than the ACL. Markers of type I collagen, the main collagen in ligaments, were strongly positive. All these findings (collagen type, organization pattern, cellularity) confirm the presence of a true ligament structure in the region in addition to capsular tissue. ALL bifurcation was clearly observed in the slides analyzed. The lateral inferior genicular vessels observed can act as guides for locating the ALL in magnetic resonance imaging scans, as suggested by Helito et al[11] in an imaging study of the normal ALL.

According to our findings, we do not agree with the conclusions of Shea et al,[21] who proposed that the ALL is an inconstant structure in the pediatric population and that it only develops after the anterolateral capsule of the knee is subjected to physiological loads. According to the dissections performed, the ALL is already present in fetuses with a mean age of 28.64 weeks and exhibits development similar to other ligaments in the knee region, such as the ACL.

The limitations of this study include the use of cadaveric specimens preserved in formaldehyde instead of fresh cadaveric specimens, which could have possibly significantly altered the anatomic and histological properties of the specimens. The number of cadaveric specimens was also low, but we believe that 20 specimens was sufficient to validate our findings based on recent anatomic studies. The age range of the fetuses, from 25.5 to 37.3 weeks, may also be considered a limitation, but based on the difficulty of obtaining fetal tissue, we believe that it did not interfere with the main results and conclusions of our study. The fact that we removed some structures to isolate the ALL may have altered the physiological joint mechanics, which could have slightly altered the measurements found during flexion and extension, although we believe that tendency was not compromised.

CONCLUSION

The ALL is a structure that is present during fetal development, with anatomic and histological characteristics similar to those of the adult ALL. The ALL increased in length with knee flexion.

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