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υπό

ΧΡΗΣΤΟΥ Β. ΚΟΥΡΑΜΑ

Τεχνολόγου Ακτινολόγου

Υπεβλήθη για την εκπλήρωση μέρους των
απαιτήσεων για την απόκτηση του
Διπλώματος Μεταπτυχιακών Σπουδών

«Υπερηχογραφική Λειτουργική Απεικόνιση για την πρόληψη & διάγνωση των αγγειακών παθήσεων»

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Τίτλος εργασίας στα αγγλικά: Ultrasonic investigation of the intermittent claudication (non-atherosclerotic reason) in young persons (popliteal artery entrapment syndrome, adventitial cystic disease)

Contents

Ευχαριστίες

Με την εκπλήρωση της παρούσας μεταπτυχιακής διπλωματικής εργασίας που πραγματοποιήθηκε στο τμήμα Ιατρικής του Πανεπιστημίου Θεσσαλίας κατά το ακαδημαϊκό έτος 2022-2023, θα ήθελα να ευχαριστήσω όσους συνέβαλλαν στην εκπόνηση της.

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1.2 Abstract

This review aims to analyze the popliteal artery entrapment syndrome and the associated anatomical abnormalities, as well as the cystic adventitial disease that can cause stenosis of the popliteal artery and blood flow reduction in the popliteal fossa.

Intermittent claudication in young persons with no atherosclerotic disease may be provoked by the popliteal artery entrapment syndrome or by cystic adventitial disease. Popliteal artery entrapment syndrome causes compression of the artery either due to anatomical variations in the popliteal fossa, or due to artery occlusion by an undefined lesion.

Doppler ultrasound scanning is a well-established and fast method that plays an important role in the investigation of intermittent claudication and diagnosis of popliteal artery entrapment syndrome.

Further tests such as duplex ultrasound of the popliteal artery with manoeuvres or the ankle-brachial index measurement must be performed to obtain a precise diagnosis.

Keywords: Ultrasound, Doppler ultrasound scanning, Popliteal artery, entrapment, PAES, popliteal fossa, anatomy, ankle-brachial index, compression, maneuvers, plantar flexion, active flexion, passive flexion, intermittent claudication

General Part

2.1 Introduction

The evaluation of intermittent claudication is the first step in recognizing the cause of claudication [9]. Intermittent claudication may be provoked by the abnormal position of the surrounding musculotendinous structures and the limited blood flow during muscle contractions [47]. This condition is defined as “popliteal artery entrapment syndrome” and it is usually observed in young adults. The syndrome is classified either as congenital, or functional in agreement with the cause of popliteal artery entrapment. The anatomical entrapment of the arteria poplitea is caused because of the abnormal relationship between the popliteal artery and the neighboring musculotendinous structures [5]. Rich et al defined five [5] anatomical alternatives of this anomaly [64]. The term “functional entrapment of the popliteal artery” was firstly used by Rignault et al [5] and it mostly appears in young athletes. There are no anatomical abnormalities except for a hypertrophic gastrocnemius muscle. The functional entrapment should be diagnosed as early as possible in order to avoid complications such as stenosis, thrombosis, and aneurysms. It is known that intermittent claudication is not usually found in elderly men with a long history of risk factors, such as cardiovascular diseases and smoking, who develop intermittent claudication due to atherosclerosis obliterans, although recent studies prove that intermittent claudication can be developed also in men in their middle-forties with adventitial cystic disease of the popliteal artery [9]. This pathology can be diagnosed by color ultrasound imaging. Color Doppler U/S is widely used in the diagnosis of vascular diseases [3] as it is easily repeatable, free of any risk or complications, and causes minimal discomfort to the patients.

The purpose of the present thesis is to analyze the diagnosis of intermittent claudication due to Popliteal Artery Entrapment Syndrome or Adventitial Cystic Disease, by using the Ultrasound imaging technique. The present thesis constitutes part of a postgraduate diploma.

2.2 Ultrasound and Doppler

Ultrasound is widely used, due to many advantages such as the lack of ionizing radiation, its wide availability, and the fact that it is well tolerated by the patient [(34)].

The frequency range used in medical ultrasound equipment is between 2 to 15 MHz. ‘‘The ultrasound travels in the body with the speed of sound’’, which is on the order of 1540m/s, and ‘‘the wavelength λ is given by’’

$$\lambda = \frac{c}{f0}.$$

The attenuation of the sound limits the penetration depth of the ultrasound, and a 3MHz probe has a maximum scan depth of 20 cm. The selection of the probe depends on the body region of interest [(34)].

The focus of the ultrasound beam is of great significance since all the parts of the beam must arrive at the same time at the (field point) tissue. A physically curved aperture can be used to focus the beam through a lens in front of the aperture or electronic delays from multi-element arrays [(34)].

Ultrasound imaging facilitates the comprehensive examination of all soft tissue structures in the body. The gray-scale B-mode imaging, specifically, proves to be advantageous for studying anatomy as it effectively displays the reflected strength of tissues.

Multi-element array transducers are capable of capturing three primary types of imaging: linear, convex, and phased. Among these, the line array transducer operates by selecting a specific area of interest through a series of elements distributed across the region. By emitting groups of adjacent elements, the transducer scans the entire imaging area. Transmit focusing is achieved by controlling the actions of individual components, resulting in the initial formation of a curved beam [(34)].

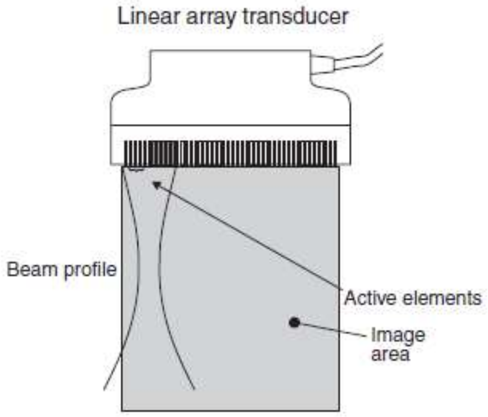

Fig. 1: ‘‘Linear array transducer J.A. Jensen/ Progress in Biophysics and Molecular Biology 93’’ [34].

An important use of medical ultrasound is the dynamic visualization of the blood flow in the human body. The Doppler System excels in detecting the flow of blood in a particular area of the body and accurately determining its velocity over time. This dynamic system can showcase a color-coded image representing the varying velocities. To achieve velocity measurements, a short ultrasound with 4-8 cycles at a frequency of 2-10 MHz is emitted. The blood cells predominantly reflect the ultrasound beam in all directions, and the transducer captures a portion of the reflected signal, converting it into a voltage signal [34] .

Echogenicity [73] pertains to a tissue's ability to reflect or transmit ultrasonic waves in relation to neighboring tissues. When sound waves are reflected from interfaces between structures, contrast differences are revealed. The echogenicity of the structures can be classified as hyperechoic (white on screen), hypoechoic (gray on screen), or anechoic (black on screen). Because ultrasonography cannot enter the bones, only the bone surface can be evaluated, which appears as a brilliant hyperechoic line with a considerable acoustic shadow behind it. Blood vessels are hypoechoic. Veins are easily distinguished because they can collapse under the pressure of the transducer, but arteries are typically free of collapse.

Oxygenated blood is transferred to the tissues by arteries, while non-oxygenated blood is transferred from the tissues by the veins. As a consequence of the blood's flow within the vessels, the color Doppler mode exhibits flow towards the probe as red, whereas outflow away from the probe appears blue [73].

2.3 Anatomy

The popliteal fossa is found on the back of the knee. The biceps femoral muscle, semimembranosus muscle, semitendinosus muscle, gastrocnemius muscle, and plantaris muscle form the popliteal fossa limits. All the main arterial structures of the lower limp pass via the popliteal fossa on their way from the femur to the tibia. Its contents include the tibial nerve, the common fibular nerve, the popliteal artery or arteria poplitea, the popliteal vein, the posterior femoral cutaneous nerve, and the popliteal lymph nodes.

Nerves are located superficially from the skin to the popliteal fossa, then veins, and finally arteries. The arteria poplitea is an anatomical continuation of the arteria femoralis, situated deeply, which terminates in the distal region of the adductor Magnus muscle. It runs into the popliteal fossa and then branches into the anterior and posterior tibial arteries near the bottom border of the popliteus muscle.

The arteria poplitea passes through the intercondylar notch at the knee joint capsule. The popliteal artery's five geniculate branches supply the knee joint capsule and ligaments. The superior lateral, superior medial, middle, inferior lateral, and inferior medial geniculate arteries are the geniculate arteries. They produce the periarticular geniculate anastomosis, which is a network of arteries encircling the knee that gives collateral circulation to the leg during complete knee flexion, which can kink the arteria poplitea. The popliteal artery's remaining branches are the anterior tibial, posterior tibial, and sural arteries. Sural arteries are two major branches that supply the gastrocnemius, soleus, and plantar muscles.

The arteria poplitea gives rise to muscular branches that supply the hamstring, gastrocnemius, soleus, and plantaris muscles. Clinically significant anastomoses exist between the superior muscle branch of the arteria poplitea and the terminal sections of the deep arteria profunda femoralis and glutea superior. Additionally, cutaneous branches originate directly from the arteria poplitea or indirectly from its muscular branches. The arteria poplitea also gives rise to five geniculate branches—two upper, two lower, and one middle—which supply the cruciate ligament and synovium of the knee joint.

There are two anterior tibial veins in human anatomy. They originate from and receive blood from the dorsal venous arch on the dorsum of the foot and drain into the popliteal vein. The anterior tibial vein drains the ankle, knee, shin-fibula, and front of the lower leg. The popliteal vein is formed by the two anterior tibial veins ascending in the interosseous membrane between the tibia and fibula and joining the posterior tibial vein. The anterior tibial vein, like other deep leg veins, has a partner artery along its path, the anterior tibial artery. Blood flows into the vena poplitea from the venae medial and lateral plantaris. They drain the back of the leg and the plantar area of the foot to the vena poplitea, which originates when the vena tibialis anterior meets the vena poplitea. The arteria tibialis posterior follows the same path as the arteria tibialis posterior. It lies posterior to the medial malleolus in the ankle. They receive blood from the most important venae perforantes: the Cockett perforators, which are the superior, medial, and inferior.

The adductor magnus is a substantial deltoid muscle located in the inner thigh and is anatomically divided into two segments. The portion originating from the ischiopubic ramus is denoted as the pubiofemoral portion, adductor portion, or adductor minor, while the portion arising from the ischial tuberosity is termed the hamstring, extensor portion, or "femoral portion". Because of their common embryonic origin, innervation, and action, the hamstring muscles, commonly known as the hamstrings, are often considered part of the adductor magnus. Consequently, the hamstring portion of the adductor magnus is considered a muscle located in the back of the thigh, while the pubic portion is classified as a muscle in the medial compartment. The anterior surface of the adductor magnus muscle is intricately connected to the pectineus, adductor brevis, adductor longus, femoral artery and vein, profunda artery, and vein, along with their respective branches. Additionally, it forms attachments with the posterior branches of the obturator artery, obturator vein, and obturator nerve.

The adductor hiatus, also known as the major hiatus in human anatomy, is the gap between the adductor magnus muscle and the femur that allows blood arteries to the femur to go from the front of the leg to the rear of the thigh and then to the popliteal fossa. It is placed about 8-13.5 cm above the adductor tubercle and is the terminal of the adductor tube. The morphology and surrounding structures of the adductor hiatus are used to classify it. The adductor hiatus has been defined as oval or bridging depending on the form of the superior border by Kale et el. Depending on whether the surrounding structure is a muscular component of the adductor magnus tendon, it can also be classified as muscular or fibrous. For example, the upper right image shows an oval fibrous adductor hiatus and the bottom shows a bridging adductor hiatus.

The adductor hiatus is related with four structures. Only two structures, the femoral artery and vein, enter and exit through the hiatus. After exiting the hiatus, these vessels persist as popliteal vessels, forming a network of anastomoses known as geniculate vessels. The knee joint is supplied by blood vessels by the geniculate vessels. The saphenous branch of the descending geniculate artery and the saphenous nerve are two more structures connected with the adductor hiatus. The saphenous nerve enters the adductor canal superficially halfway rather than through the adductor hiatus.

2.4 Popliteal Artery Entrapment Syndrome

‘‘Popliteal Artery Entrapment Syndrome (PAES) is the abnormal anatomical relationship between the arteria poplitea and the surrounding musculotendinous structures’’ [(28)]. Frequently, the arteria poplitea experiences compression due to one of the calf muscles [(22)] . PAES was first described by Stuart in 1879 [(17,31,49,65,54)] This infrequent syndrome predominantly affects young athletes and demonstrates a pronounced predilection for males [(26,77)]. The estimated prevalence of this condition ranges from approximately 0.17% to 3.5% [(26,74)]. Moreover, PAES (Popliteal Artery Entrapment Syndrome) is believed to account for a substantial number of vascular symptoms, particularly intermittent claudication, observed in younger patients without atherosclerotic risk factors [(43)]. Intermittent claudication is characterized by muscle pain in the legs when exercising. Popliteal artery entrapment syndrome can be a cause of severe disability and injury, resulting in rapid damage to the popliteal artery with subsequent risk of limb loss [(43)].

PAES are further classified into two types: anatomical and functional. Entrapment and eventual blockage of the arteria poplitea due to an anatomical lesion are anatomical PAES situations [74]. Love and Whelan created the PAES categorization system, which was later updated by Rich, who defined six subtypes of PAES. Rich's categorization scheme is based on the relationship of the popliteal artery to the gastrocnemius medial head [14]. ‘‘In PAES type 1 variation, the arteria poplitea assumes a medial course to the medial head of the gastrocnemius (MHOG). This results from the arteria poplitea maturing before the medial head of the gastrocnemius migrates medially and consequently being swept medially by the migrating muscle. In type 2, the arteria poplitea lies medial to the MHOG but partially obstructs its medial movement, leading to the muscle attaching more laterally to the femur. Type 3 involves the arteria poplitea being entrapped by the gastrocnemius collateral ligament. In type 4, a portion of the popliteal axial artery does not degenerate, and the mature distal popliteal artery penetrates into the popliteal muscle. When any of these anatomical variations occur in combination with the popliteal vein, it is termed type 5. Type 6, on the other hand, refers to functional popliteal entrapment syndrome (functional PAES) in which none of the aforementioned anatomical variations are present. [64].

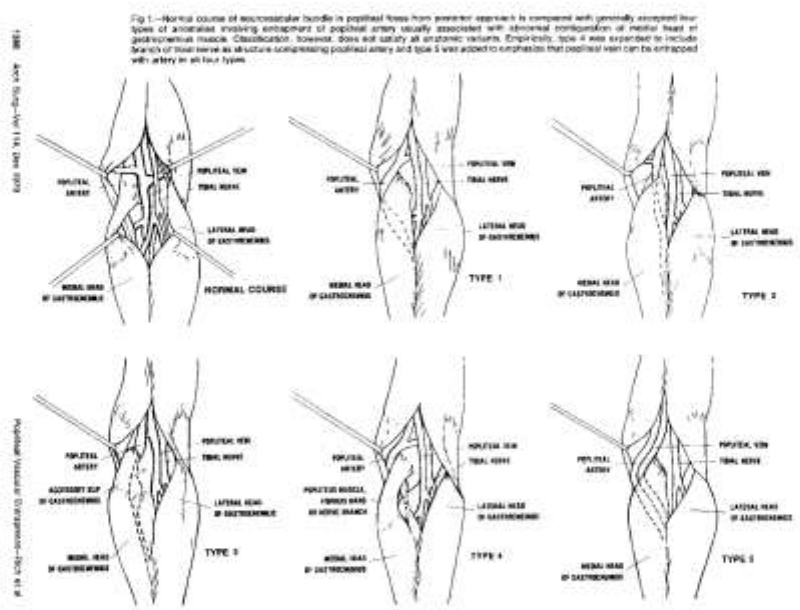

Fig.2: 5 Types of PAES [64]

The term Functional PAES was first used by Rignault et al in 1985 [5]. Functional PAES relates to a larger subgroup of people [74] usually with no anatomical abnormalities, although with severe reproducible symptoms cured with an operative exploration of the popliteal space [22]. ‘‘In functional PAES, an indeterminate lesion leads to arterial occlusion and subsequent claudication’’. Anatomical PAES typically affects older patients, whereas patients who suffer from functional PAES are considered younger and more active [75]. According to Baltopoulos et al. The syndrome is bilateral in approximately 25-76% of cases [5] PAES is rare and the pathogenesis is unknown [45], but the syndrome may be underreported [43] and the incidence may be higher. The popliteal artery, a significant vascular conduit, is situated behind the knee and serves as the primary supplier of blood to the calf and foot. Due to the decrease of blood in the calf during exercise, the pain is typically vague and localized in the rear of the calf [74,50], but if the anterior tibial artery is squeezed, the pain is transferred anteriorly and laterally until the exercise ceases [74,50]. The symptoms may appear when running or walking uphill. At rest, the posture of the leg during effort or provocation may create discomfort. Other symptoms such as coldness and paraesthesia have also been observed [60].

2.5 Cystic Adventitial Disease

The first description of Cystic Adventitial Disease dates back to 1946 when Atkins and Key reported a case in a 40-year-old man with claudication resulting from an external iliac lesion (4) that affected the right iliac artery [33]. The three layers that make up the popliteal artery are the intima, media, and adventitia. The atherosclerotic disease affects the innermost layer of the artery, and the popliteal adventitia is closely related to the rare condition cystic adventitia [44,59,71]. The clinical features of popliteal artery compression syndrome and cystic adventitia are often similar.

‘‘Cystic adventitia is a rare condition that combines mucopolysaccharides and mucins from the adventitial mucous material of arteries and veins [24]. The disease can affect any peripheral artery or vein, but the susceptibility to the popliteal artery is striking [41]. The disease affects young and middle-aged males with a male to female ratio of 15:1’’ [24,41,43].

Several theories have been proposed for the pathogenesis of the disorder, including microtrauma, development, and synovial.

Micro-traumatic: The condition tends to affect middle-aged males with heavy leg-related occupational activity, and there have been a few cases of confirmed trauma prior to cyst discovery (23). Repeated strain injuries may lead to cystic degeneration (24).

Developmental: Embryologically, the mucin-secreting cells of the knee joint are believed to contribute to the artery's adventitia development. The formation of tense cysts is attributed to the gradual emergence of mucin-secreting cells originating from the endothelium of the knee joint over several years (24). Accordingly, this concept suggests that the composition of the adventitial cyst is defined more by epithelial secretion rather than the degradation of collagen and ground material. (24).

Synovium: Ectopic synovial ganglia travel through the nearby knee capsule's vascular branches in the synovium (41). The coexistence of adventitial cysts and nearby periarticular tendon ganglia is supported by radiological and surgical findings, demonstrating a connection between these cysts or adventitial cysts and the knee joint (48,72).

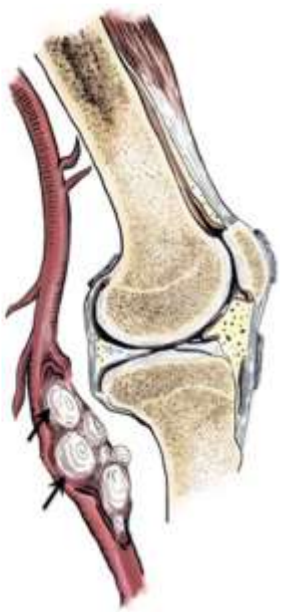

Fig.3: Picture of Adventitia Cystic Disease [33]

According to a recent investigation into cystic adventitial disease, arterial wall cysts were found in 13% of reported cases, independent of the artery involved (41). This link between the adventitial cyst and the surrounding joint capsule was recently discovered and recognized intraoperatively (64). As a result, it is supported by some form of dysplasia (13,8,12).

Collagen and ground substance breakdown products are included in the biochemical nature of the cystic content. The synovial theory holds preference over the developmental theory (48,72).

Levien et al. reported a modified developmental theory that supports the hypothesis that cystic adventitial disease is not due to synovial cells but other less differentiated joint-related mesenchymal cell rests (53). An argument was introduced, that in all reported cases of adventitial cystic disease, the cystic lesion is formed in the 15th to 22nd gestational weeks, in which is included the development of joint structures. ‘‘The theory of the development of the nonaxial arteries and the adjoining knee, hip, wrist, or ankle joints lends credence to the theory that the mesenchymal tissue that forms joints is trapped in the nearby growing nonaxial vasculature’’.

2.6 Ankle-Brachial Index

"The Ankle-Brachial Index (ABI) entails the utilization of a Doppler probe or an oscillometric instrument to assess the systolic blood pressure at both the arm (brachial arteries) and the ankle (dorsalis pedis or posterior tibial arteries) while the individual is in a supine position" (37). Typically, the lower limbs are under more pressure than the upper limbs. The usual ratio of the two pressures takes into account values between 1 and 1.4 (68). The Ankle Brachial Index is useful for diagnosing peripheral artery disease and grading disease severity. The Ankle Brachial Index is the first-line test for detecting peripheral artery disease because it is a non-invasive and inexpensive approach with excellent sensitivity and specificity when compared to invasive angiography, which is the gold standard method for diagnosing peripheral artery disease (37). ‘‘An ABI of 0.9 indicates peripheral artery disease, which is classified as mild to moderate if the index is from 0.9 to 0.4, or severe if the value is 0.4 (36). However, a score of more than 1.4 is deemed abnormal, indicating calcifying noncompressible artery disease and increased cardiovascular mortality’’ (36). ‘‘It is computed as the difference between the greatest peak systolic velocity measured by a Doppler device in the ankle and the highest peak systolic velocity obtained by a Doppler device in the humerus''.

ABI	
	Ranges
Normal	0.92 ≥ ABI ≤ 1.4
Mild	0.75 ≥ ABI ≤ 0.91
Moderate	0.50 ≥ ABI ≤0.74
Severe	0.35 ≥ ABI ≤0.49
Ischaemic	≤ 0.35

Intermittent claudication is suspected when the mean is approximately 0.59 and the standard deviation is 0.15. ABI calculations provide a formal approach to evaluating the severity of lower leg artery disease and predicting the risk of cardiovascular events, such as ischemia or stroke. Because of the syndrome's heterogeneity, popliteal artery involvement was not related to systemic disease or cardiovascular risk factors. However, the serious impairment may arise from local insufficiency and artery wall injury.

Specific Part

3.1Aim

This review aims to analyze the popliteal artery entrapment syndrome and the related anatomical abnormalities responsible for this. Therefore, the present study presents the anatomical variants and the presence of cystic adventitial disease that can cause stenosis of the popliteal artery, because of blood flow reduction in the popliteal fossa.

3.2 Material and Methods

This review was performed according to the guidelines of the British Medical Journal. The present study constitutes part of the Master in Ultrasonic investigation of intermittent claudication in young persons (popliteal artery entrapment syndrome, adventitial cystic disease) of the Department of Medicine, University of Thessaly. The following databases were searched: MEDLINE, PubMed, and the Cochrane Central Register of Controlled Trials (CENTRAL). The following terms were combined to collect all studies relevant to the main topic of the review: popliteal artery, compression, entrapment, syndrome, anatomy, popliteal fossa, pathology, ultrasound, sonography, duplex, PAES, ankle-brachial index, cystic adventitial disease, adventitial, intermittent claudication, color ultrasound. Seventy-eight (78) studies were found composed of 6 Cohort studies, 3 case reports, and 69 systemic reviews. Thirteen (13) of them published in the last decade were chosen as being more relevant to the topic. Two (2) of the 13 articles were case reports and the rest of them were systemic reviews.

4 Results

4.1 Duplex Ultrasound scanning of Popliteal Artery

Individuals who experience intermittent claudication during intense physical activity or regular walking might be afflicted by popliteal artery stenosis caused by popliteal artery entrapment syndrome or cystic adventitial disease. An additional noteworthy indication is the occurrence of paresthesia following exercise [2].

The evaluation of the popliteal artery could be performed using Duplex Ultrasound scanning in the interim of the rest and the plantar flexion. The scanning process is executed from the arteria femoralis to the infragenicular popliteal artery using a color ultrasound system and a 9.5 MHz linear array transducer. According to the protocol, ‘‘before the examination, all patients must relax for 15 minutes’’. ‘‘In order to guarantee freedom of movement, it is imperative to evaluate the popliteal artery in a horizontal prone position, with the knee supported at a 15-degree flexed angle, and the feet hanging over the edge of the table’’. Doppler Ultrasound Scanning of the arteria poplitea is conducted in this neutral posture to detect occlusive disease, aberrant course, or aneurysmal alterations. DUS is then performed as vigorously as feasible with the patient in plantar flexion while a second examiner applies counterpressure to guarantee maximal muscular strength. The plantarflexion test is used to assess DUS during movements [2].’’ ‘‘The angle established between the plantar aspect of the foot and the surface of the scale is approximately 50 to 60 degrees, facilitating the patient in attaining maximal foot flexion during the provocation technique’’. To prevent any cranial movement of the entire body during vigorous plantar flexion, the patient's shoulders are supported by a rack positioned on the examination bed. [30]. The identification of the arteria poplitea involves using a color signal or, in case of artery obstruction, discerning the vascular wall that accompanies the vena poplitea. Occlusions can be identified by segmental signal loss in signified arteries or by signal attenuation distally relative to proximally [21]. The existence of colored flow signals, when plantar flexion achieves maximal pressure, indicates the absence of popliteal artery compression [30]. Important stenosis can be characterized by a peak systolic ratio that doubled the compared velocities in the adjacent normal vessel part [21]. ‘‘By keeping the angle of insonation below 60 degrees, the velocities in the center stream of the vessels are determined’’. The diagnosis of Popliteal Artery Entrapment Syndrome (PAES) is ascertained by observing the outcomes of plantar flexion testing performed in the presence of occlusion or substantial stenosis of the arteria poplitea.

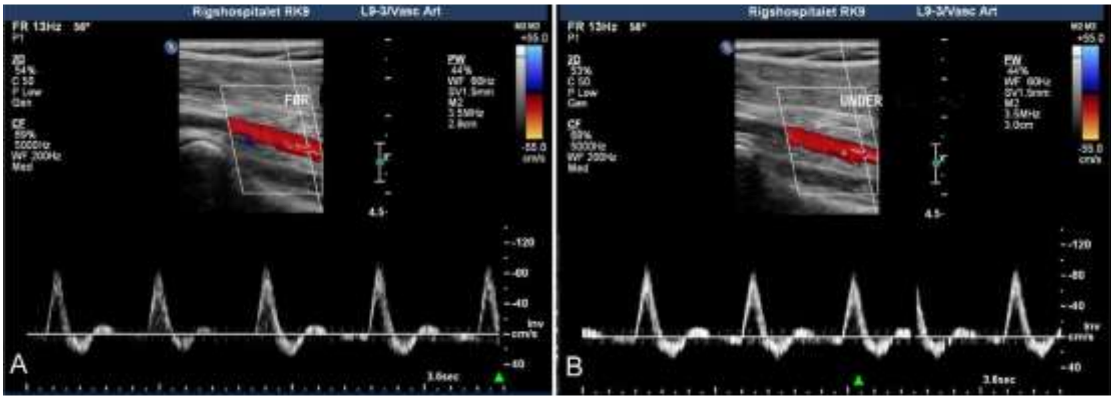

Fig.4: A, Duplex ultrasound scanning of the popliteal artery (in a healthy volunteer) in rest showing triphasic signal. B, Duplex ultrasound scanning of the popliteal artery (in the same participant as in [A]) during plantar flexion test showing unchanged normal flow pattern andunchanged max velocity [2]

4.2 Cystic Adventitial Disease

Intermittent Claudication is the most familiar symptom in cystic adventitial disease but the presence of critical acute and chronic limb ischemia may exist [11]. Because it is a rare condition, the prevalence of Cystic Adventitial Disease (CAD) is unknown and it is estimated that accounts for < 0.1% of the cases of intermittent claudication [18]. With a reported male-to-female ratio of 5:1 [32,57] and a peak age of onset between 40 and 50 years of age [18], CAD primarily affects those who have no or few cardiovascular risk factors. Due to obstruction of the popliteal artery during the treatment, the patient presented clinically with the Ishikawa sign, pulse in the distal lower extremity of the afflicted side of the body with hyperflexion of the knee. [18, 57].

Imaging is crucial in the diagnosis of cystic adventitial disease. Ultrasound imaging serves as a viable method for identifying this condition, which is characterized by the presence of anechoic or hypoechoic circular lesions with well-defined edges and posterior acoustic enhancement emanating from the artery wall. Incidental imaging conducted to examine knee or calf discomfort detects CAD of arteria poplitea [55]. Because of the gelatinous substance, these lesions may have low-level echoes and maybe multilocular with thin septa [24]. Peak systolic velocities in

Doppler ultrasonography are depending on the degree of stenosis because fluid collection in the adventitial layer of an artery can produce luminal constriction or even full blockage [18,57].

According to the suggestion of Brodmann et al. [10], color Doppler ultrasonography is the most sensitive imaging technique for detecting cystic adventitial disease. The differentiation between cystic degeneration of the popliteal artery and secondary occlusion may present considerable challenges when employing contrast-enhanced computed tomography, as this modality primarily highlights the cystic pattern, which is a common feature observed in both pathological conditions. To address this limitation, a combined approach involving simultaneous MRI and color Doppler examinations has been advocated, with the latter demonstrating higher sensitivity than MRI [52,70]. Cross-sectional imaging, in such cases, assumes paramount clinical significance as a diagnostic tool, particularly when duplex ultrasound fails to visualize indicative signs of cystic adventitial disease.

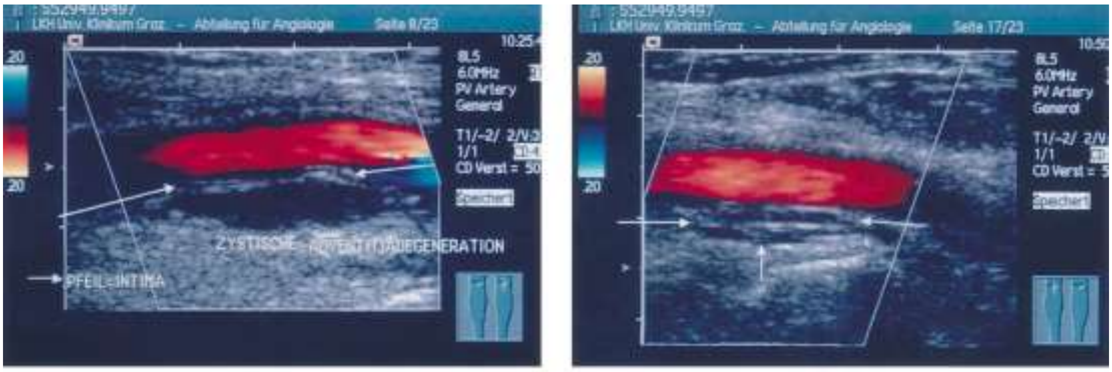

Fig. 1 Fig. 2

Fig.5: A. It is depicted cyctic lession in the left popliteal artery

B. It is depicted cyst in the right popliteal artery

In the treatment of Cystic Adventitial Disease (CAD), the surgical procedure encompasses the excision of the cyst and the affected arterial segment, followed by the placement of a vein patch or synthetic graft. The cyst aspiration and interposition grafting report an initial success rate of 94% [24]. Ultrasound-guided cyst aspiration has been reported as a potential treatment approach for Cystic Adventitial Disease

(CAD); however, it is important to note that this method exhibits a higher recurrence rate. As a result, considering alternative therapeutic strategies such as surgical intervention with cyst excision and graft placement may be warranted for improved treatment efficacy and long-term outcomes. [51].

4.3 Popliteal Artery Entrapment Syndrome

The arteria poplitea generally flows between the heads of the gastrocnemius muscle down the popliteal fossa. Intermittent claudication can be caused by a lack of flow during muscle contractions as a result of abnormal interaction between the artery and the surrounding musculotendinous tissues [47]. The calf may push on the surrounding vena poplitea and nerve, as well as the artery, causing redness, edema, and paresthesia. During repose, most patients do not have leg discomfort. On the other hand, the discomfort goes away while they relax [29].

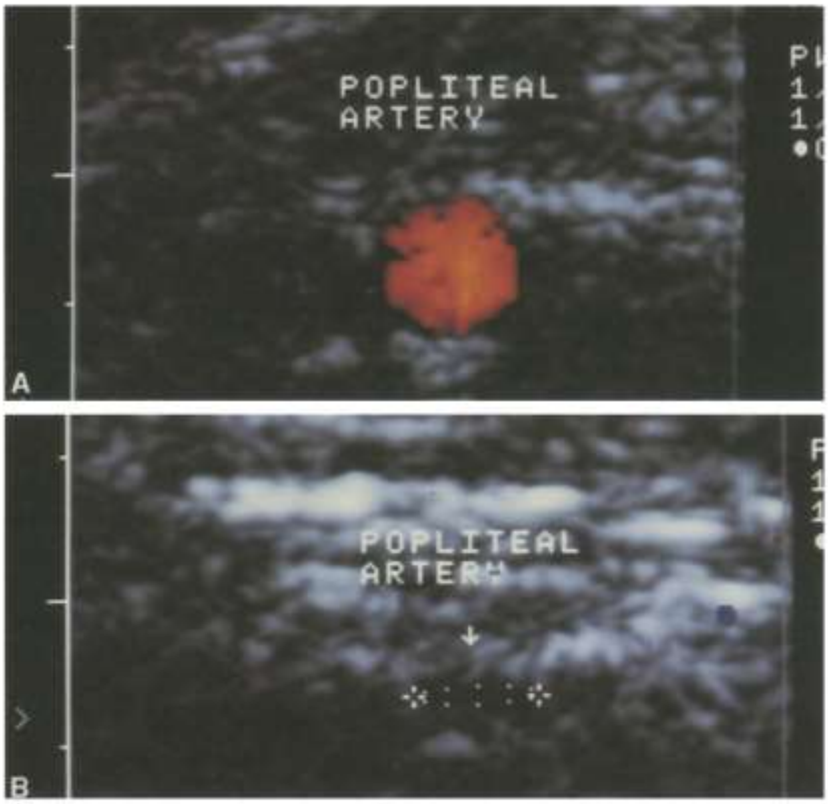

Fig. 6: Color duplex sonography of popliteal artery (transverse section) in normal position (upper panel) and during active plantar flexion (lower panel). In normal position, color flow signal ofpopliteal artery is well visualized. During plantar flexion, vessel is compressed and flow signal completely disappears [30]

Doppler Ultrasound is the initial tool used to investigate PAES since it is a low-cost, non-invasive, and easily accessible procedure for assessing flow via the popliteal artery [2,22]. Regardless of the source, PAES symptoms often appear before the late teen or early twenties. Patients diagnosed with Popliteal Artery Entrapment Syndrome (PAES) typically belong to the younger athletic population and notably do not exhibit any of the conventional atherosclerotic risk factors, such as smoking or diabetes. It is important to highlight that individuals engaging in activities that promote accelerated muscle growth are at increased susceptibility to developing functional PAES. There is no gender component that influences the progression of the syndrome. [74].

The first test to diagnose PAES is the Ankle-Brachial Index [29]. To establish the possibility of the presence or non-presence of arterial occlusion, Collins et al. conducted a Doppler ultrasound assessment of the posterior tibial artery and dorsal artery of the foot at the ankle for every participant in their study, with the purpose of establishing the Ankle Brachial Index (ABI)[78]. The patients with a score ABI < 1, were considered to have steady arterial lesions. The test was performed before and after the exercise [29]. ‘‘The treadmill test, classified as a cardiovascular stress test, necessitates meticulous monitoring of the patient's electrocardiography (ECG) and blood pressure’’ . This stress test is conducted either on a treadmill or a stationary bicycle and is carried out within a specialized laboratory under the supervision of a qualified healthcare professional. Throughout the examination, electrodes are affixed to the patient's chest, and their electrical signals are linked to an ECG machine, enabling the recording of the heart's electrical activity. Before initiating the exercise program, baseline measurements of resting ECG, heart rate, and blood pressure are ascertained to establish a reference point for subsequent observations during the stress test. The protocol is divided into consecutive 3-minute increments, each requiring the patient to walk faster and with a steeper incline. The test protocol can be adjusted based on patient tolerance, with a target duration of 6 to 12 minutes. For those who cannot exercise vigorously, there is a modified Bruce protocol that adds two lighter workload stages to the standard Bruce protocol, both of which require less effort than stage 1. The patients with a normal ABI were examined with an exercise treadmill test as described by McDonald et al [16]. Blood pressure cuffs are placed in both arms and legs at rest to measure blood pressure. In this way, we have a baseline measurement of the arms and legs pressure at resting state.

In their study, Collins et al. conducted an exercise treadmill test on their patients, and recommended a 3-minute treadmill test at 3 mph with a 0% gradient. Subsequently, ABIs were reassessed, and if the patient's symptoms were reproduced and ABI reached 1, the test was considered positive for probable popliteal entrapment. In cases where ABIs did not decrease, a more demanding treadmill test was administered at 4.2 mph with a 10% gradient, lasting at least 10 minutes. Additional exercises were performed to determine ABIs if they elicited the patient's complaints (16). The recurrence of symptoms and decline in ABI values could be attributed to increased muscle mass within a confined compartment, such as the popliteal fossa, which elevates pressure on the fixed artery due to aberrant musculotendinous attachments. The repetitive traumatization of the arteries by the entrapment structure might result from another degenerative process that occurs during higher-level activity (16,22). The reduction in ABI after the treadmill test is caused by progressive vascular stenosis and the transient development of vessel vasospasm. However, in cases where a normal treadmill test or activity is performed, a thorough history and physical examination may be deemed sufficient to warrant arteriography for further investigation of the possibility of PAES or another arterial occlusive condition (16).

Duplex Ultrasound serves as an additional examination technique for diagnosing PAES. The examination of the arteria poplitea is conducted with the individual in a prone position. The examined leg is meticulously positioned in a neutral stance, aided by a small pillow under the ankle joint, permitting the feet to hang freely over the examining table. The knee is flexed at approximately 15%, while the ankle is positioned in slight plantar flexion of 10%, thus achieving the ideal flexed position.. A stenotic disease or anatomic variety of the popliteal artery can be detected by a Duplex scan in this neutral position (1).'' ''The arteries are examined by emerging from Hunter's canal inferiorly to the arteria tibialis anterior and the proximal Truncus tibiofibularis. Flow velocity patterns need to be recorded at rest and during foot movements when narrow areas are detected. Measurements are obtained at three points: 5 cm above the knee joint (proximal), at the knee joint, and 1 cm proximal to the anterior tibial artery origin (distal) (1). Measurements of passive dorsiflexion and passive plantarflexion with the foot in a neutral posture and the duplex probe fastened. Finally, dynamic duplex scanning necessitates the patient actively flexing the foot dorsally, followed by plantarly.'' A second investigator must give counter pressure during these maneuvers to ensure maximal muscle action [1]. The combined examination of the patients with Duplex ultrasonography and B-Mode ultrasound imaging can give us the advantage of anatomic information from the B-Mode imaging with the qualitative and quantitative analysis of the arterial flow of Doppler ultrasound [8].

(A) (B)

Fig.7: ''A) Patient prone pushing against the wall at 25%maximum plantar flexion force. B) patient erect and plantar flexing against full body weight [29]''

5.1 Discussion

A number of recent articles will be presented according to their results in the ultrasound examination of the popliteal artery, in cases of Popliteal Artery Entrapment Syndrome and Cystic Adventitial Disease.

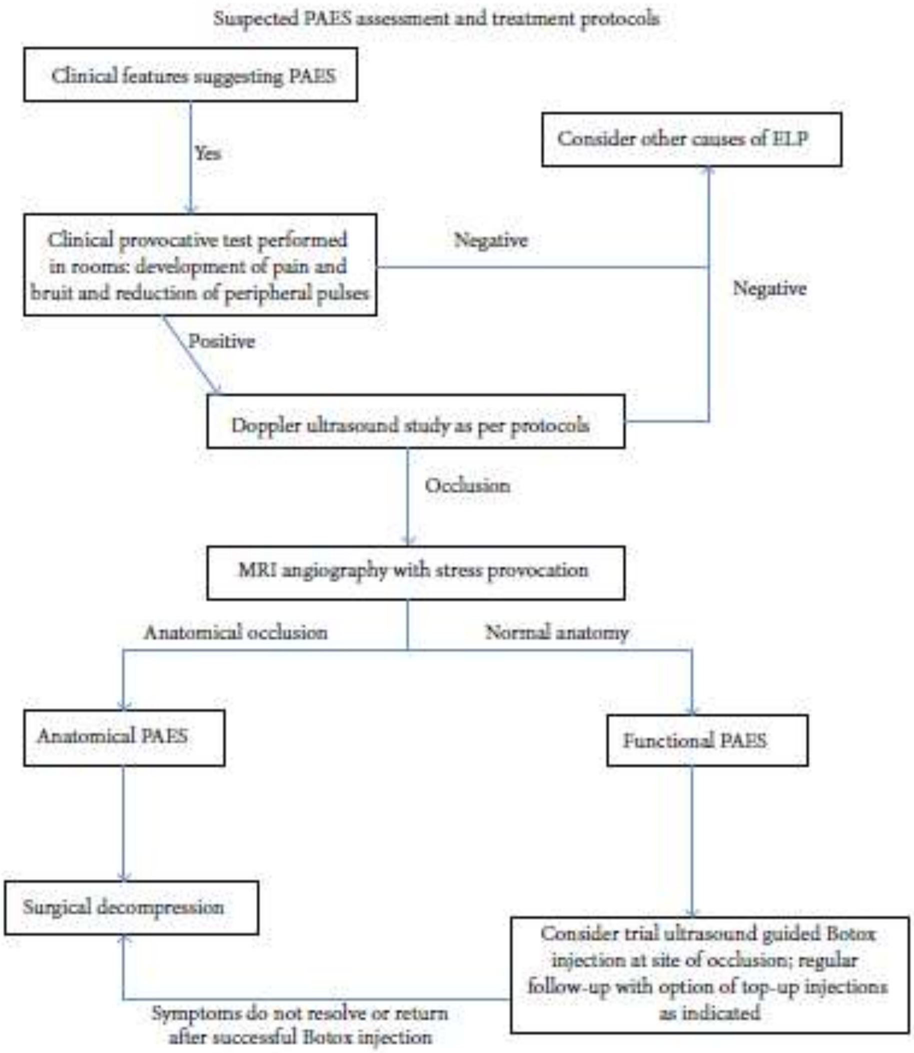

Fig.8: ''Assessment and treatment protocol for suspected PAES[29]''

Akkersdijk et al. conducted an investigation into the potential association between popliteal artery compression and active plantar flexion of the limb during the evaluation of PAES. Additionally, they examined the impact of these triggered limb motions on the outflow patterns of the arteria popliteal in a group of normal healthy volunteeers, with an average age of 25 years. According to Akkersdijk, Peak Systolic Velocity (PSV) changed at all levels during plantar flexion. With active plantar flexion of the foot, a decrease in flow was found in the more proximal course of the arteries. This can be explained by the distal arterial channel narrowing or occluding [1]. As a result, vascular output to the superior and inferior genital arteries, as well as the lateral circumflex arteries of the knee, was decreased.

Reduced blood flow is due to immediate compression of the arterial distal course by bordering tendon structures or reduced outflow. In his study, we know that in as many as 59% of the arteries studied, blood flow is lost during active plantarflexion, which is equivalent to the entire closure of the artery. Another 13% doubled their PSV, meaning a significant reduction in streaming. Finally, low flow was noted in 13% of patients, suggesting more distal stenosis or occlusion [1].

In the study by Akkerddijk et al. note that the median PSV in a neutral position decreases with excitation action and normal three-phase flow pattern from 100 cm/s proximally to 90 cm/s distally in the artery. Application of passive foot movements or active dorsiflexion had any effect on PSV at any level of the arteria poplitea. Changes in the PSV were induced only by the active plantar flexion, with a reduction of the median PSV in the proximal part of the artery from 65 cm/s to 40 cm/s, at the knee joint level [1].

	Median PSV (range)				
Popliteal artery	Neutral	Passive dorsal	Passive plantar	Active dorsal	Active plantar
Proximal	100 (45–145)	95 (50–140)	100 (45–140)	95 (60–140)	65 25–140)
Knee joint	95 (60–160)	95 (50–150)	90 (50–120)	83 (50–150)	40 (15-130)
Distal	90 (30–120)	90 (45–120)	90 (60–120)	80 (50–200)	* (0–200)

Fig.9: ''Median peak systolic flow velocities (cm/s) of 16 healthy subjects in a neutral position and during provocation maneuvers [1]''

Altintas et al. focused on the evaluation of popliteal artery entrapment syndrome with emphasis on the applicability of duplex ultrasound scanning. He also examined the correlation between the duplex ultrasound findings scanning and the intraoperative discoveries in symptomatic limbs. In a period of 12 months, he examined 11 symptomatic limbs in 8 patients with a middle age of 29 years. According to Altintas et al., the Duplex Ultrasound Scanning findings were in agreement with the intraoperative findings. Also, it was found that there is a difference between patients with PAES and patients with a typical elderly atherosclerotic vascular disease, due to the predominance of PAES in young men with bilateral symptoms which is a characteristic factor of this condition [66,19,43]. Intermittent Claudication is presented mostly during strenuous exercise, while critical limb ischemia is rare [19,43,27,67,69]. The final hypothesis of Altintas et al. was that the compression of the arteria poplitea in the interim of plantar flexion is a physiological phenomenon because the flow changes of the examined popliteal arteries of the normal population are more than 85% and the applicability of DUS in the diagnosis of PAES is debatable. Finally, false-positive results may occur due to incorrect performance of the plantar flexion test, since the probe must be stabilized and sudden movements during calf muscle contraction should be avoided [1,30]. If the diagnosis of PAES cannot be made with certainty with the above methods, it is recommended to perform an angiogram [29].

The primary objective of the Lejay et al. study was to evaluate the long-term prognosis of surgery for popliteal artery entrapment syndrome. Their research lasted six years. The average age of the patients at the time of surgery was 35, with a range of 15 to 49 years old. They refer to a brief list of literature reports concerning the result of PAES surgical therapy in their retrospective evaluation. But especially, it is annotated on the difficulty of frequency of the condition as well as the underestimation of PAES. Functional PAES is related with gastrocnemius medial head hypertrophy and popliteal artery occlusion during contraction. Because non-invasive tests like as ABI may be abnormal in a significant proportion of the asymptomatic population, treating Functional PAES may be challenging. [40,42,74].

Perlowski et al. investigated athletes who reported symptoms or clinical findings consistent with vascular disease. According to Perlowski et al., the therapy for Functional PAES is conservative, consisting of relative entrapment, lower extremity elevation, and stretching [58]. When the symptoms become severe or worsen, surgery is recommended. The surgical treatment of Functional PAES includes partial excision of the medial head of the gastrocnemius muscle [58]. According to Perlowski et al, the post-surgical prognosis is favorable since the patient recovers fully and resumes sports activity within 6-8 months. [5].

Baniakowski et al. presented a case report of a 22-year-old male cyclist and the results of the imaging methods in the diagnosis of intermittent claudication and how they assisted in operative planning. Also, she reported that several imaging modalities have been reported in the diagnosis of PAES but many of them are often non-diagnostic. Also, it is reported that the unreliability of the Duplex Ultrasound is due to the presence of a functional occlusion in normal popliteal arteries in both neutral and active plantar flexion [22,61]. In addition to being indicated as an additional tool in the diagnosis of functional PAES and as a staged procedure during preoperative workup, intravenous ultrasound (IVUS) may also be used as an adjuvant to angiography to aid in operational planning since it not only can offer information on the precise site of the compression, but it can provide information about the vessel wall [7]. The IVUS's accurate planning support for operations based on the specific location of the lesion and the prospective requirement for artery repair is another benefit [7].

5.2 Conclusion

Intermittent claudication, pain, and cramping of the calf muscle during exercise, especially in young athletes without typical atherosclerotic risk factors, are the most common symptoms that may pique someone's interest to investigate the possibility of Popliteal Artery Entrapment Syndrome (PAES) or Cystic Adventitial Disease (ACD). The absence of obvious signs of the condition on the physical exam may lead to misdiagnosis. So, further tests such as duplex ultrasound of the popliteal artery with maneuvers or the ankle-brachial index measurement must be performed to have a right and precise diagnosis. The duplex ultrasound is a well-established, fast, and precise image method to explain the cause of intermittent claudication, if the symptoms are caused by the compression of the popliteal artery, as long as the follow-up of people with known PAES or ACD.

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