Ultrasound-Guided Knee Cartilage Exploration: An Assessment Protocol

Exploração da Cartilagem do Joelho Guiada por Ecografia: Um Protocolo de Avaliação

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Abstract

Introduction: *The knee joint consists of three distinct articulations: medial and lateral femorotibial joints and the patellofemoral joint. It is composed of hyaline articular cartilage that envelops the femoral condyles, tibial plateaus, trochlear grooves, and patellar facets. Additionally, fibrocartilaginous menisci are present. Ultrasonography (US) is increasingly employed in musculoskeletal medicine for precise measurement and identification. This study aims to develop a systematic ultrasound evaluation of knee cartilage to enhance diagnostic accuracy and therapeutic guidance by recognizing the typical anatomical structure.*

Methods: *The authors describe a stepwise protocol for ultrasound exploration of the cartilaginous components of the knee joint with a special focus on patient positioning, ultrasound probe placement, and commonly encountered ultrasound images in knee cartilage exploration. A linear probe (9-12 MHz) was used..*

Results: *On the anterior surface of the knee, it is possible to assess ultrasound imaging of the trochlear cartilage of the femur and the patellar cartilage, the latter partially. The patient should perform a maximum flexion of the knee to expose a greater amount of trochlear cartilage. To assess the medial meniscus, the patient should be in a supine position with the knee flexed at approximately 30º and the leg externally rotated. For evaluating the lateral meniscus, the patient should be in a supine position with the knee flexed at approximately 30º and the leg internally rotated. On the posterior surface of the knee, it is possible to assess ultrasound imaging of the posterior articular cartilage of the femoral condyles as well as the posterior horns of the menisci. The patient should perform a prone position with a complete extension of the knee.*

Conclusion: *In summary, the ultrasound protocol for evaluating knee cartilage is crucial due to its accessibility, cost-effectiveness, real-time imaging, and ability to measure cartilage thickness. While additional imaging may be necessary for a thorough diagnosis, due to the limitations of using US, the ultrasound protocol significantly enhances knee cartilage assessment and improves overall patient care.*

Keywords: *Cartilage, Articular/diagnostic imaging; Knee Joint/diagnostic imaging; Ultrasonography*

Resumo

Introdução: A articulação do joelho é composta por três articulações: as articulações femorotibiais medial e lateral e a articulação patelofemoral. É composta por cartilagem hialina que reveste os côndilos femorais, os pratos tibiais, o sulco troclear e as facetas da rótula. Adicionalmente, existem meniscos fibrocartilaginosos presentes. A ecografia está a ser cada vez mais utilizada na área músculo-

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esquelética para medições e caracterização de estruturas anatómicas. Este estudo tem como objetivo desenvolver uma avaliação sistemática por ecografia da cartilagem do joelho para aprimorar a precisão do diagnóstico e orientação terapêutica.

Métodos: Os autores descrevem um protocolo passo a passo para exploração ecográfica das estruturas cartilaginosas da articulação do joelho, com especial foco na posição do doente, colocação da sonda e imagens ecográficas frequentemente encontradas na exploração da cartilagem do joelho. Foi utilizada uma sonda linear com frequência de 9-12 MHz.

Resultados: Na superficie anterior, é possível avaliar a cartilagem troclear do fémur e a cartilagem rotuliana, esta última de forma parcial. O doente deve realizar uma flexão máxima do joelho para expor uma maior quantidade de cartilagem troclear. Para avaliar o menisco medial, o doente deve estar em decúbito dorsal com o joelho flectido a aproximadamente 30º e com o membro inferior em ligeira rotação externa. Para avaliar o menisco lateral, o doente deve estar em decúbito dorsal com o joelho flectido a aproximadamente 30º e o membro inferior em rotação interna.

Na superfície posterior do joelho é possível visualizar a cartilagem articular posterior dos côndilos femorais bem como os cornos posteriores dos meniscos. O doente deverá estar em decúbito ventral com extensão completa do joelho.

Conclusão: O protocolo ecográfico para avaliação da cartilagem do joelho é relevante devido à sua acessibilidade, custo-efectividade, capacidade de obter imagens em tempo real e capacidade de medição da espessura da cartilagem. Embora outros exames de imagem possam ser necessários para um diagnóstico completo, o protocolo ecográfico de exploração de cartilagem do joelho melhora a avaliação das estruturas cartilaginosas quanto à presença de dano e o tratamento do doente.

Palavras-chave: ecografia; Articulação do joelho/diagnóstico por imagem; Cartilagem articular/diagnóstico por imagem; Ecografia

Introduction

The knee comprises three separate articulations: medial and lateral femorotibial joints and patellofemoral joints. Regarding cartilage, the knee is composed of hyaline articular cartilage that covers femoral condyles, tibial plateaus, trochlear groove, and the facets of the patella; and two menisci (medial and lateral) that are fibrocartilaginous structures located between the femoral condyles and tibial plateaus, histologically composed of collagen, fibrochondrocytes, water, proteoglycans, glycoproteins, and elastin.[1]

Recently, there has been an increasing utilization of ultrasonography (US) by physicians who specialize in musculoskeletal pathologies. This is due to the numerous benefits that the US offers. In addition to aiding in the identification and monitoring of various conditions, the US has also made it possible to measure several structures with greater accuracy,[2] compared to plain radiography.

The US can examine the hyaline cartilage in both small and large joints. The data gathered is contingent upon the acoustic window, as US waves may encounter barriers posed by bony structures, thus imposing limitations on the comprehensive evaluation of the joint cartilage.[3] High-quality equipment with transducers of different frequencies (7.5 MHz for deeper structures up to 20 MHz for superficial structures) is required to visualize the cartilage.[4]

Normal hyaline cartilage is observed as a homogeneous anechoic band delimited by a deep and superficial interface. The ultrasound beam must intersect the cartilage perpendicularly, resulting in conspicuous reflection characterized by sharp boundaries at the deep osteochondral interface (thicker and more refringent) and at the superficial chondrosynovial interface (thinner and less refringent). The distance between both lines represents the thickness of the cartilage.[5]

The hyaline cartilage of most joints should be examined in both the longitudinal and transverse planes. In the knee joint, the examination should be performed with the joint in maximum flexion, to expose a greater amount of cartilage.[4]

In contrast to hyaline cartilage, fibrocartilage exhibits a homogeneous hyperechoic appearance, displaying consistently high echogenicity close to the bone or joint capsule. Nonetheless, owing to their deep anatomical location, these structures typically present limitations in their complete visualization via ultrasound imaging.[6] Fibrocartilage (medial and lateral meniscus) should be examined in the longitudinal plane with the knee joint in 30º flexion in the supine position for the anterior horn and total extension in the prone position for the posterior horn. That degree of flexion to examine the anterior horn is considered the best position to avoid the overlap of the femoral condyles and tibial plates.[4]

The objective of this study is the development of a systematized ultrasound evaluation of knee cartilage and fibrocartilage in order to recognize the typical structure of these anatomical surfaces and improve the diagnostic approach and therapeutic guidance.

Methods

The authors describe a stepwise protocol for ultrasound exploration of the cartilaginous components of the knee joint with a special focus on patient positioning, ultrasound probe placement, anatomical diagrams, and commonly encountered ultrasound images in knee cartilage exploration. The authors systematize the ultrasound exploration of the knee by sections: anterior, medial, lateral, and posterior surface.

The equipment used was General Electric® ultrasound machine, model LOGIQ® P9 R3, with a linear probe model 12L-RS with a frequency range between 9-12 MHz.

Results

Anterior surface

On the anterior surface of the knee, it is possible to assess ultrasound imaging of the trochlear cartilage of the femur.

A. Trochlear Cartilage

a. Patient positioning

i. The patient should perform a maximum flexion of the knee to expose a greater amount of trochlear cartilage, as depicted in Fig. 1.

Figure 1 - Position of the knee for evaluation of the trochlear cartilage and positioning of the probe in the transverse axis.

b. Ultrasound probe placement

i. A dynamic exploration is performed from cranial to caudal with transducer in the transverse axis and from medial to lateral in the longitudinal axis.

c. Ultrasound images

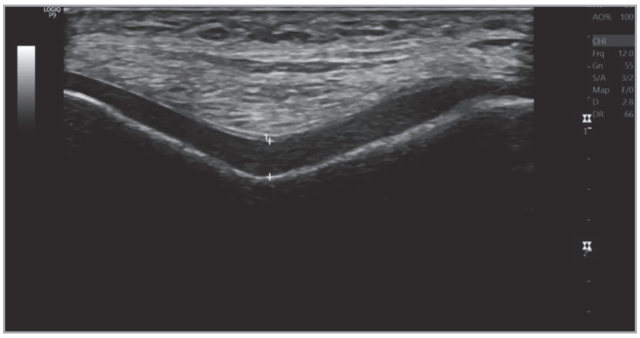

Figure 2 - Ultrasound image of the trochlear cartilage in the transverse axis; The distance between asterisks represents the thickness of the cartilage.

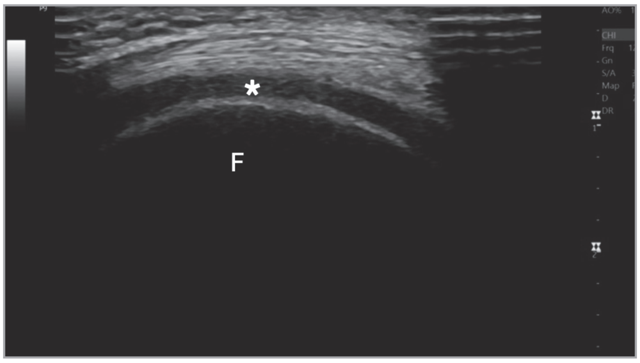

Figure 3 - Ultrasound image of the trochlear cartilage in longitudinal axis.

F – femur; * - trochlear cartilage.

Medical surface

On the medial surface of the knee, it is possible to assess ultrasound imaging of the medial meniscus.

B. Anterior Horn of the Medial Meniscus

a. Patient positioning

i. The patient should be positioned in a supine position with a 30º flexion of the knee and an external rotation of the leg. The corresponding position is depicted in Fig. 5.

Figure 4 - Exploratory position to evaluate the medial meniscus with the probe following the axis of the leg.

b. Ultrasound probe placement

i. An exploring motion is performed from anterior to posterior with transducer in the longitudinal axis of the medial femorotibial joint.

c. Ultrasound image

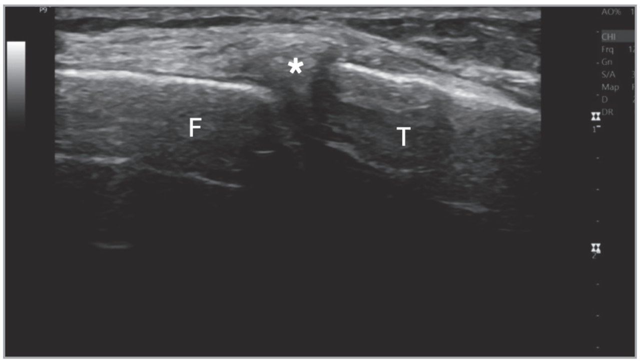

Figure 5 - Ultrasound image of the medial meniscus with the probe in longitudinal axis.

F – femur; T – tibia; * - medial meniscus.

b. Ultrasound probe placement

i. An exploring motion is performed from anterior to posterior with transducer in the longitudinal axis of the lateral femorotibial joint.

c. Ultrasound image

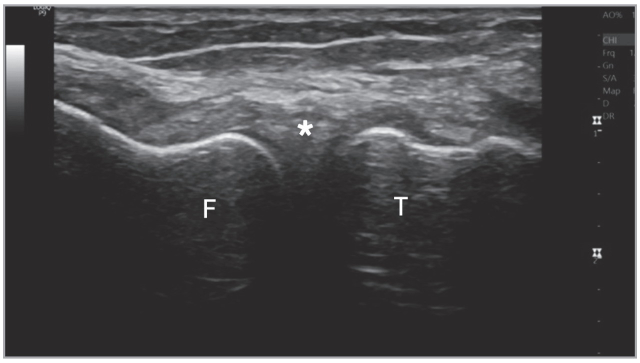

Figure 7 - Ultrasound image of the lateral meniscus with the probe in longitudinal axis.

F – femur ; T – tibia ; * - lateral meniscus.

Lateral surface

On the lateral surface of the knee, it is possible to assess ultrasound imaging of the lateral meniscus.

C. Anterior Horn of the Lateral Meniscus

a. Patient positioning

i. The patient should be positioned in a supine position with a 30° flexion of the knee and an internal rotation of the leg. The corresponding position is delineated in Fig. 7.

Figure 6 - Exploratory position to evaluate the lateral meniscus with the probe following the axis of the leg.

Posterior surface

On the posterior surface of the knee, it is possible to assess ultrasound imaging of the posterior articular cartilage of the femoral condyles as well as the posterior horns of the menisci.

D. Posterior articular cartilage of the femoral condyles

a. Patient positioning

i. The patient should be positioned in a prone position with a complete extension of the knee, as illustrated in Fig. 9.

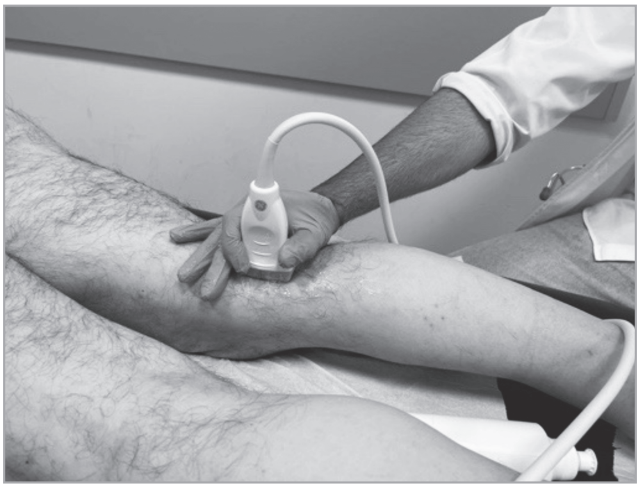

Figure 8 - Position of the knee for exploration of the posterior surfaces in the long axis of the leg.

b. Ultrasound probe placement

i. An exploring motion is performed from lateral to medial with transducer in the longitudinal axis.

c. Ultrasound image

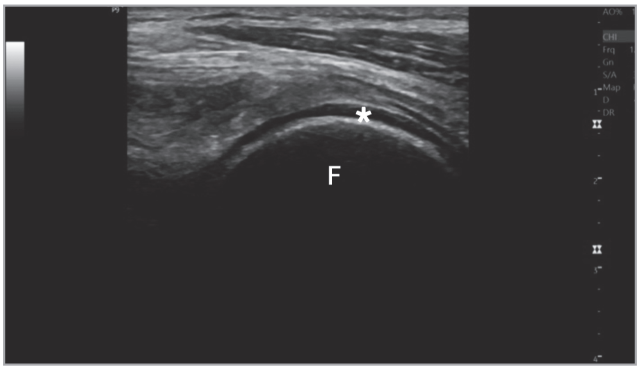

Figure 4 - Ultrasound image of the posterior articular cartilage of the medial femoral condyle.

F – femur; * - articular cartilage.

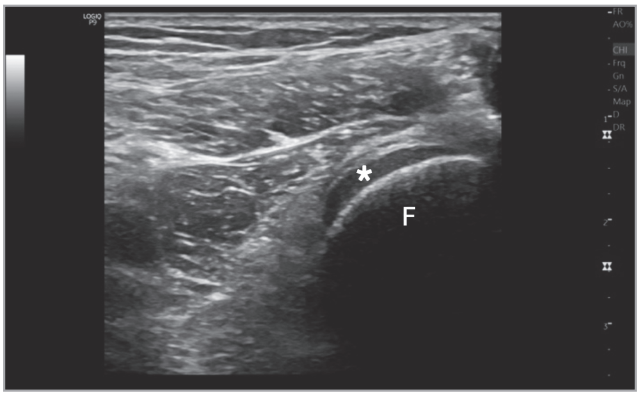

Figure 5 - Ultrasound image of the posterior articular cartilage of the lateral femoral condyle.

F – femur; * - articular cartilage.

E. Posterior horns of the menisci

a. Patient positioning

i. The patient should be positioned in a prone position with a complete extension of the knee, in a similar approach to the US evaluation of posterior articular cartilage of the femoral condyles.

b. Ultrasound probe placement

i. An exploring motion is performed from lateral to medial with a transducer in the longitudinal axis of the femorotibial joint.

c. Ultrasound image

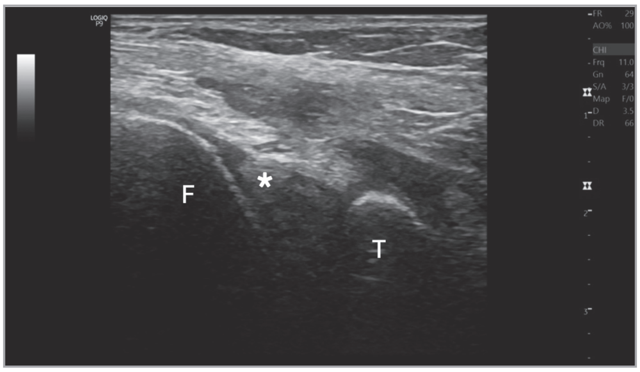

Figure 6 - Ultrasound image of the posterior horn of medial meniscus.

F – femur; T – tibia; * - posterior horn of medial meniscus.

Discussion

US has emerged as a valuable alternative due to its accessibility, cost-effectiveness, ability to provide real-time and dynamic imaging, and its non-ionizing radiation properties.[7] Due to its portable nature, the US enables direct observation of the anatomical structures in question during the overall assessment of the patient's physical examination and clinical evaluation, whereas computed tomography (CT) or magnetic resonance imaging (MRI) scans are often not readily available in the clinic.[8] The ability to provide real-time imaging permits dynamic assessments of knee cartilage throughout different joint movements. This capability facilitates a thorough assessment of the cartilage's integrity and functionality, enabling the performance of guided minimally invasive procedures such as intra-articular injections or aspirations that specifically target the knee joint.[9] In 2018, Cao and colleagues introduced a novel classification framework for evaluating femoral cartilage lesions in the knee using the US. This system shares similarities with the International Cartilage Repair Society (ICRS) scale and exhibits strong consistency among different raters. The researchers also conducted a comparative analysis between ultrasound findings and MRI outcomes, concluding that there is an inability to visualize the lateral and medial condyles near the intercondylar notch with conventional US, even at the maximum angle of knee flexion. According to the authors, the blind areas of the US can be examined through a dynamic method, varying the flexion angle between 0° to 135°. However, patients with cartilage defects should undergo other diagnostic procedures, such as MRI. This study shows differences between US and MRI in all cartilage defect grades on each articular surface (trochlear surface; medial condyles and lateral condyles). Generally, compared with MRI, no significant differences were obtained in detecting grades 0, 2, 3 and 4 defects in cartilage, but a lower detection rate with US for grade 1 defects was obtained.

Hence, ultrasound has the potential to serve as an initial screening tool for evaluating cartilage abnormalities in patients who present with knee pain and/or disability during their first visit.[10]

Additionally, the US enables the measurement of knee joint space width and cartilage thickness, essential parameters for assessing the advancement of cartilage degeneration and monitoring the efficacy of regenerative medicine treatments. Furthermore, the identification and grading of localized cartilage abnormalities through the US can aid in determining the appropriate treatment approach or the need for further imaging investigations.[8]

Cartilage thickness is an important measure in detecting both osteoarthritis (OA) onset and progression.[11] While the initial stages of OA may lead to an initial thickening of cartilage, it is widely recognized that the structural changes associated with the development and progression of clinical OA primarily involve the erosion and deterioration of articular cartilage.[11-13]

Regarding rheumatic diseases US can reliably identify pathologic features of gout, calcium pyrophosphate crystals deposition (CPPD), osteoarthritis and other inflammatory arthritis.[14]

In gout, monosodium urate crystals (MSU) are deposited predominantly in the superficial portions of the articular cartilage that are not readily demonstrated with conventional diagnostic imaging, including CT or conventional radiography. The physics of the US makes it an ideal tool to detect crystalline material in soft tissues and has been reported to be a valuable modality for diagnosing gout as it could detect early deposition of MSU crystals in some joint structures, such as the surface of hyaline cartilage.[15] Crystalline material found in gouty joints reflects ultrasound waves more strongly than surrounding tissues and can thus be readily distinguished.[16] This creates a double contour sign (deposition of the MSU crystals on the surface of hyaline cartilage) that describes the deposition of monosodium urate crystals on cartilaginous surfaces that form an irregular hyperechoic band paralleling the bone contour (typically as bright as the bone contour). This sign is highly specific for gout (97.3%-100%), mainly during flares. However, its sensitivity is less consistent (36.8%-92%).[15] Fig. 12 demonstrates these findings.

In contrast to gout, calcium pyrophosphate crystals tend to aggregate in the center of both hyaline and fibrous cartilage.[17] The sparkling reflectivity of CPPD crystals allows the clear depiction of even minimal aggregates.[18] In hyaline, cartilage appears as a hyperechoic, irregular line (similar to bony cortex) embedded in anechoic appearing hyaline cartilage and does not create a posterior shadowing.[19] Fig. 13 provides these findings.

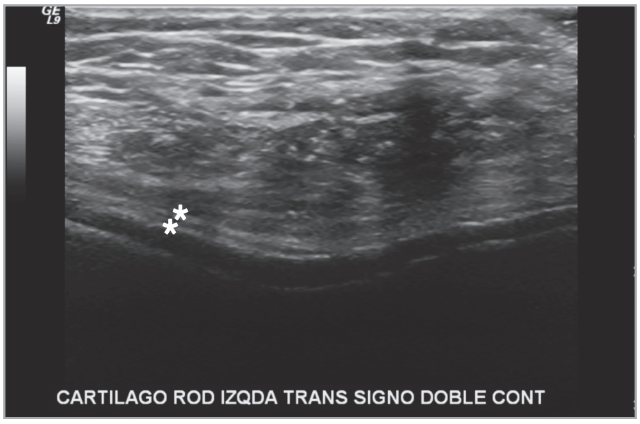

Figure 7 - Ultrasound image of the trochlear cartilage in the transverse axis in a patient with gout. Double signing represented by the two asterisks.

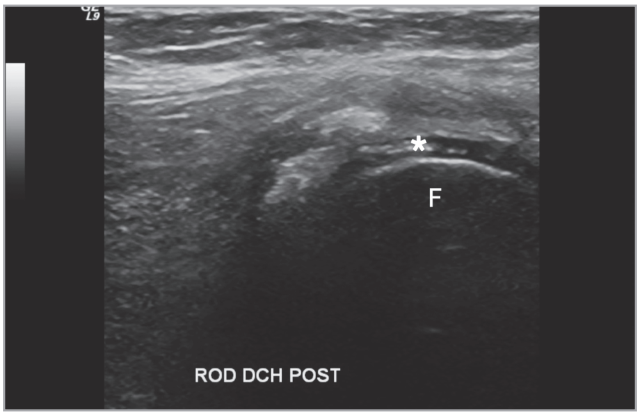

Figure 8 - Ultrasound image of the posterior articular cartilage of the femoral condyle in a patient with CPPD crystals.

F – femur; * - CPPD crystals.

In fibrocartilage, the crystals appear as more irregular punctate hyperechoic deposits of variable size within the cartilage. These aggregates are more typically found within the menisci of the knee and in the triangular fibrocartilage of the wrist. Calcium pyrophosphate crystal deposition can thus be readily distinguished from gout. Ultrasound was found to be more sensitive in the detection of hyaline cartilage calcifications when compared with conventional radiography.[19]

In OA, the clinical findings and conventional radiography have been the gold standard for diagnosis. However, conventional X-ray has clear limitations in imaging and directly visualizing hyaline cartilage, which is frequently involved with disease progression. In addition, plain radiographs have very low sensitivity in demonstrating minimal cartilage involvement in early disease. Thus, ultrasound can help assess early changes in the joint.[20] US allows for the detection of typical findings in OA, particularly in the cartilage and bony cortex. Common findings include osteophytes, joint effusion, and synovial proliferation and may also depict increased vascularization (power Doppler sign) suggestive of inflammatory activity. Ultrasound demonstrates a large set of changes involving the hyaline cartilage from early to late disease. Initial findings are represented by blurring of the edges, which become irregular and lose their normal sharpness. Initially, they involve the superficial cartilaginous margin and correspond to the micro-cleft formation due to tissue deterioration. Later, changes in the echotexture appear, with evidence of loss of homogeneity and transparency. With disease progression, focal and asymmetric narrowing is usually present; subsequently, diffuse thinning is charted up to the complete absence of the cartilaginous layer that corresponds to cartilage breakdown and bony denudation.[20,21] Figs. 9 and 10 provide some typical findings of knee OA.

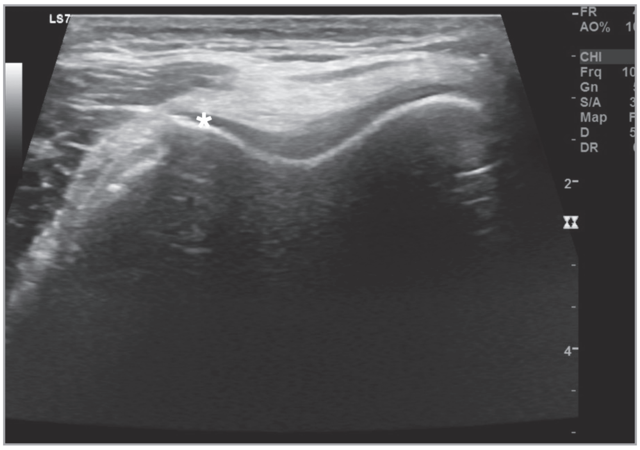

Figure 9 - Ultrasound image of the trochlear cartilage in a knee with OA.

* - narrowing of the trochlear cartilage.

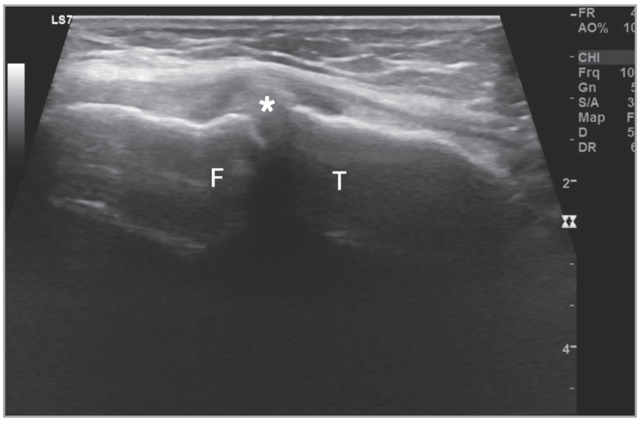

Figure 10 - Ultrasound image of medial meniscus extrusion.

F - femur; T - tibia; * - medial meniscus.

When considering the limitations of the US in evaluating knee cartilage, it is important to note the following factors: operator dependence, where the quality of ultrasound imaging is influenced by the skills and experience of the physician, and the lack of widely accepted standardized examination protocols, which exacerbates the variability of results attributable to operator dependence. Additionally, there is a significant learning curve associated with acquiring proficiency in ultrasound techniques,[22] and a limited penetration and visualization because the US has restrictions in visualizing deep structures or areas covered by bone, such as the body of the meniscus, the posterior structures of the knee and all of the ones which visualization is jeopardized by the US reflexion in the cortical bone. In such cases, complementary imaging modalities like MRI may be necessary to ensure comprehensive evaluation. As Naredo *et al* reports, a variable portion of the knee joint is occult to the US beam, which compromises the joint structural evaluation in specific areas. Flexion may be important to make these areas accessible for the US beam. However, some patients may not be able to flex the knee beyond 125° due to inflammatory or degenerative changes.[23]

Although it was developed as a stepwise approach, it can be used to detect certain pathological findings related to knee cartilage, such as degenerative and inflammatory/rheumatologic lesions. However, this protocol has limitations in terms of visualizing the entire extent of the articular cartilage of the knee, such as lateral and medial condyles near the intercondylar notch, internal parts of the menisci and patellar cartilage, so additional imaging modalities may be necessary for a clearer diagnosis and therapeutic decision-making.

Conclusion

In summary, the ultrasound protocol for evaluating knee cartilage and fibrocartilage is crucial due to its accessibility, cost-effectiveness, real-time imaging, and ability to measure cartilage thickness. It allows for comprehensive assessment of different knee joint surfaces, identification of abnormalities, and assists in initial screening, treatment planning, and progress monitoring. While additional imaging may be necessary for a thorough diagnosis, the ultrasound protocol significantly enhances knee cartilage assessment and improves overall patient care.

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