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Khamidov O.A.

ULTRASOUND TECHNOLOGIES IN THE DIAGNOSIS OF KNEE JOINT INJURIES

(Monograph)

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COMPILERS:

Khamidov O.A. - Head of the Department of Medical Radiology, Faculty of Postgraduate Education, Samarkand State Medical University, DSc.

REVIEWERS:

Khodjibekova Y.M. - Professor of the Department of Oncology and Medical Radiology Doctor of Medical Sciences Tashkent State Dental Institute Doctor of Medical Sciences .

Urinbayev P.U. - Professor of Traumatology and Orthopedics at Samarkand State Medical University, Doctor of Medical Sciences

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Scientific Secretary, Associate Professor: Ochilov U.U.

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LIST OF CONVENTIONAL SYMBOLS AND TERMS

US – ultrasound examination

MRI – magnetic resonance imaging

CT – computed tomography

PET – positron emission tomography

ACL – anterior cruciate ligament

KJ – knee joint

MDCT – multi-detector computed tomography

MSCT – multi-spiral computed tomography

CDI – color doppler imaging

EI – energetic image

TP – true positive

TN – true negative

FN – false negative

FP – false positive

T1R – T1 width

T2R – T2 width

18F- ftor 18

Tc99 – technician 99

Ga67- gallium 67

ENTRANCE

Knee injuries are incredibly common, making up nearly a quarter of all musculoskeletal injuries worldwide. With the rise of active lifestyles and extreme sports in recent decades, we've seen a significant increase in these cases. Looking at the data, ligament injuries are the most frequent type of knee trauma, accounting for almost half of all cases. For athletes, damage to the internal structures of the knee is particularly common. Ruptures of the anterior cruciate ligament (ACL) are reported in up to 92% of cases, while meniscal injuries occur in 84%. Persistent or repeated injuries to the cruciate ligaments, menisci, and cartilage can lead to long-term degenerative changes. This often results in a significant decline in quality of life and can even cause permanent disability.

In recent years, ultrasonography (US) has been widely adopted for the assessment of knee joint injuries. This diagnostic modality is non-invasive, cost-effective, and suitable for repeated examinations, making it particularly valuable for detecting early pathological changes and monitoring them over time. Ultrasonography offers substantial diagnostic capabilities that are often comparable to magnetic resonance imaging (MRI) and arthroscopy, especially in terms of informativeness and accessibility.

Globally, extensive scientific research is being conducted on the ultrasonographic evaluation of knee joint injuries and complications. Such studies focus on improving visualization of intra-articular damage, validating ultrasonography against arthroscopic and MRI findings, developing methodological guidelines to enhance diagnostic accuracy, and formulating comprehensive diagnostic algorithms.

In Uzbekistan as well, the healthcare system prioritizes early diagnosis, effective management, and prevention of complications resulting from traumatic injuries and tumor-related diseases. Within this context, emphasis is placed on improving the quality and accessibility of medical services, integrating advanced diagnostic technologies, developing effective models of outpatient and dispensary care, and promoting preventive healthcare strategies. Therefore, the scientific exploration of ultrasonographic methods in the diagnosis and management of knee joint injuries remains a pressing and highly relevant issue in modern medical radiology.

CHAPTER I. MODERN APPROACHES TO RADIOGRAPHIC DIAGNOSTICS OF INJURIES OF THE INTERNAL STRUCTURES OF THE KNEE JOINT AND THEIR COMPLICATIONS

§1.1. Anatomical characteristics of the knee joint

The knee joint represents one of the most complex biomechanical systems in the human body, composed of multiple anatomical structures that work synergistically to ensure stability, mobility, and weight-bearing function. The susceptibility of the knee to various injuries is largely associated with the unique architecture, mutual positioning, and biomechanical properties of its components. Therefore, a comprehensive understanding of the knee's structural and functional anatomy is essential for elucidating the mechanisms of trauma and guiding accurate diagnosis.

Ligaments and Stabilizing Structures

The principal stabilizers of the knee joint are the ligaments, which function in coordination with other soft-tissue and osseous elements. Anatomically, stabilizing structures are commonly classified into three groups:

Passive stabilizers – including bony structures and the articular capsule;

Relatively passive stabilizers – menisci, ligaments, and fibrous components of the joint capsule;

Active stabilizers – muscles and their associated tendons, which contribute to dynamic stability.

The medial and lateral collateral ligaments protect the joint from valgus and varus stresses, while the anterior and posterior cruciate ligaments (ACL and PCL) provide central stabilization, particularly against anterior-posterior translation and rotational forces. Together, these ligamentous structures maintain congruence and functional integrity of the joint during movement.

Articular Cartilage and Synovial Membrane

The articular cartilage of the knee is primarily composed of hyaline cartilage, which ensures smooth articulation between the femoral condyles, tibial plateau, and patella. It contains a matrix of collagen fibers, glycoproteins, elastin, and glycosaminoglycans, organized into distinct zones that enable load distribution and resistance to shear forces. Nutrition of the cartilage is supplied by diffusion from the synovial fluid, which itself is secreted by the synovial membrane.

The synovial membrane plays a crucial role not only in joint lubrication but also in proprioception, given its rich vascular and neural supply. Its close anatomical relationship with cruciate ligaments highlights its importance in inflammatory and degenerative pathologies.

Menisci

The medial and lateral menisci are crescent-shaped fibrocartilaginous structures interposed between the tibia and femur. They serve as essential shock absorbers and secondary stabilizers. The lateral meniscus transmits approximately 75% of the load in its compartment, whereas the medial meniscus sustains around 50% of the medial compartment’s load.

Structurally, meniscal tissue more closely resembles tendon than cartilage, consisting of collagen fibers arranged in radial and circumferential patterns. These fiber orientations allow the menisci to withstand compressive and tensile forces. However, the medial meniscus, due to its stronger capsular and ligamentous attachments, demonstrates reduced mobility and, therefore, is more prone to injury compared with the lateral meniscus.

Blood supply to the menisci is limited to the peripheral one-third (the “red zone”), while the central two-thirds (the “white zone”) are largely avascular and dependent on diffusion from synovial fluid. This restricted vascularization explains the poor healing capacity of central meniscal tears.

Muscular Support

Surrounding musculature provides dynamic stabilization of the knee joint. Quadriceps and hamstring groups not only facilitate motion but also reduce stress on passive stabilizers. The semitendinosus, semimembranosus, and biceps femoris, through their capsular and meniscal attachments, contribute to both posterior and medial stability.

Vascular and Neural Supply

The knee joint receives arterial blood supply primarily from branches of the popliteal artery, which forms an extensive anastomotic network around the capsule, ensuring adequate perfusion during varying biomechanical demands. Venous and lymphatic systems complement metabolic exchange and clearance of joint effusions.

Innervation of the joint capsule is provided by branches of the femoral, obturator, tibial, and common peroneal nerves. Nociceptive and proprioceptive fibers are distributed unevenly, with the densest networks located in the medial and posterior quadrants, thereby explaining the frequent localization of pain in these areas during pathology.

Functional Significance

Altogether, the anatomical composition of the knee—its osseous framework, ligamentous architecture, meniscal structures, and neuromuscular components—ensures both mobility and stability. However, these same features make the joint particularly vulnerable to traumatic and degenerative conditions. A thorough knowledge of these anatomical and functional characteristics is indispensable for clinicians and radiologists in understanding mechanisms of injury, selecting appropriate imaging techniques, and designing optimal treatment strategies.

§1.2. Diagnostic efficacy of radiological research methods in injuries and complications of the internal structures of the knee joint

Significance of Early Diagnosis. Among the key determinants of prognosis and therapeutic success in knee joint (KJ) disorders is the ability to establish an accurate diagnosis at an early stage of the pathological process. Clinical manifestations alone are often insufficient to reveal the full scope of intra-articular lesions. Reported diagnostic accuracy of physical examination varies considerably, ranging from 33% to 96%. Therefore, along with medical history, presenting complaints, and physical as well as laboratory assessments, the application of instrumental, non-invasive imaging modalities is essential for ensuring diagnostic precision.

Role of Radiological Imaging in Modern Medicine. Contemporary orthopedic and rheumatologic research is inseparable from radiological visualization methods. These modalities are indispensable not only for diagnosis but also for the classification and monitoring of joint diseases. Continuous technological progress has significantly improved the quality and scope of information obtainable about joint tissues, resulting in greater precision in identifying, staging, and evaluating musculoskeletal pathologies.

The medical and social burden of musculoskeletal diseases—particularly those affecting large joints such as the knee—is profound. Their high prevalence, progressive and chronic course, diagnostic challenges at early stages, increased risk of disability, and substantial healthcare expenditures underscore their clinical significance.

- Classification of Knee Joint Changes
- Structural alterations detected within the joint can generally be divided into:
- Traumatic injuries: involving tendons, ligaments, capsules, menisci, periarticular fat pads, bones, and occasionally nerves.
- Inflammatory processes: affecting ligaments, synovium, muscles, and bursae.
- Degenerative-dystrophic conditions: e.g., osteoarthritis.
- Neoplastic lesions: such as synovioma or synovial sarcoma.
- Combined disorders: mixed degenerative and traumatic changes.

Among these, degenerative-inflammatory diseases represent the most common cause of chronic disability. Osteoarthritis alone is observed in 10–20% of older adults, while traumatic injuries of the knee are more frequent in younger, working-age populations. In children, up to 70% of musculoskeletal injuries involve the knee.

Modern Diagnostic Modalities. Conventional Radiography. Radiographs remain the most widely available imaging tool, especially valuable for assessing bone structures, osteophytes, subchondral sclerosis, and joint space narrowing. Despite their limited sensitivity for detecting ligamentous and meniscal lesions, X-rays remain indispensable for fracture assessment and osteoarthritis staging. Their disadvantages include low sensitivity for soft tissues, difficulty in evaluating the patellofemoral region, and radiation exposure with repeated use.

Computed Tomography (CT). CT provides higher resolution images and allows for three-dimensional reconstructions, proving especially effective in complex fractures, postoperative assessment, and detection of cystic lesions. The introduction of multidetector CT (MDCT) has dramatically improved image acquisition, even in patients with metal implants. However, CT has restricted capability for evaluating ligaments, cartilage, and menisci, while radiation exposure remains a drawback.

Magnetic Resonance Imaging (MRI). MRI is considered the gold standard for intra-articular soft tissue evaluation, with sensitivity and specificity approaching 90–100% for cruciate ligaments and meniscal tears. MRI also enables early detection of degenerative changes and synovial pathologies in conditions such as rheumatoid arthritis. However, MRI is costly, less accessible, and contraindicated for patients with pacemakers or extensive metallic hardware.

Ultrasound (US). Ultrasonography has gained wide clinical acceptance due to its non-invasive nature, affordability, real-time dynamic imaging, and absence of radiation. It is especially effective for diagnosing injuries of ligaments, menisci, tendons, effusions, Baker's cysts, and periarticular soft tissues. The addition of Doppler techniques provides valuable information about synovial vascularity in inflammatory diseases. Nonetheless, sonography is highly operator-dependent and has limitations in imaging deep intra-articular structures obscured by bone.

Scintigraphy and PET. Nuclear medicine techniques, such as scintigraphy and positron emission tomography (PET), provide metabolic information beyond anatomical imaging. Scintigraphy demonstrates high sensitivity (up to 95%) in inflammatory conditions and is useful for monitoring therapy response. PET, especially with 18F-FDG, has emerged as a powerful tool in musculoskeletal oncology and systemic inflammatory diseases, allowing whole-body assessment.

Arthroscopy as a Reference Standard. Arthroscopy remains the most informative method for intra-articular evaluation by allowing direct visualization and palpation of joint structures. Despite its diagnostic accuracy, arthroscopy is used sparingly for diagnostic purposes, reserved mainly for therapeutic interventions (about 20% of cases). Its indications include persistent pain unresponsive to conservative therapy, suspected loose bodies, and inconclusive findings from US or MRI.

Emerging Imaging Technologies. Recent decades have witnessed the evolution of novel diagnostic modalities such as:

- High-resolution ultrasound with Doppler and 3D/4D modes, improving visualization of vascularity and structural integrity.
- Sonoelastography, enabling the assessment of tissue stiffness, useful in differentiating tumors or evaluating fibrosis.
- Contrast-enhanced ultrasound, expanding the diagnostic capacity for inflammatory hyperemia.
- Advanced MRI protocols (e.g., fat-suppression, cartilage-sensitive sequences) that improve differentiation of cartilage and synovial fluid.
- These innovations significantly enhance diagnostic precision, enable earlier detection of disease, and optimize therapeutic planning.

Challenges and Limitations. Despite significant progress, diagnostic inaccuracies persist in up to 30% of cases. Delayed or incorrect diagnoses may result in inappropriate treatment in 45–75% of patients, eventually leading to irreversible degenerative changes. Moreover, differences in operator expertise, variability in international classification systems, and limited visualization of specific structures (e.g., meniscal body) contribute to diagnostic discrepancies across institutions.

Conclusion

In summary, the integration of clinical examination with radiological imaging technologies—including X-ray, CT, MRI, ultrasound, and scintigraphy—constitutes the cornerstone of effective diagnosis for knee joint pathologies. The rational selection of imaging modalities, guided by clinical necessity and cost-effectiveness, is vital. Continuous refinement of diagnostic algorithms, incorporation of new technologies, and closer collaboration between radiologists and clinicians will ensure greater accuracy, better treatment outcomes, and reduced disability in patients with knee joint disorders.

CHAPTER II. ULTRASOUND SEMIOTICS OF INJURIES AND COMPLICATIONS OF THE INTERNAL STRUCTURE OF THE KNEE JOINT

Sonographic examinations of the knee joints were performed in real time on an expert-class Sonoscape S50 ultrasound scanner. As a result of the data obtained, the following main indicators of injuries to the internal structures of the knee joint were identified during ultrasound examination: meniscal injuries, cruciate ligament injuries, synovitis, bursitis, meniscal cysts, and hemarthroses.

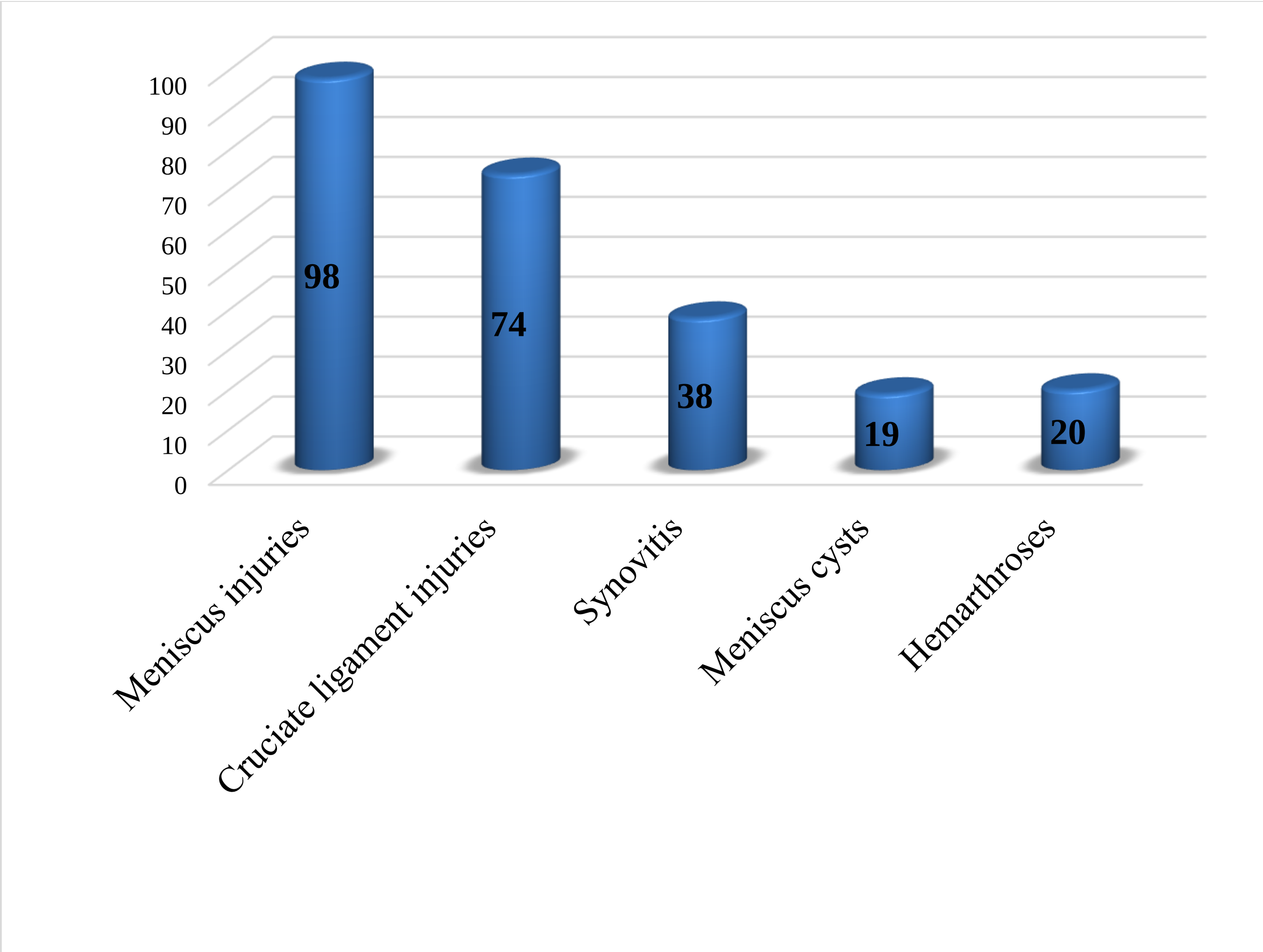


Figure 2.1. Nosology of the examined joints

Ultrasound examination of meniscal lesions is traditionally performed in lateral longitudinal, medial longitudinal, posterior and anterior transverse approaches, with the joint space serving as the main ultrasound target, in which a transverse triangular section of the meniscus of the knee joint is determined.

When examining volunteers from the control group (20 people), the unchanged meniscus has the following visual picture on the ultrasound image:

• triangular in shape, directed with its apex towards the joint cavity;

• isoexogenic (medium exogenic) area, with decreased exogenicity near the edges

• sufficient uniformity ("fine-grained");

• with clear boundaries, smooth contours;

• avascular in CDI modes.

This structure mainly corresponds to the avascular or "white" zone of the meniscus. The boundaries of the vascular zone of the meniscus are not clearly visible and are visible in the paracapsular part (Figure 2.2).

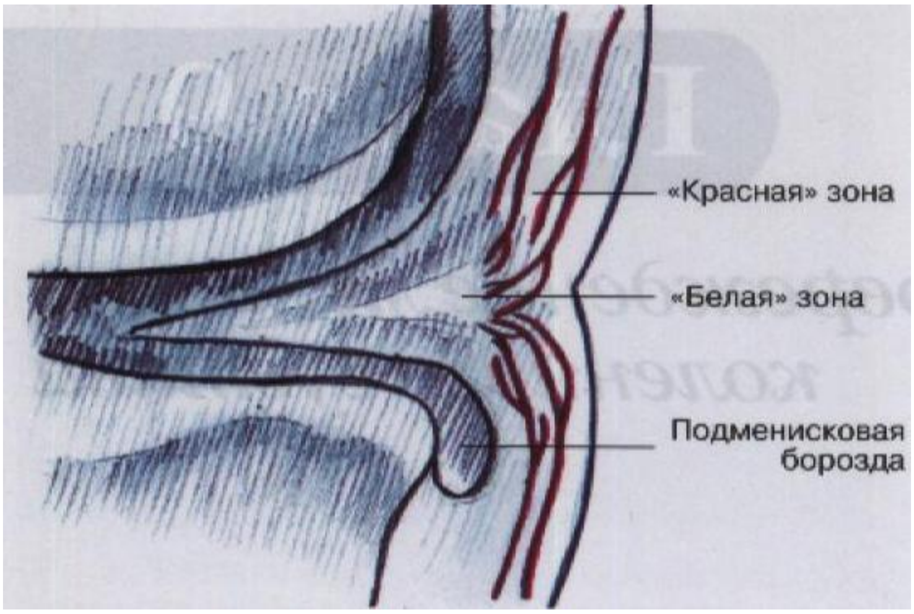


Figure 2.2. The «red» and «white» zones of the meniscus. Diagram of the knee joint in the coronal plane

A peculiarity of using sonography in the diagnosis of meniscal pathology is that it is impossible to see the image in all parts of the “white” zone. This is more true for the lateral meniscus; the main reason for this is that its posterior horn and body are located at the posterior outer corner of the patellar tendon and ligament apparatus, which leads to attenuation of the signal in the meniscus (Fig. 3.3). In some cases, we performed additional scans in the longitudinal projection along the joint space, which served to better visualize the image of the marginal zones of the meniscus. In this case, the marginal area of the meniscus is better visible.

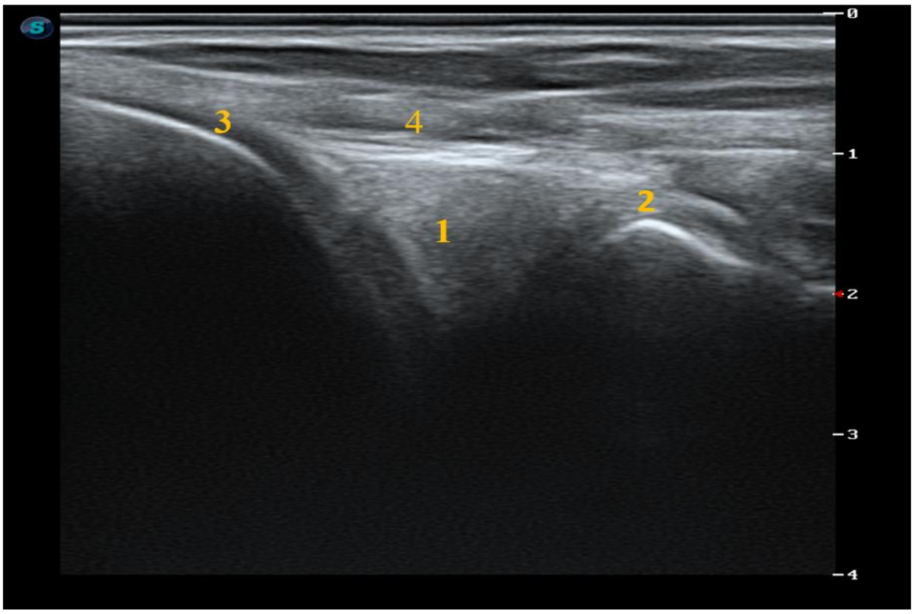


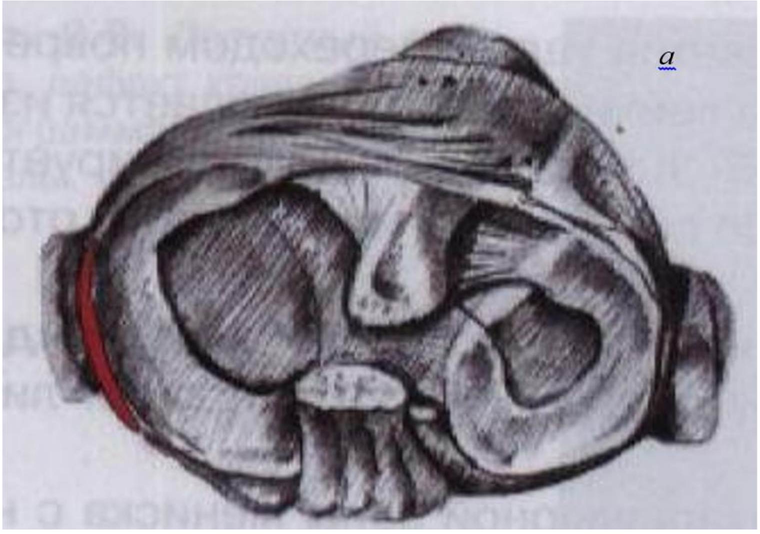
Figure 2.3. Exogram of patient A., 26 years old (control group) gray scale mode. Sagittal projection (medial approach). Medial meniscus is normal. 1-medial meniscus, 2-tibial bone, 3-femur, 4-tibial ligament

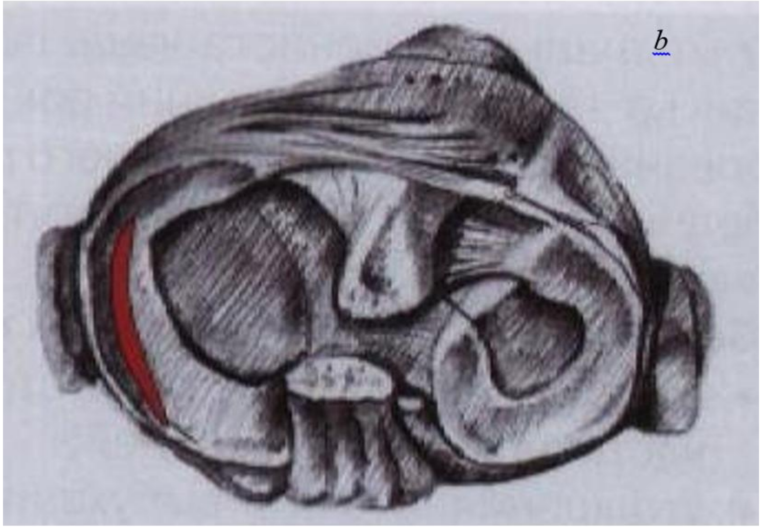
In this projection, the paracapsular, vascularized parts of the meniscus are much better visible than the peripheral cartilage. In the "red" zone, regeneration processes may occur, and when fluid accumulates, especially in the lateral space of the lateral meniscus, the paracapsular sections tend to stretch.

In the control group, the paracapsular part of the meniscus is more exopositive, fairly uniform, and blood flow is often not detected. In the CDI mode, a spotty image of very small caliber blood vessels appears at the menisco-capsular border, which is characteristic of perimeniscal arterial tangle.

Out of 122 joints examined, meniscus lesions were detected in 81 of the examined joints, which is 66.39%. According to the anamnesis, the causes of meniscus rupture are indirect or combined injuries, which are caused by external (for the medial meniscus) and internal (for the lateral meniscus) rotation of the tibia. In addition, the analysis of the results of the examination of patients shows that the cause of meniscus injury is a sudden, very rapid displacement of the joint from a flexed position, and in rare cases, a direct injury (as a result of slipping off the edge of the stairs or hitting the joint with a moving object). There are several types of meniscus injuries of the knee joint, which are schematically shown in Figure 2.4.

Observations most often reveal horizontal (up to 95.5%), less often combined (up to 2.8%) and vertical (up to 1.7%) tears. Usually, combined injuries of the meniscus and general damage to the OA are noted (up to 82%). Meniscal tears are complete (19%), incomplete (21%), longitudinal ("watering can") (24%), transverse (22%), clotted (8%), and fragmented (6%). Medial meniscus tears are most often associated with damage to the OA.





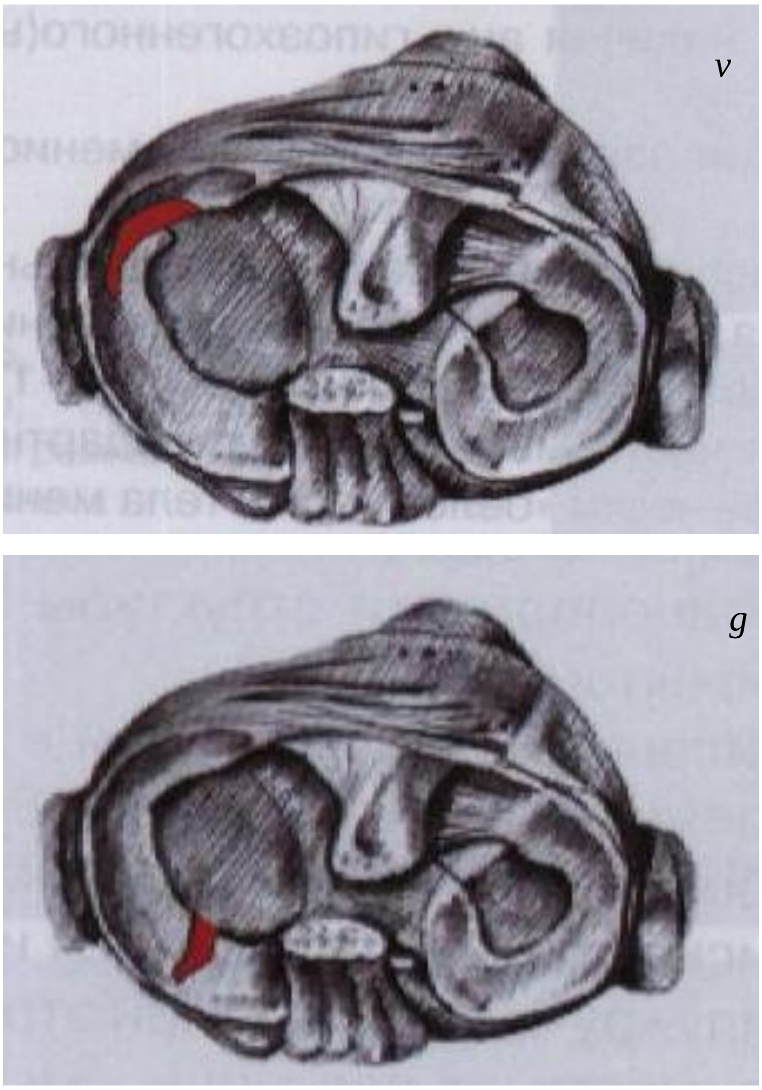


Figure 2.4. Schematic representation of various types of damage to the meniscus of the knee joint in the axial plane: a-meniscocapsular separation and paracapsular tear, b-longitudinal tear in the form of a "watering can handle", cap tear, c- scissor-shaped tear, g- radial tear

In patients with meniscus injuries, acute and chronic periods are distinguished. In the acute period, ultrasound diagnosis of meniscus injuries is difficult due to the presence of reactive nonspecific inflammatory symptoms arising from injuries of other internal structures of the joint. The more pronounced the edematous syndrome of the knee joints, the more signal attenuation is noted and the lower the level of ultrasound imaging.

It should be noted that in patients with a single injury, abrasions, tears, sprains, and even crushing of the meniscus without tearing and separation from the capsule often occur. Degenerative changes and inflammatory processes in it predispose to complete rupture of a previously uninjured meniscus.

After the subsidence of reactive processes, a subacute period develops within 2-3 weeks. The degree of manifestation increases with the appearance of specific clinical symptoms: capsule infiltration and local pain against the background of joint space, often increased fluid in the joint and blockages.

In the main percentage of ultrasound observations, the following characteristic semiotics of meniscus damage are determined:

• with complete or partial loss of the structure of the deformed triangular cross-section of the meniscus;

• with thickening, swelling of the paracapsular zone of the meniscus, with unclear external contours;

• decreased exogenousity of meniscus tissues;

• heterogeneity of the structure due to the presence of an- or hypoexogenous defect;

• increased vascularization in the projection of the paracapsular zones of the meniscus in the RDT mode.

Figures 2.5-2.9 show specific examples of exograms of various injuries of the meniscus of the knee joint according to observations.

Medial meniscus body injuries are often associated with the transfer of damage to the posterior or anterior horn (the so-called “watering can” sign), with isolated damage to the posterior horn being more common (30%), and anterior horn injuries being less common (9%). Tears are observed with displacement or with complete protrusion of the tear site, or with the absence of signs of displacement.

The results of the study show that the most typical and simple sign for detecting a medial meniscus tear is a true blockade of the joint (a “watering can” tear of the meniscus). In this case, the joint is fixed at an angle of 150-170° during the examination, depending on the size of the torn part of the meniscus, and in the standard projection, the absence of a “white” zone of most of the meniscus body is noted. The formation of additional hypoechoicity in the anterior or posterior horn of the meniscus is a sign of a “watering can” type tear of the meniscus, a displacement of the articular cartilage or the edge of the meniscus body. It should be noted that the true blockade of the meniscus should be distinguished from reflex muscle contracture, which often occurs as a result of injuries, damage to the capsular-ligamentous apparatus and compression of the intra-articular components (chondromalacia, chondromatosis, Kenig's disease, Goff's disease, etc.). Unlike the meniscus, the short-term compression of the joint blockade is easily eliminated, but often there is an increase in synovial fluid.

Simultaneous damage to the medial and lateral meniscus of the knee joint was detected in only 5 patients or 4.5%.

When the lateral meniscus is damaged, joint blockade is extremely rare, since the meniscus is more likely to be compressed than torn due to its mobility. In addition, the joint is crushed by the tubercles of the meniscus, which, with repeated injuries, leads to degeneration and often to its cystic degeneration. On ultrasound, in patients examined in these cases, the lateral meniscus is enlarged, which is clearly visible in the anterior horn, in a clearly heterogeneous state, reduced exogenousity and anexogenic cystic formations of various sizes are visible.

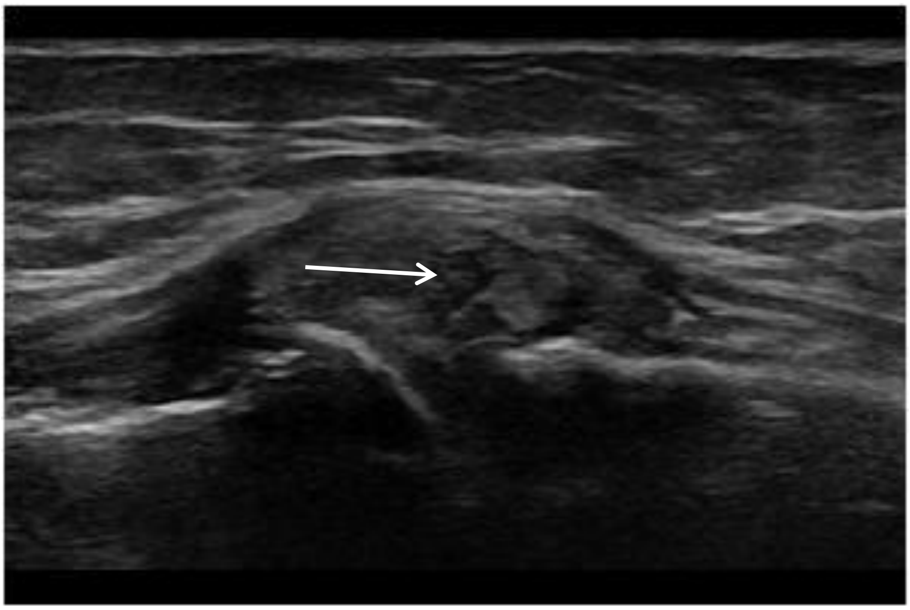


Figure 2.5. Exogram of patient A., 55 years old, in gray scale mode. Coronal projection (posterior approach). Tear of the posterior horn of the medial meniscus protruding from the joint space. An anechoic line with an uneven contour is detected in the meniscus area.

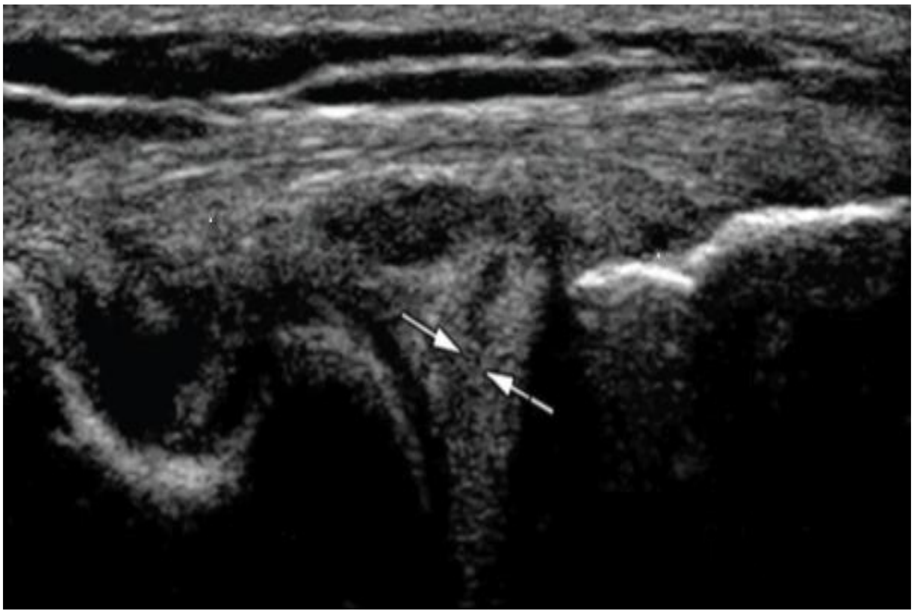


Figure 2.6. Exogram of patient U., 22 years old, in gray scale mode. Sagittal projection (lateral medial approach). Meniscus tear. The meniscus is not enlarged, its structure is heterogeneous, its exogenity has not changed, and a transverse anexogenic line is noted

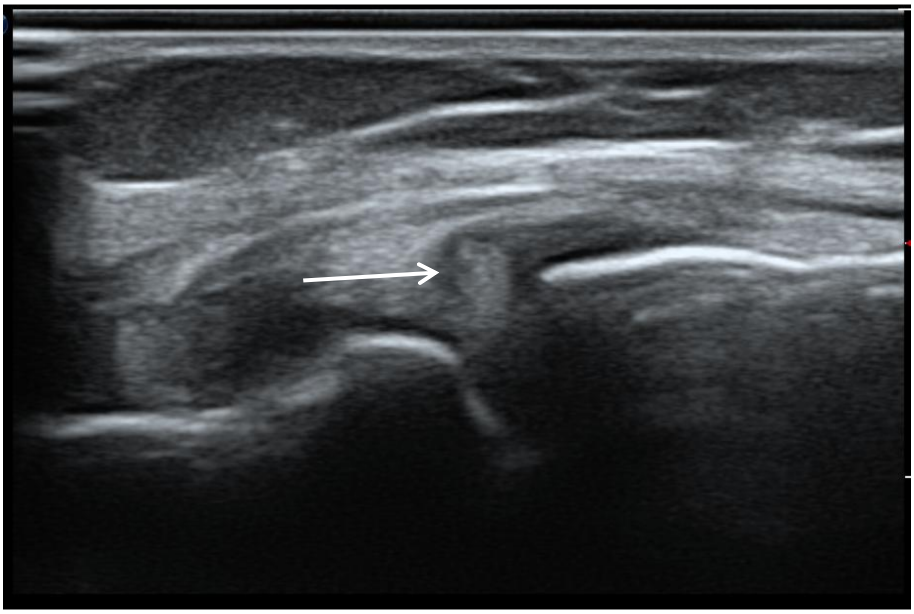


Figure 2.7. Exogram of patient F., 20 years old, in gray scale mode. Coronal projection (posterior approach). Partial separation of the posterior horn of the meniscus. The meniscus is not enlarged, the structure is heterogeneous, hyperechogenic

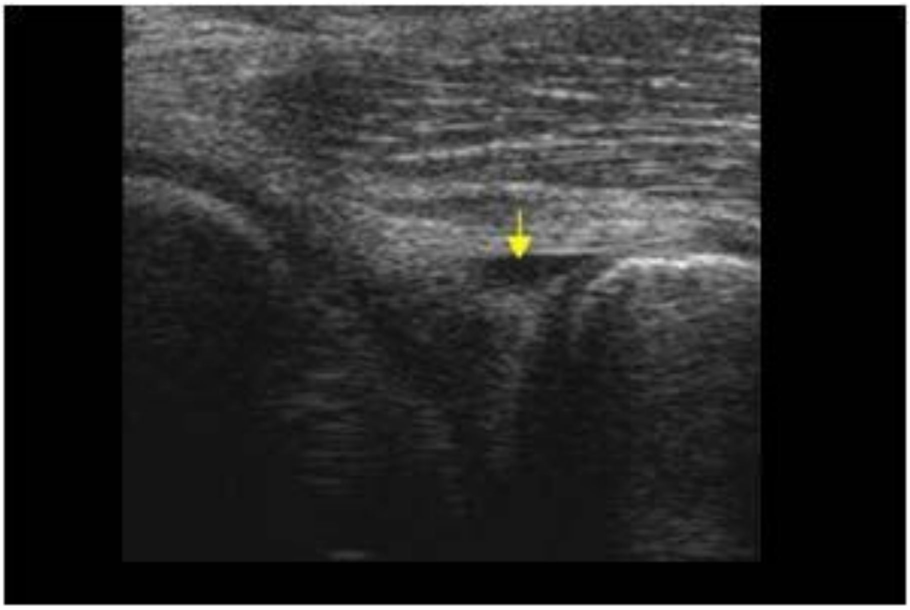


Figure 2.8. Exogram of patient S., 34 years old, in gray scale mode. Coronal projection (posterior approach). Paracapsular meniscus tear with pronounced inflammatory edema in the "red" zone. The meniscus is enlarged, heterogeneous in structure, hypoechogenic, an anechoic area is noted in the "red" zone

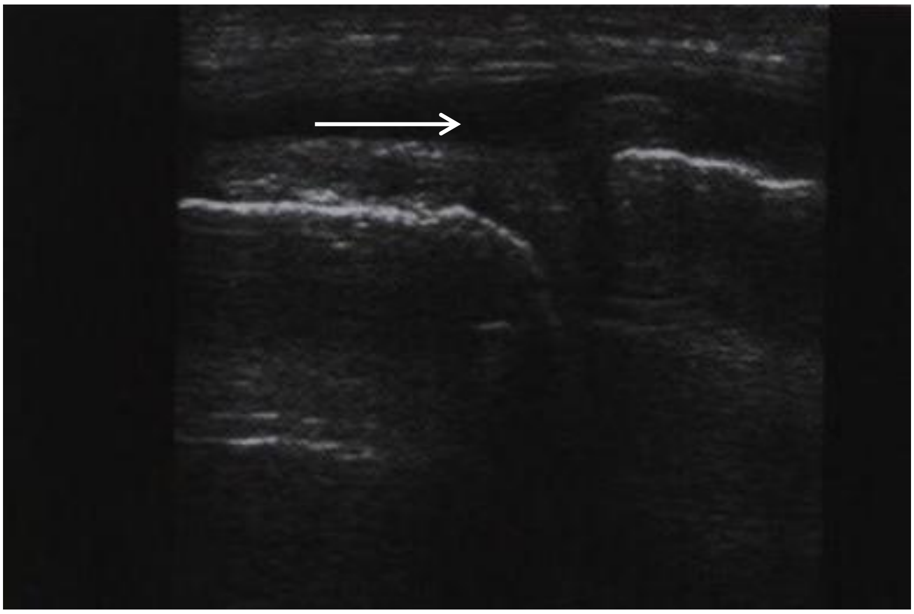


Figure 2.9. Exogram of patient X., 29 years old, in gray scale mode. Coronal projection (posterior approach). Appearance of separation of the medial meniscus from the greater trochanter. The meniscus is not enlarged, its structure is heterogeneous, heteroexogenic, an anexogenic area is noted between the greater trochanter and the red zone.

Further examinations show that in 74 patients (60.1%) with intra-articular injuries, separate or combined injuries of the cruciate ligaments are noted. It should be noted that sonography is of high diagnostic value in the diagnosis of articular ligament pathologies and it is necessary to perform it in a longitudinal section parallel to the long axis of the ligament.

In 5 cases of cruciate ligament sprain, the ligament has a thickened appearance, and its structure is hypoechoic. Due to partial or complete injury of the ligament, its anatomical continuity is disrupted. The size and degree of disruption depend on the type of rupture. The hyperechogenic structure of the ligament becomes hypo- or anexogenic at the site of rupture, and the injury site is filled with hematoma. This is determined as hypoechoic or anexogenic zones with and without hyperechoicity. Ultrasound examination accurately identifies the location of the damaged ligament ends.

The anterior cruciate ligament is examined using two approaches (anterior and posterior approaches). It should be noted that the anterior longitudinal (sagittal plane) path to the distal segment of the ligament is considered, while the knee joint should be flexed more than 90°. In this case, the ligament is found to be homogeneous, hypoexogenous, 5-6 mm thick, as a stretch, with clearly flat contours, located under the fat pad, parallel to the femoral plateau. At the entrance to the area where the OA is attached, the transverse ligament of the knee joint is often detected, which connects the anterior horns of the tibia and meniscus. The fibers of this ligament are perpendicular to the fibers of the OA, and their high exogenity is noted. The thickness of the transverse ligament in this projection is approximately 2-3 mm.

In ultrasound examinations of the knee joint, the location of the OA is difficult to determine due to gross sclerotic changes in the fat body and its hypertrophy, which were noted in 16 cases, resulting in a significant decrease in the signal in the ligament area. Examination of the proximal segment of the OA is performed using a convex transducer through a posterior transverse approach. In this case, the OA is often seen attached to the inner surface of the lateral condyle of the femur (Fig. 2.10).

Cruciate ligament injuries can be reliably evaluated with ultrasonography, which provides detailed visualization of local pathological alterations when compared with the contralateral, unaffected knee. In instances of a complete rupture, the site of discontinuity is frequently filled with hematoma, resulting in a loss of the normal fibrillar echogenic structure and its replacement by hypoechoic or anechoic zones. Conversely, partial tears are more subtle and are characterized by focal hypo- or anechoic regions, thickening of ligamentous fibers, partial loss of continuity, and peri-ligamentous soft tissue swelling. It should also be emphasized that the diagnostic yield of ultrasonography increases when dynamic scanning is performed, allowing assessment of ligament tension and joint stability under functional stress. Moreover, the sensitivity of ultrasound in detecting acute cruciate ligament injuries is particularly high when performed in the early post-traumatic phase, before secondary degenerative changes obscure the echotexture.

In cases involving the anterior cruciate ligament (ACL), ultrasonography most commonly reveals a reduction in echogenicity, observed in nearly 69% of patients, along with thickening of the ligament fibers in about 67% when compared to the contralateral side (Fig. 2.11–2.12). Despite these characteristic findings, the diagnostic performance of ultrasound can be restricted due to the narrow anterior acoustic window. This limitation is particularly evident in acute injuries, where pain and swelling often prevent patients from achieving adequate knee flexion, thereby reducing the quality of visualization. Posterior scanning, however, can improve diagnostic accuracy. In approximately 26% of cases, hypoechoic fluid accumulations have been identified along the lateral margin of the intercondylar notch, consistent with intra-articular hematomas. These findings not only provide indirect evidence of ACL disruption but also reflect associated post-traumatic changes within the joint capsule. Additionally, dynamic ultrasound examination, when feasible, may further enhance sensitivity by assessing ligament continuity and tension under stress maneuvers, although this requires considerable operator expertise and patient cooperation.

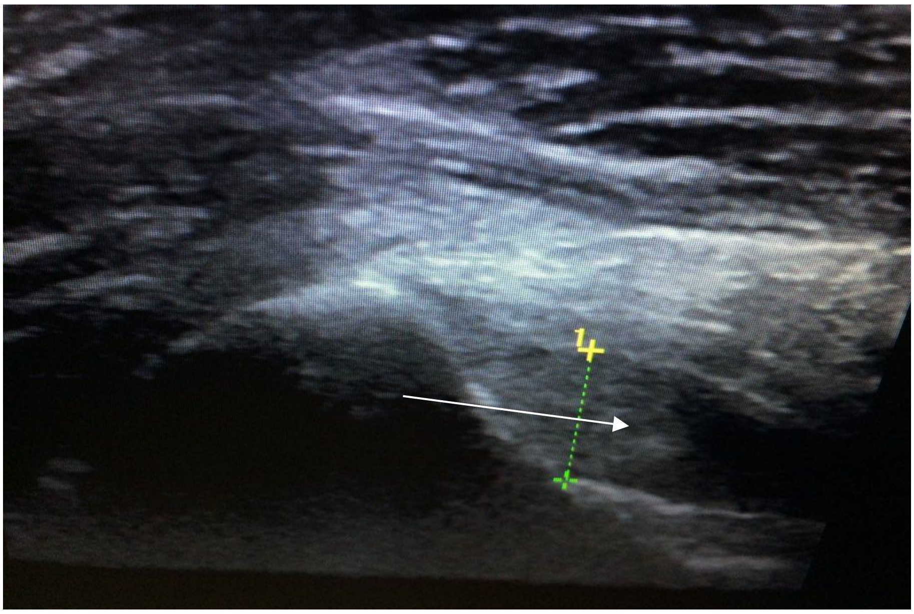


Figure 2.10. Exogram of patient A. at the age of 26 (control group) in gray scale. Coronal projection (anterior approach). Anterior cruciate ligament is normal

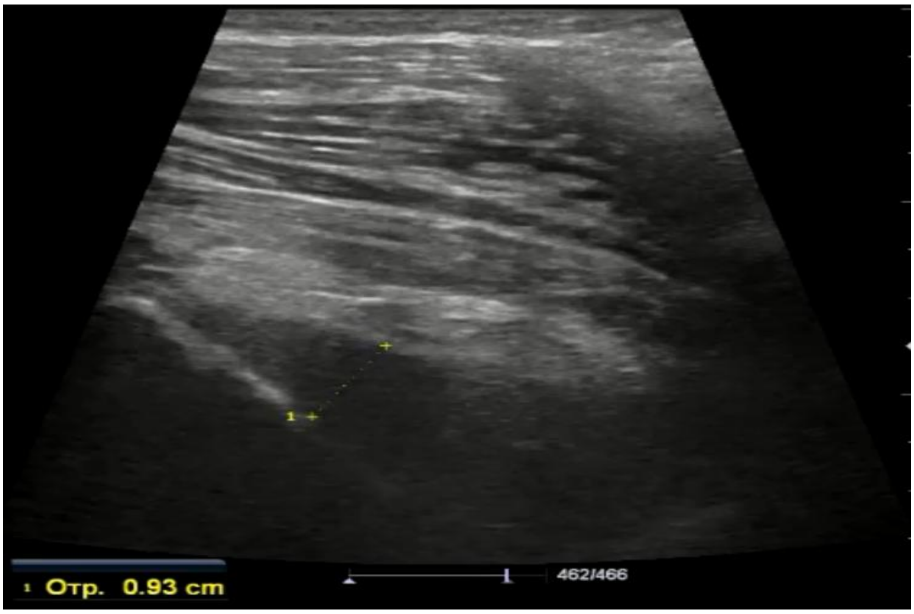


Figure 2.11. Exogram of patient X., 29 years old, grayscale mode. Axial projection (posterior approach). Anterior cruciate ligament rupture. The distal part of the cruciate ligament is thickened up to 9 mm and has a hypoechogenic appearance.

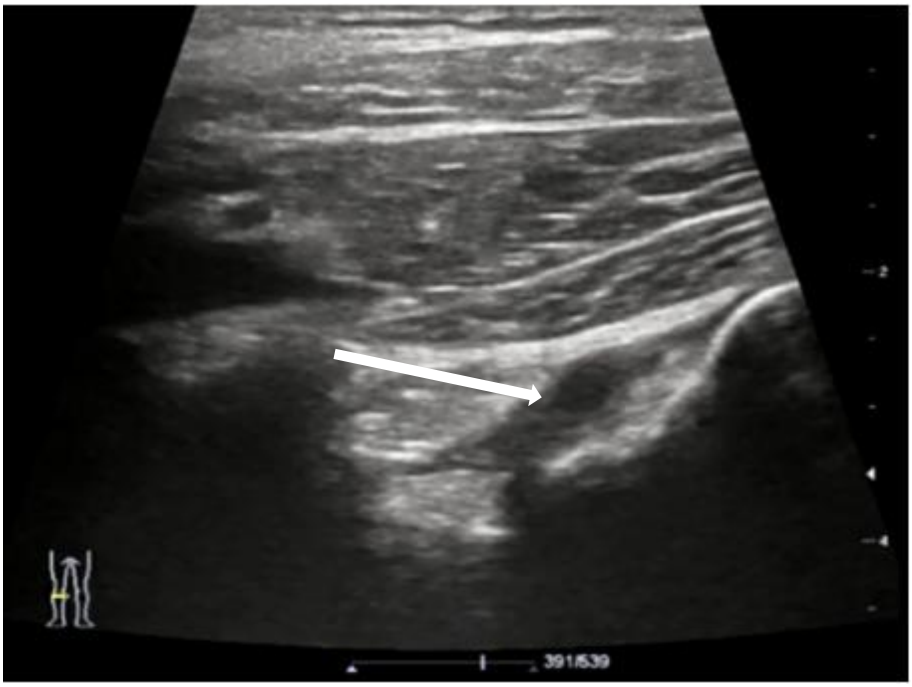


Figure 2.12. Exogram of patient A., 26 years old, grayscale mode. Axial projection (posterior approach). Anterior cruciate ligament rupture. The distal part of the cruciate ligament is thickened up to 9 mm and has a hypoechoic appearance.

In studies, partial rupture of the ACL accounted for 32% of all its injuries. ACL injuries most often occur at the proximal end, since the ACL is denser in the area of its connection with the big toe. The following signs of ACL injuries, which are often recorded by ultrasound in the anterior projection, were identified:

• significant thickening of the distal end of the ligament (up to 7,5-10,5 mm);

• uneven swollen contour;

• significant decrease in exogenity (relative to fatty tissue);

• deformed orientation of the fibers;

• heterogeneous structure, anexogenic defects and cystic inclusions in the structure of the anterior bundles of the ligament.

Such changes occur as a result of interstitial edema and traction of the damaged fibers of the distal part.

Also, with a posterior approach, thickening of the ACL was detected in partial ruptures, and at the same time the absence of a ligament image in this projection indicates a proximal rupture.

It is important to emphasize that several indirect ultrasound signs also contribute to the diagnosis of cruciate ligament pathology. These include fibrosis and thickening of the infrapatellar fat pad, manifestations of anteromedial insufficiency within the ligamentous complex, as well as thickening and reduced echogenicity of the anterior knee ligament and the adjacent greater trochanter region (Fig. 2.13).

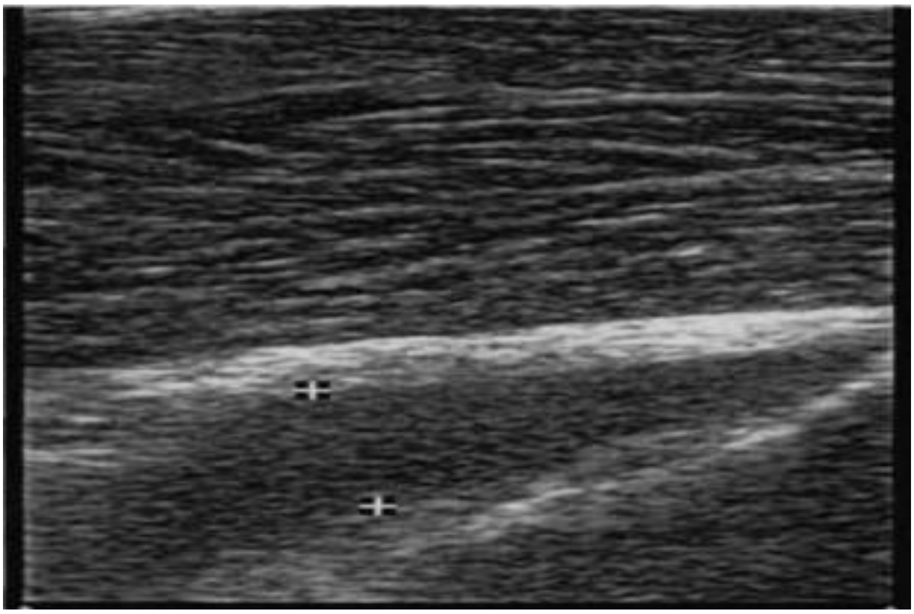


Figure 2.13. Exogram of patient M., 32 years old, gray scale mode. Coronal projection (posterior approach). Thickening of the distal end of the ligament as a result of damage to the ACL.

It should be emphasized that the diagnostic accuracy of ultrasound in detecting cruciate ligament injuries of the knee is largely determined by several key factors: the expertise and clinical experience of the examining specialist, the technical class of the ultrasound equipment, and the frequency of the transducer employed during the study.

In the patients we examined, complications of knee joint injuries were most often diagnosed with synovitis, hemarthrosis and cystic degeneration. Thus, synovitis was detected in 38 (31.1%) cases.

Synovitis is an inflammatory reaction of the synovial membrane resulting from any intra-articular (usually traumatic) injuries. The cause of synovial inflammation is rarely the result of allergic, neurogenic, endocrine, infectious factors. The synovial membrane is a structure that often responds to external injuries with the formation of fluid in its cavity. The main ultrasound criteria for synovitis in our patients were: the ingress of various degrees of exudate into the joint cavity, as well as changes in the synovial membrane.

Most often, synovitis was diagnosed in the largest suprapatellar bursa of the knee joint (upper fold). In very rare cases, inflammation of the prepatellar and infrapatellar bursa occurred.

Quantitative assessment of synovial exudate was difficult due to the complex shape of the fold. For dynamic control, as a rule, the maximum thickness of the fluid layer was assessed in the supine position of the patient, with the joint flexed. Often, traces of fluid in the upper fold were not separately noted.

The quality of the fluid is assessed based on its visual characteristics. During acute inflammation (14 patients), the appearance of the fluid is uniform, anechoic (Fig. 2.14). In the process of chronic inflammation, a large number of hyperechogenic particles are detected in the fluid, which are remnants of cell membranes, fibrin threads, collagen fibers, cartilage fragments. The presence of a large amount of suspension in the synovial fluid is called the symptom of “snow in the cartilage”.

24 patients were examined, and hyperplasia and edema of the synovial layer, as well as intraarticular effusions, were detected. The exogenous nature of the thickened synovial layer is directly related to its edema and inflammatory hyperemia. An increase in the exogenous nature of the thickened synovial layer is detected after the development of hyperplastic and sclerotic processes against the background of a long-term inflammatory process.

The villi in the upper cavity also do not have the same structure. Often, small, fibrous villi are detected in the joint even in the absence of chronic inflammation, for example, in young patients with acute trauma.

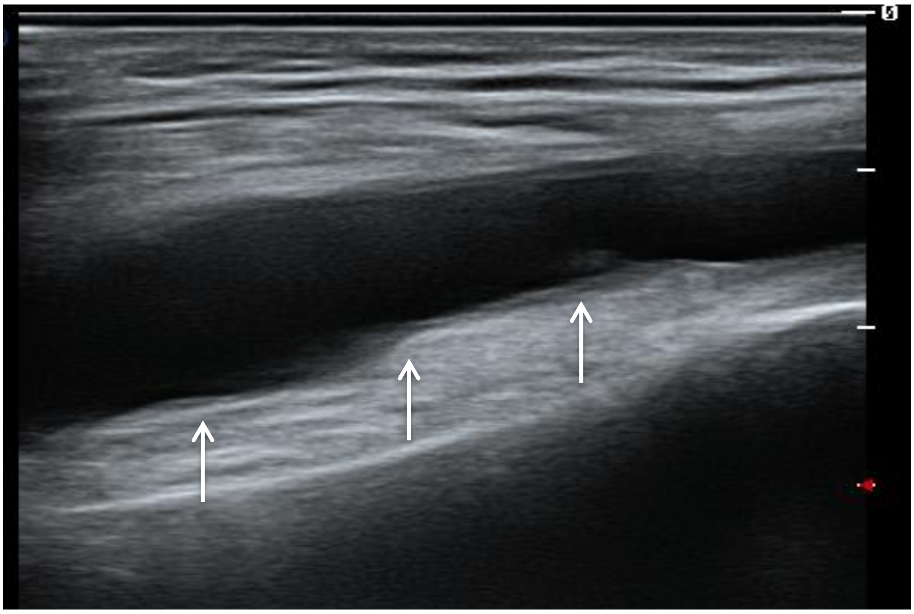


Figure 2.14. Exogram of patient Sh., 49 years old, in gray scale. Coronal projection (posterior approach). Acute synovitis. An anechoic mass is detected in the upper space of the knee joint.

In 6 patients with osteoarthritis, chronic synovitis was accompanied by long exocytosis, irregular, leaf-shaped changes of the villi in combination with scar elements. A clear example of rheumatoid arthritis is the presence of hypoechogenic villi resembling thick fingers. Calcified villi are the result of degenerative changes in the synovial layer against the background of arthrosis with metaplasia, that is, a manifestation of synovial chondromatosis.

Another complication identified after injuries to the internal structures of the joint in 19 examined joints was hemarthrosis of the knee joint.

Hemarthrosis is the release of blood into the joint cavity, which often occurs after acute rupture of the meniscus and anterior cruciate ligament of the knee joint. Ultrasound examination of hemarthrosis is specific, and the synovial fluid is presented in the form of a hyperechogenic finely dispersed suspension. Later, thrombotic masses form within the space, forming scar adhesions and closing the pockets of the synovial layer, which disrupts the circulation of synovial fluid, limiting the mobility of the joint structures. In the case of large lesions within the joint with the involvement of bone structures, lipohemarthrosis is formed, which is manifested by a characteristic horizontal hypoechogenic fat layer against a background of hyperechogenic fluid (Fig. 2.15).

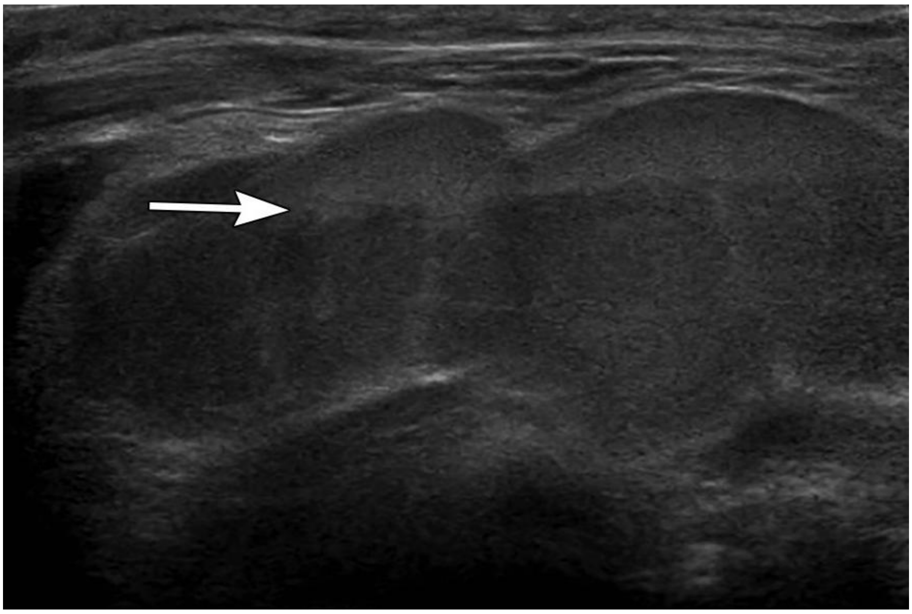


Figure 2.15. Exogram of patient A., 31 years old. Gray scale. Coronal projection (posterior approach). Hemarthrosis. An isoechoic mass is detected in the superior knee space.

Cystic degeneration of the meniscus - 20 were detected by ultrasound in knee joints. Meniscal cysts were detected only when they reached the second and third degrees, since the first degree of cystic degeneration of the meniscus tissues is detected only microscopically. Moderate damage and infiltration of the capsule are clinically detected.

At grade II, cystic changes extend to the tissues of the meniscus and the capsule zone. Clinically, a slight swelling is detected, which decreases or disappears when the knee joint is pressed.

At grade III, the cyst occupies the parameniscal tissue; mucinous degeneration occurs not only in the meniscus tissues, but also in the surrounding capsule and ligaments with the formation of cystic spaces. The tumor-like formation is noticeably visible and does not disappear when the joint is pressed (Fig. 2.16).

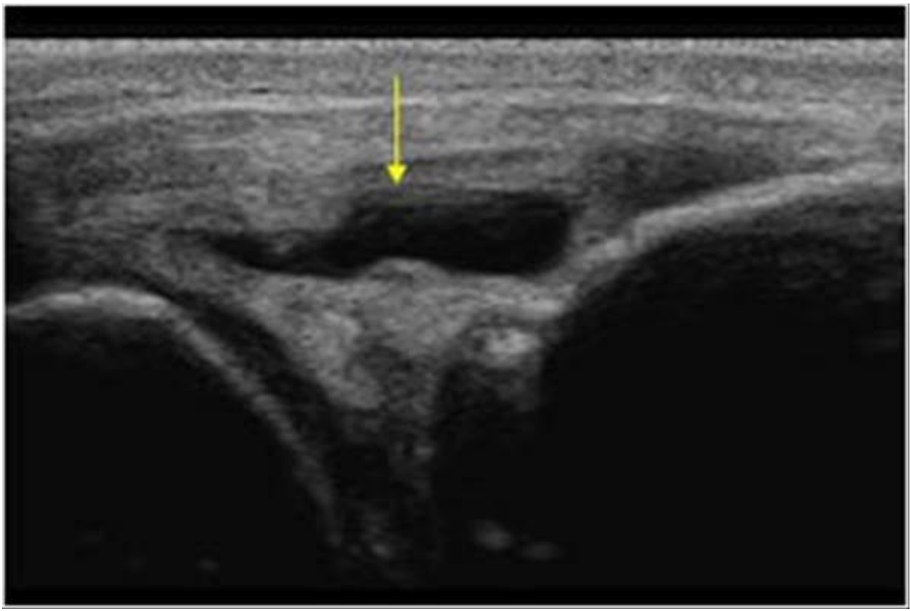


Figure 2.16. Exogram of patient D., 31 years old, in gray scale. Coronal projection (posterior approach). Meniscus cyst. A 26x15mm anechoic mass is detected in the posterior meniscus area.

In patients who have undergone examination, bursitis and Baker's cyst are often diagnosed as concomitant diseases with injuries of the meniscus and cruciate ligament of the knee joint. These pathologies were detected in 7 joints.

Bursitis is a consequence of wear of the knee joint, especially after injuries of the anterior parts and patella. It should be noted that a peculiarity of ultrasound diagnostics of anterior patellar bursitis is that when compressed by the transducer, a small amount of fluid flows into the bag, which is sometimes missed if the doctor is not qualified enough. When examining the control group, the walls of the bag were very thin, and fluid was not detected between the pieces of fatty tissue, in the pockets and usually inside the bag. The exudate that accumulates as a result of injuries of the knee cap often has an anechoic, and in rare cases, hemorrhagic content on ultrasound. Almost always, the entire anterior surface of the knee joint is edematous with subcutaneous fat, and the interlobular hypoechoic appearance of the fat tissue is detected.

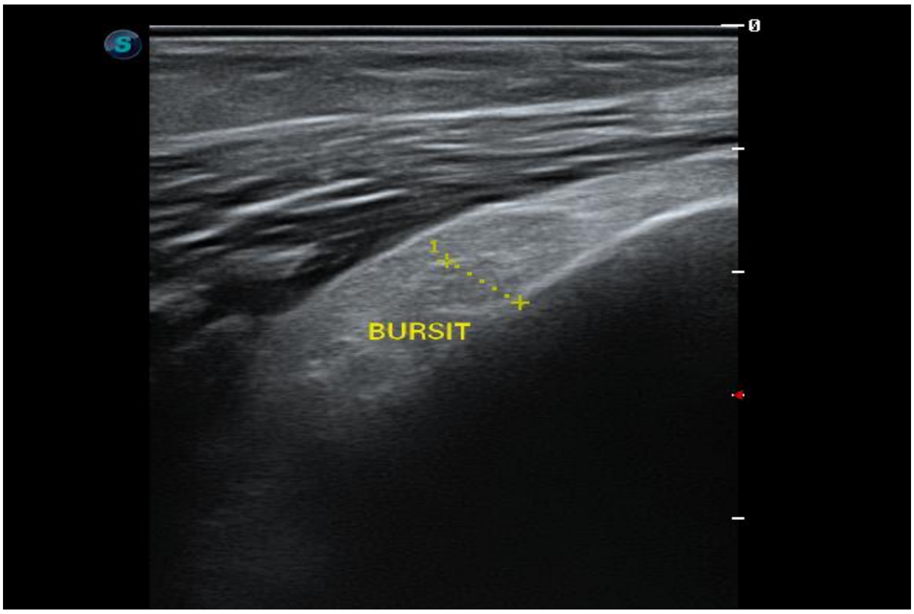


Figure 2.17. Exogram of patient R., 31 years old, in gray scale. Coronal projection (anterior approach). Bursitis. Soft tissue edema of the anterior superior part of the patella is detected.

In the examined patients, bursitis and Baker's cyst were often diagnosed as concomitant diseases of injuries of the internal structures of the knee joint. Thus, these pathologies were detected in 7 (5.7%) joints.

A specific consequence of chronic synovitis is the formation of a Baker's cyst. According to modern concepts, the cyst is a complex of the biceps femoris muscle and the semimembranous bursa, most often connected to the joint cavity by a narrow neck. The usual location of the cyst is between the medial parts of the popliteal fossa, the semimembranous and biceps femoris muscles. Often, a neck is detected in these cysts, and in most cases, their obliteration is detected. When pressing harder with a probe on the cyst area, its size sometimes decreases, which indicates its connection with the joint cavity.

The typical ultrasound appearance of Baker's cysts is as follows: in the medial areas of the popliteal fossa, they appear anechoic (due to fluid), have an oval or round shape, often with fairly thick walls (more than 1-2 mm), are covered with synovial membrane, are characterized by villi, fibrous elements, adhesions, and often have a non-uniform exostructure.

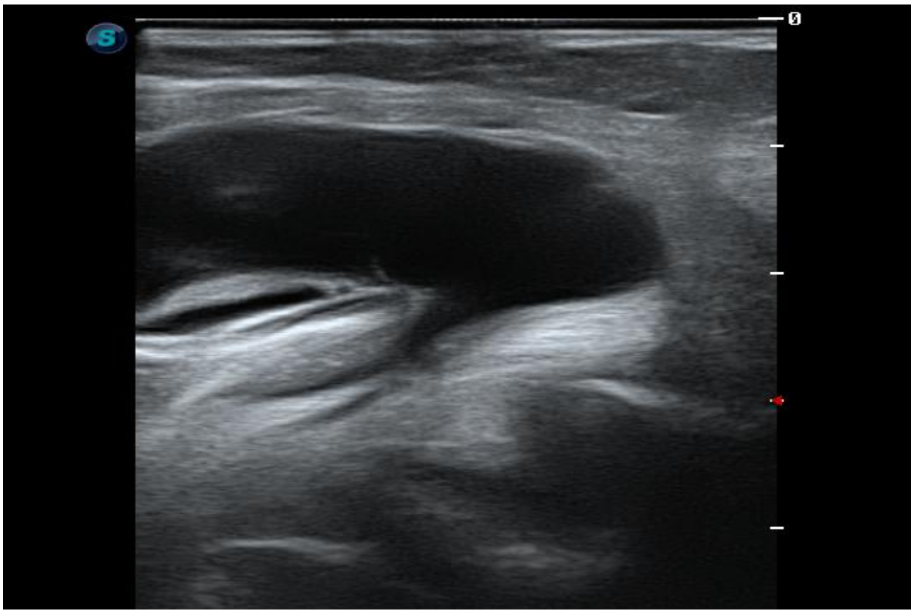


Figure 2.18. Exogram of patient B., 41 years old, gray scale. Coronal projection (posterior approach). Baker's cyst. A large mass is detected in the posterior fossa of the knee.

Thus, high-resolution ultrasound is an effective diagnostic method for morphological study of menisci, patellar tendons and knee ligaments in various pathological conditions in real time. The advantages of this method are non-invasiveness, harmlessness, efficiency, versatility and relatively low cost.

CHAPTER III. EFFECTIVENESS OF ULTRASOUND DIAGNOSTICS IN COMPARISON WITH ARTHROSCOPY AND MAGNETIC RESONANCE TOMOGRAPHY IN KNEE JOINT INJURIES

§3.1. The effectiveness of US diagnostics in meniscus injuries

The effectiveness of ultrasound and MRI in diagnosing meniscus injuries was studied in comparison with arthroscopy data, which revealed meniscus tears in 98 of 122 joints examined.

In this cohort, almost all patients reported a history of traumatic events in their anamnesis. The predominant clinical complaints included knee pain, swelling, restricted range of motion, a subjective sensation of joint protrusion, and episodes of stiffness. Among patients in the first group, the most frequent clinical manifestation was localized tenderness on palpation, observed in 95% of cases. The so-called “blockade” symptom, characterized by a sudden restriction in flexion or extension amplitude, was documented in 57% of patients. Fewer individuals demonstrated specific meniscal signs: pain elicited in the medial meniscus projection during tibial flexion (Baykov’s sign) in 34% of cases, and exacerbation of knee pain during stair descent (Perelman’s sign) in 27,5% of cases.

In 58% of cases of meniscus rupture, fluid is detected in and around the joint cavity. In 52.5% of this group, signs of deforming arthrosis were observed. In 4% of patients with meniscus damage, bone marrow edema was observed.

In 22% of patients, meniscus damage is indirectly recorded during X-ray examination in the form of a decrease in the height of some part of the joint. This method allows you to exclude injuries to bone structures, tumors and other diseases.

As highlighted in the previous chapter, meniscal injuries are characterized by complex disruptions in the ultrasound architecture of the tissue. These pathological alterations are predominantly associated with compromised meniscal integrity. On ultrasonography, such changes are characterized by a distinct hypoechoic defect reaching the articular surface, deformation or discontinuity of the meniscal contour in the injured region, and the absence of a clearly demarcated boundary between the meniscus and the neighboring articular cartilage. In some cases, additional indirect sonographic signs include thickening of adjacent synovial folds and the presence of small periarticular fluid collections, which may reflect secondary synovitis.

From the perspective of magnetic resonance (MR) imaging, the semiotics of meniscal tears relies on a set of key diagnostic markers that provide a robust basis for confirming structural damage. The primary feature is the identification of a linear hyperintense signal within the meniscal matrix, which shows definite extension to the articular surface. This sign is considered highly specific, as it directly reflects the communication of intrameniscal disruption with the joint cavity. A secondary feature, no less important, is the detection of morphological abnormalities such as irregular meniscal contours, localized deformation, or partial fragmentation. These changes not only indicate the presence of a tear but also help differentiate between acute traumatic lesions and degenerative alterations.

Moreover, the diagnostic accuracy of MR imaging in meniscal tears is enhanced when multiple imaging planes (sagittal and coronal) are evaluated simultaneously, with an optimal slice thickness of 3–4 mm. Complementary use of proton density-weighted images with fat suppression further increases sensitivity by improving visualization of subtle intrameniscal signal changes. Thus, the integration of both morphological and signal-based criteria ensures a comprehensive and reliable assessment of meniscal pathology. The second is the identification of abnormal meniscal morphology, including irregular shape, deformation, and fragmentation.

In our material, MRI findings of meniscal tears were distributed as follows:

Linear hyperintense signal with extension to the articular surface — 84 cases (93.7%);

Irregular meniscal contour, deformation, or fragmentation — 71 cases (79.2%).

The most diagnostically informative images were obtained in the coronal and sagittal planes, with slice thickness ranging from 3–5 mm. The severity of signal alterations within the meniscus was assessed according to the Stoller classification (1987):

Grade 0: Meniscus with uniformly low signal intensity.

Grade I: A rounded or poorly defined focus of increased signal intensity confined to the meniscal substance on T1- and T2-weighted images, without extension to the articular surfaces. Histologically, this corresponds to early mucoid degeneration, hypocellular zones with chondrocyte deficiency, and areas poorly stained with hematoxylin and eosin.

Grade II: Characterized by a linear intrameniscal hyperintense signal that does not reach the articular surface but extends toward the peripheral capsular margin. This pattern is typically associated with progressive mucoid degeneration, accompanied histologically by microscopic fragmentation of collagen fibers within areas of hypocellular fibrocartilaginous tissue.

Grade III: Defined by a linear hyperintense signal traversing the entire meniscus and extending to the articular surface. Such alterations are often accompanied by reduction in meniscal height and distortion of its normal triangular morphology. Importantly, Grade III degeneration invariably corresponds to a true structural tear or advanced degenerative lesion (Fig. 3.1).

For reliable diagnosis of a meniscal rupture, it is essential that Grade III pathological changes be identified consistently across at least two orthogonal imaging planes.

Figure 3.1. MR image of the knee joint of patient S., 31 years old. Sagittal projection. Tear of the posterior medial horn of the meniscus. The shape of

the medial meniscus is normal, and a hyperintense line is detected in its structure.

Degenerative alterations and meniscal tears are optimally evaluated using T1- and T2-weighted sequences, as well as proton density images with fat suppression.

Based on the localization of the rupture, meniscal injuries in our cohort were distributed as follows:

- Posterior horn tears were predominant, identified in 37 cases (80.4%).
- Anterior horn tears were observed in 5 cases (10.9%), of which 3 involved the anterior horn of the medial meniscus, and 1 represented a tear of the anterior horn of the lateral meniscus.

With regard to tear morphology:

- The majority, 36 cases (78.3%), represented horizontal or longitudinal tears, typically associated with degenerative processes.
- Combined tears were identified in 4 cases (8.7%) (Fig. 3.2).
- Vertical tears accounted for 6 cases (13%) (Fig. 3.3).

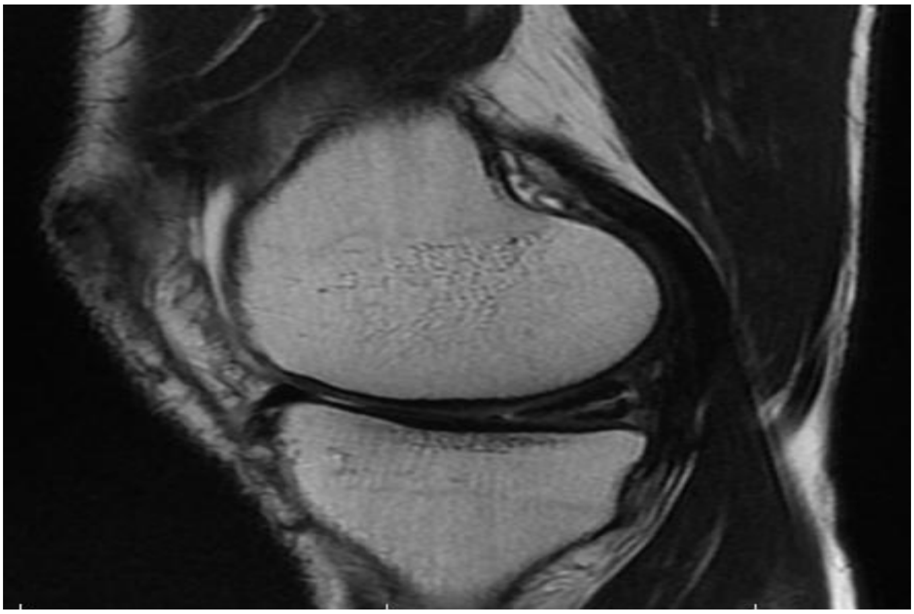


Figure 3.2. MR image of the knee joint of patient R., 36 years old. Sagittal projection. Combined tear of the posterior medial horn of the meniscus. The shape of the medial meniscus is normal, with a vertical and horizontal hyperintense line in its structure.

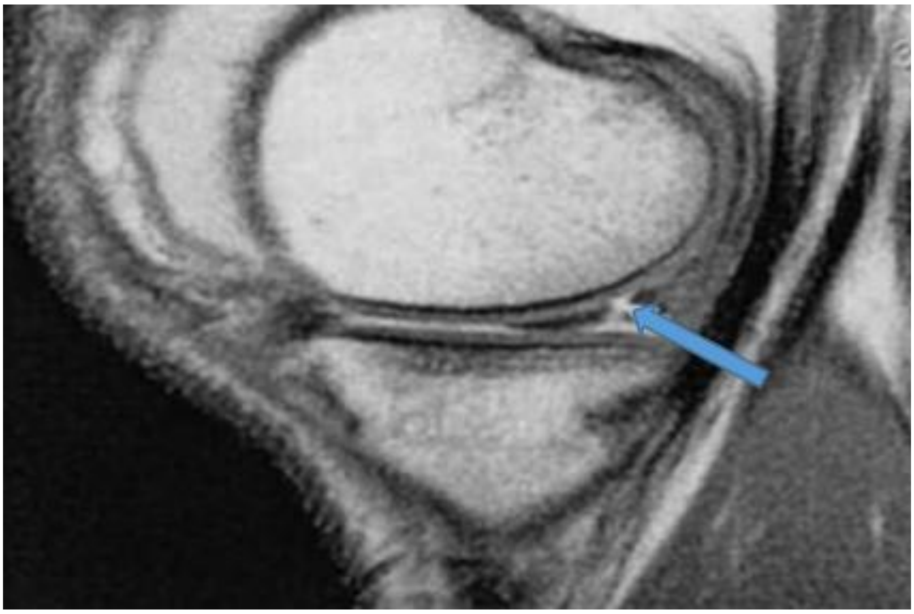


Figure 3.3. MR image of the knee joint of patient Sh., 46 years old. Sagittal projection. Vertical tear of the posterior medial horn of the meniscus. The medial meniscus is normal in shape, a vertical hyperintense line is detected in its structure

Clinical example:

Patient S., 28 years old. The patient presented with persistent pain and crepitus in the left knee joint, discomfort during weight-bearing along the medial aspect of the leg, nocturnal pulling and grinding sensations, as well as occasional episodes of twisting during awkward movements. The initial trauma had occurred two years earlier as a result of a road traffic accident, after which the patient reported acute, severe pain.

Objective examination: The left knee joint demonstrated mild swelling and localized tenderness on palpation along the medial surface. Range of motion was restricted.

Radiographic findings: Standard X-ray examination of the left knee did not reveal any pathological abnormalities.

Ultrasound findings: Ultrasound examination demonstrated a small accumulation of anechogenic fluid within the suprapatellar recess. In addition, a well-defined elongated anechogenic structure extending toward the articular surface was visualized in the posterior horn of the medial meniscus (Fig. 3.4a).

<u>Conclusion:</u> Synovitis. UT signs of a rupture of the posterior horn of the medial meniscus.

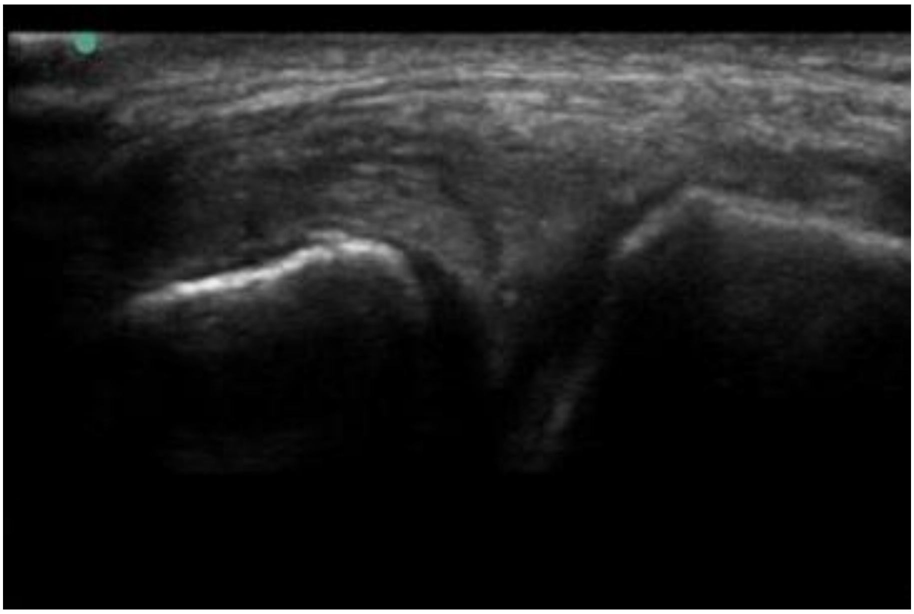


Figure 3.4a. Exogram of patient S., 28 years old, in gray scale mode. Sagittal projection (posterior approach). Tear of the posterior medial horn of the meniscus. The meniscus is not enlarged, its structure is inhomogeneous, its exogenity has not changed, an anexogenic line is detected in the middle part

Figure 3.4b. MR image of the knee joint of the same patient. Sagittal projection. Tear of the posterior medial horn of the meniscus. The medial meniscus is in a normal shape, with a horizontal hyperintense line in its structure.

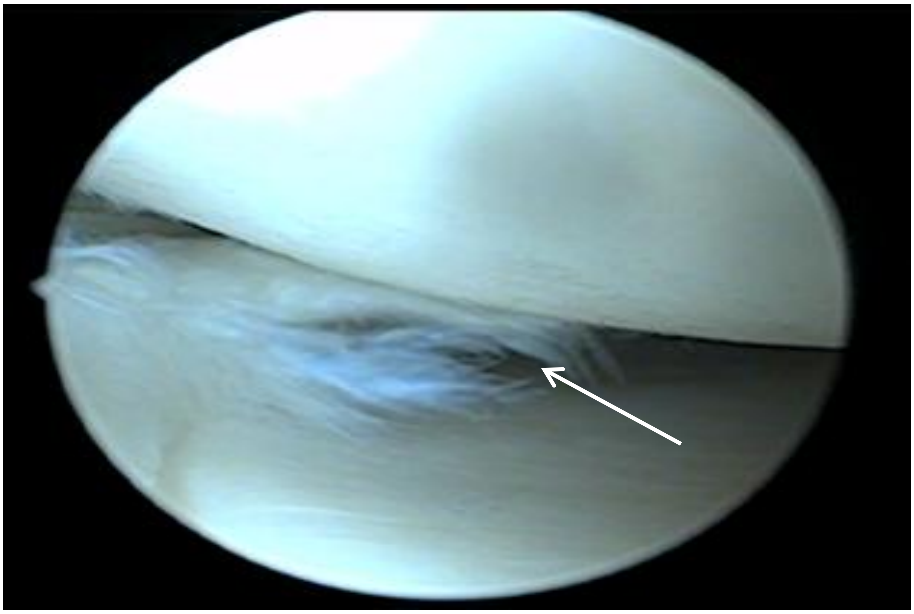


Figure 3.4c. Arthroscopic view of the knee joint of the same patient. Tear of the posterior medial horn of the meniscus.

Magnetic Resonance Imaging (MRI):

MRI of the left knee demonstrated a small accumulation of joint effusion within the anterior superior and medial-lateral recesses, accompanied by swelling of the periarticular soft tissues. Within the posterior horn of the medial meniscus, MRI revealed a linear hyperintense signal traversing the meniscal substance and extending to the articular surface (Fig. 3.4b).

Conclusion: Imaging findings are consistent with a tear of the posterior horn of the medial meniscus of the left knee joint, associated with concurrent exudative synovitis.

Arthroscopy:

Diagnostic arthroscopy was performed via an anterolateral portal with cannulation into the suprapatellar recess. Upon re-examination, approximately 15 ml of clear synovial fluid was aspirated. The synovial capsule appeared unremarkable. Arthroscopic evaluation confirmed the presence of a tear in the posterior horn of the medial meniscus (Fig. 3.4c). The anterior cruciate ligament (ACL) appeared intact. A partial meniscectomy of the posterior horn of the medial meniscus was performed.

Final Clinical Diagnosis:

Tear of the posterior horn of the medial meniscus of the left knee joint.

Clinical Observational Analysis:

This case underscores that meniscal tears, often radiographically occult, can be reliably identified through ultrasound, MRI, and arthroscopy, with the latter serving as both a diagnostic and therapeutic modality.

Comparison with arthroscopic data shows that of 98 cases of meniscal tears, ultrasound was correctly diagnosed in 82 cases, false negatives were recorded in 10 cases, and false positives were recorded in 6 cases (Table 3.1).

Table 3.1

Comparison of US and MRI data with arthroscopy data for knee meniscus tears

Verification method	TP	FP	FN	TN
US	88	6	10	18
MRI	93	3	5	21

Based on the data in Table 3.1, the effectiveness of ultrasound in the diagnosis of meniscal injuries of the knee joint was calculated. The sensitivity of ultrasound in detecting meniscal injuries was 89.7%, the specificity was 75%, and the accuracy was 86.8%.

Six false-positive results were recorded during ultrasound examination due to the difficulty of distinguishing degenerative changes in the fibrocartilage of the meniscus from its complete rupture. In ten cases, false-negative results occurred due to poor visualization of the meniscus due to muscle and subcutaneous fat in large and obese patients.

Of the 98 meniscal tears, 90 were detected using MRI, 5 false-negative cases, and 3 false-positive cases.

The estimated sensitivity of MRI in the diagnosis of meniscal tears was 94.8%, with a specificity of 87.5% and an overall diagnostic accuracy of 93.4%, thereby exceeding the diagnostic performance of ultrasound. Despite its high diagnostic accuracy, MRI produced three false-positive and five false-negative results. False negatives were most often linked to small peripheral tears of the posterior horn of the medial meniscus, whereas false positives arose from increased intrameniscal signal intensity and the misinterpretation of neighboring anatomical structures, including the transverse ligament of the knee, meniscofemoral ligaments, and hamstring tendons.

In summary, the evidence strongly indicates that ultrasound, magnetic resonance imaging (MRI), and arthroscopy possess significantly higher diagnostic value than conventional radiography. While plain X-ray images are limited to visualizing bone structures and can only indirectly suggest intra-articular pathology, modern non-invasive imaging modalities make it possible to directly identify soft tissue abnormalities that remain completely undetectable on standard radiographs. This advantage is particularly crucial in the evaluation of meniscal and ligamentous injuries, where early and accurate visualization guides both prognosis and therapeutic strategy.

From the ultrasonographic standpoint, the cornerstone diagnostic criterion for meniscal rupture is the identification of an anechoic or hypoechoic defect within the fibrocartilaginous substance, which extends to the articular surface and signifies a loss of structural integrity. Complementary sonographic features include contour deformation, localized discontinuity of the meniscal outline, and blurring of the interface between the meniscus and the adjacent articular cartilage. In certain cases, secondary findings such as periarticular effusion, synovial thickening, or reactive changes in surrounding soft tissues may further reinforce the suspicion of a meniscal tear.

Moreover, ultrasound offers unique advantages as a first-line diagnostic tool due to its accessibility, absence of radiation exposure, dynamic assessment capability, and suitability for repeated follow-up examinations. However, when sonographic findings are inconclusive, MRI remains the gold standard for comprehensive evaluation, while arthroscopy continues to serve as both a diagnostic and therapeutic procedure.

In MRI evaluation, the hallmark of a meniscal tear is a linear hyperintense signal within the meniscus in direct continuity with the articular surface, confirmed by its reproducibility on at least two orthogonal imaging planes. Additional MRI indicators include irregular meniscal morphology, deformation, and fragmentation.

Overall, while the diagnostic signs of meniscal tears on ultrasound and MRI are largely comparable, the non-invasiveness, relative simplicity, and widespread availability of ultrasound — even in rural or district-level healthcare facilities — highlight its practical superiority as a first-line diagnostic modality.

§3.2 The effectiveness of US diagnostics in cruciate ligament injuries

In a comparative study evaluating the diagnostic efficacy of ultrasound and MRI in cruciate ligament injuries, arthroscopic examinations were performed in patients with confirmed ligament ruptures in 74 of 122 knee joints.

Among these cases, 40.5% of the affected joints demonstrated flexion limitation accompanied by intra-articular fluid accumulation, while no signs of deforming arthrosis were identified in this cohort.

Clinically, cruciate ligament injuries present with diverse manifestations, most commonly pain, swelling, restricted range of motion, and the “pull” symptom. Conventional radiography showed limited diagnostic utility: no pathological changes were detected in 80.8% of cases, while only 19.2% demonstrated signs of joint dislocation.

On ultrasound examination, the principal diagnostic markers of cruciate ligament rupture were identified as a reduction in echogenicity in 98% of cases when compared with the contralateral side, along with ligament thickening in 92% of cases.

In magnetic resonance imaging (MRI), cruciate ligament injuries are typically characterized by alterations in signal intensity and fiber continuity within the ligament substance. The most frequent finding is a hyperintense signal on T2-weighted sequences, indicating edema, hemorrhage, or fiber disruption.

For anterior cruciate ligament (ACL) ruptures, both direct and indirect signs are diagnostically significant:

Direct MRI signs of ACL rupture:

- Discontinuity or complete absence of ligament fibers, resulting in a non-visualized segment.
- Abnormal signal intensity, usually hyperintense on T2-weighted images and hypointense on T1 sequences.
- Abnormal orientation of the ligament axis, including anterior bowing, concavity, or a wavy appearance of fibers.
- Thickening or thinning of the ligament due to partial rupture or chronic elongation.
- Complete absence of the normal low-signal band, replaced by heterogeneous high-intensity areas reflecting edema or hematoma.

Indirect (secondary) MRI signs of ACL rupture:

- Bone contusions or marrow edema, most commonly involving the lateral femoral condyle and posterolateral tibial plateau.
- Anterior tibial translation relative to the femur, typically greater than 5 mm.
- Posterior cruciate ligament (PCL) buckling, due to altered biomechanics and abnormal tibiofemoral alignment.
- Meniscal injuries, especially posterior horn tears of the medial meniscus, often associated with chronic ACL deficiency.
- Lipohemarthrosis or joint effusion, reflecting acute trauma.
- Segond fracture (avulsion fracture of the lateral tibial plateau), which is highly specific for ACL rupture.

Together, these direct and indirect MRI features form a robust diagnostic framework, allowing radiologists to detect ACL injuries with high sensitivity and specificity. Importantly, correlating imaging findings with clinical assessment and, where necessary, arthroscopic confirmation provides the most reliable approach to definitive diagnosis.

Direct MRI indicators of ACL damage included:

- hypointense signal on T1-weighted sequences (92%),
- hyperintense signal on T2-weighted sequences (90%),
- partial or complete loss of ligament visualization (84%),
- deviation of the ligament axis or abnormal orientation,
- and the presence of a concave or undulating anterior ligament contour (75%) (Fig. 3.5).

Acute ligament trauma was consistently associated with edema and hemorrhage of varying intensity, which frequently limited complete visualization of the ACL on MRI due to overlapping hemorrhagic or edematous changes within its projection. In these circumstances, indirect (secondary) MRI signs provided critical diagnostic value, including:

- lateral bulging of the femoral condyle, bone contusions of the articular surfaces, or compressed subchondral fractures (19.3%),
- anterior displacement of the tibia (6.4%),
- and lateral fractures of the proximal tibial epiphysis (5.2%).

Ultimately, arthroscopic evaluation was performed in all patients to confirm the presence and extent of cruciate ligament injuries.

Figure 3.5. MR image of the knee joint. Patient T., 50 years old. Sagittal projection. Damage to the anterior cruciate ligament. The anterior cruciate ligament is thickened, there are no changes in the signal characteristics.

Clinical Observation:

The patient presented with persistent pain in the left knee joint, accompanied by marked limitation of motion, mechanical locking during flexion, and extensive periarticular swelling. The injury was sustained two months prior in the context of a motor vehicle accident.

Clinical Examination:

Inspection revealed an enlarged left knee joint with significant tenderness on palpation. Both active and passive ranges of motion were markedly reduced. Additionally, a weakly positive traction sign was identified.

Ultrasound Findings:

Ultrasonography of the left knee revealed a thickened anterior cruciate ligament with reduced echogenicity compared to the contralateral side (Fig. 3.6a). No sonographic evidence of meniscal injury was identified.

Conclusion (US): Ultrasound signs consistent with left-sided anterior cruciate ligament injury.

Magnetic Resonance Imaging (MRI):

MRI demonstrated pronounced synovial swelling within the infrapatellar fat pad and the intercondylar notch region, along with diffuse swelling of the periarticular soft tissues. Additionally, areas of bone marrow edema were observed in both femoral condyles, more pronounced laterally. Importantly, there was a complete absence of the anterior cruciate ligament image, consistent with a full-thickness ACL rupture (Fig. 3.6b).

Conclusion: ACL injury. Bone marrow edema of both femoral condyles.

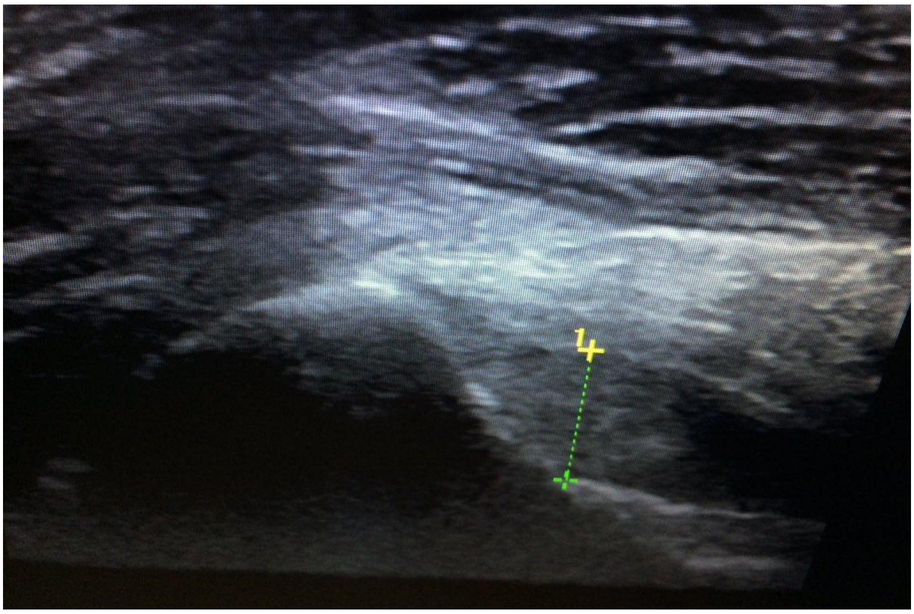


Figure 3.6a. Exogram of the knee joint, patient V, 41 years old, gray scale mode. Sagittal projection (posterior transverse approach). Anterior cruciate ligament injury. The anterior cruciate ligament is thickened and has decreased exogenity compared to the contralateral side

<u>Arthroscopy of the left knee joint:</u> an anterolateral approach is used to insert an arthroscope, a cannula is inserted into the superior bend. Intraoperative Findings and Management:

Upon arthroscopic revision, pronounced swelling and hyperemia of the synovial membrane were observed. Examination revealed reduced ligament tension and a partial rupture of the anterior cruciate ligament (ACL). A partial resection of the frayed, unstable ACL fibers was performed (Fig. 3.6c).

Final Clinical Diagnosis:

Partial tear of the anterior cruciate ligament of the left knee joint.

Summary:

The analysis of presented clinical cases demonstrates that ultrasonography and magnetic resonance imaging (MRI) are highly effective in detecting injuries of the ligamentous apparatus. Furthermore, the combined application of these modalities in diagnostically ambiguous situations significantly enhances the accuracy of the final diagnosis.

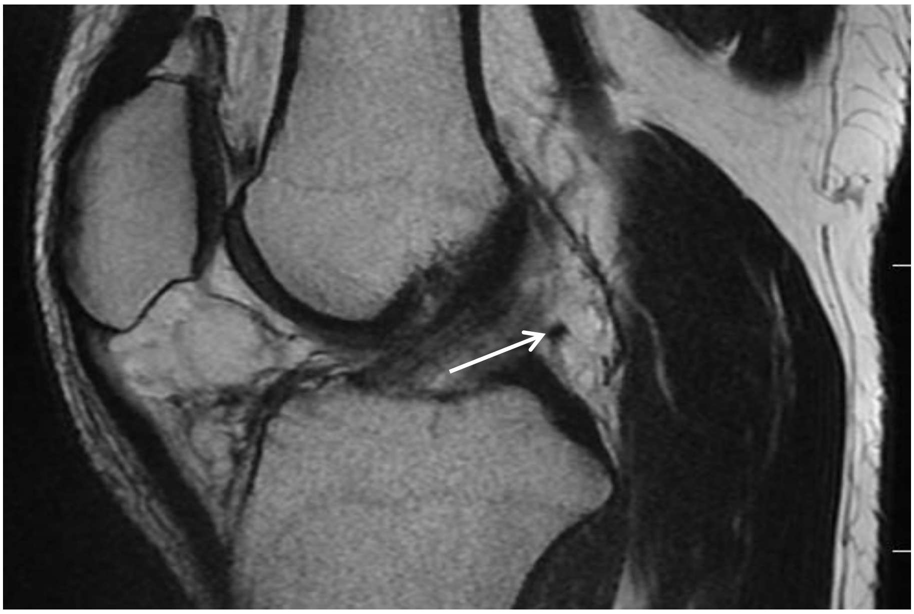


Figure 3.6b. MR image of the knee joint, same patient. Sagittal projection. Anterior cruciate ligament injury. Anterior cruciate ligament thickened, no changes in signal characteristics

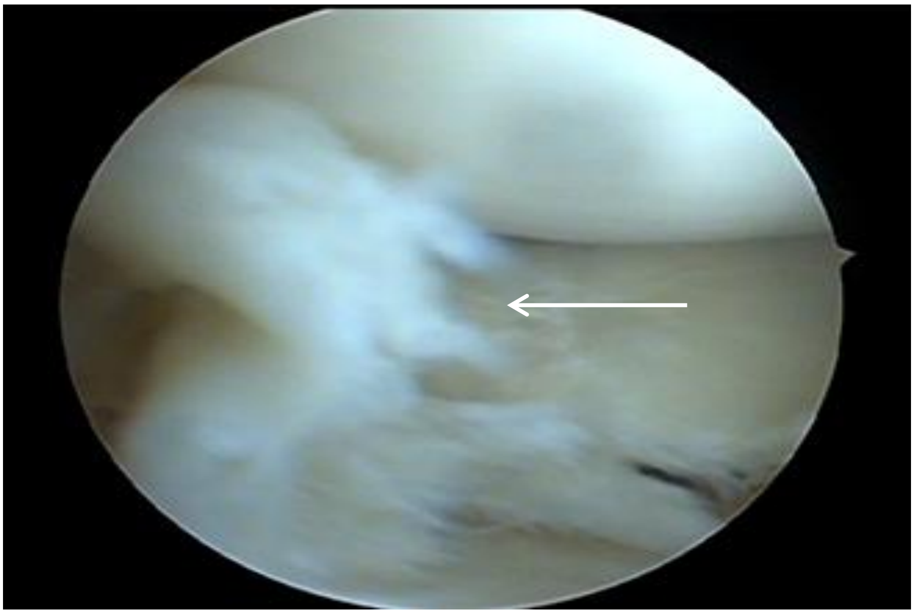


Figure 3.6c. Arthroscopy of the same patient. Anterior cruciate ligament tear

Comparison with arthroscopic data shows that ultrasound correctly diagnosed 58 of 74 ACL tears. There were 10 false negatives and 6 false positives (Table 3.2).

Table 3.2

Comparison of CT and MRI data with arthroscopy data for cruciate ligament ruptures of the knee joint

Verification method	TP	FP	FN	TN
US	64	6	10	42
MRI	70	2	4	46

Based on the data in Table 3.2, the ultrasound parameters in the diagnosis of cruciate ligament injuries of the knee joint were calculated. The sensitivity of ultrasound in the diagnosis of cruciate ligament injuries was 86.5%, specificity was 87.5%, and accuracy was 86.8%.

Six false-positive results were recorded on ultrasound examination, which were misinterpreted as ligament thickening as rupture, and ten false-negative results were recorded, which were confirmed as ruptures when compared with arthroscopy data. All false-negative results were due to the lack of maximum knee flexion for optimal access to the ligament, as well as poor visualization of the cruciate ligament due to the thickness of the muscle and subcutaneous fat layer in large and obese patients.

Of the 74 ACL ruptures diagnosed by arthroscopy, 68 were correctly diagnosed by MRI. There were 4 false-negatives and 2 false-positives.

The sensitivity of MRI in diagnosing ligament ruptures was 94.5%, specificity - 95.8%, and accuracy - 95%.

Thus, ultrasound and MRI demonstrate high diagnostic capabilities in diagnosing knee ligament ruptures. As in the case of meniscus injuries, MRI also better identifies cruciate ligament ruptures.

As a result of studying the analyzes of patients in this group, the following ultrasound signs of knee cruciate ligament ruptures were identified: basic ultrasound criteria, thickening of the ligament and a decrease in exogenity, violation of the integrity of the fibers, violation of their anatomical continuity. Additional signs are intra- and periarticular edema.

In general, the main advantages of MRI over ultrasound are the ability to obtain images in any projection, the tomographic nature of the method, as well as the high contrast of soft tissue images. However, the use of high-frequency transmitters and the use of modern high-resolution ultrasound scanners and the latest developments in increasing the number of pixels allow for highly effective ultrasound examination of the intra-articular structures of the knee joint. The advantages of using ultrasound as the primary method of examining patients with knee joint injuries are: time-saving, low cost, and reliable detection of intra-articular injuries. The results obtained indicate that MRI is not needed when there are reliable ultrasound signs of pathological changes in the internal structures of the knee joint. This method is especially effective for diagnosing meniscus and cruciate ligament tears. In patients presenting with ligament and meniscal injuries, even if they have clear clinical symptoms, but no clear signs of injury are recorded on ultrasound, MRI is performed as a follow-up diagnostic method as a definitive investigation.

The data obtained showed a relatively high efficiency of primary ultrasound for diagnosing meniscal and cruciate ligament injuries.

Taking into account the high potential of ultrasound, MRI and arthroscopy in the diagnosis of injuries of the internal structures of the knee joint, an algorithm for the complex use of these methods was proposed.

Based on the presented algorithm, X-ray and ultrasound examinations should be performed at the initial stage of examination, without exception, in patients with clinical suspicion and at the same time with injuries of the knee joint. Indications for MRI are differentiated based on the results of ultrasound examination. Arthroscopy can be performed only at the last stage. Indications for this invasive examination method depend on the results of ultrasound and, in some cases, MRI.

Algorithm for radiographic examination of patients with injuries to the internal structures of the knee joint

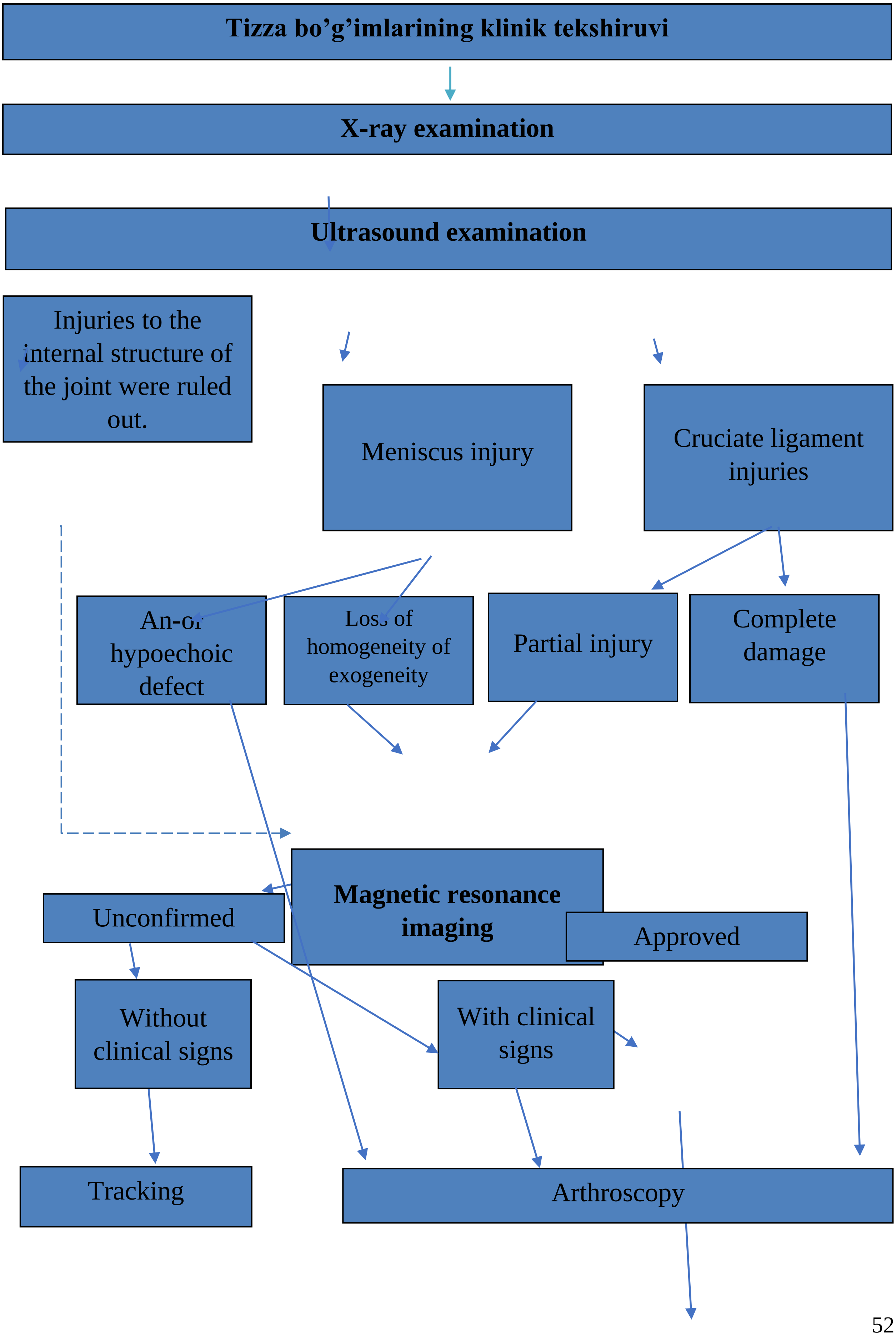


Figure 3.7.

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