Article published online: 2023-11-23

Popliteal Artery-Related Pathologies in Athletes —A Primer for Musculoskeletal Radiologists

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Indian J Radiol Imaging 2024;34:283–290.

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Abstract

Vascular complications in athletes are common and mimic musculoskeletal injuries such as muscle sprains, fractures, and cartilage abnormalities. They include traumatic vascular injuries and more subtle pathologies like entrapment syndromes, pseudoaneurysms, arterial occlusions, and venous thrombosis. Such vascular complications may be occult on imaging and can be difficult for a musculoskeletal radiologist to diagnose, resulting in a lack of timely diagnosis and potentially limb-threatening consequences. Although the final diagnosis may require multidisciplinary input from orthopaedic, sports and exercise medicine, and vascular and interventional radiology inputs, a musculoskeletal radiologist with prior knowledge of such conditions can be the first to diagnose such conditions aiding the athlete's performance. A musculoskeletal radiologist should pay due attention to anatomical courses of vascular channels and look for potential causes of vascular compression, aberrant myotendinous bands, accessory muscles, etc., before concluding a computed tomography (CT) or magnetic resonance imaging (MRI) as normal. Doppler ultrasound, CT, or MR angiography are commonly employed techniques for primary evaluation, whereas digital subtraction angiography is generally reserved for troubleshooting as advanced dynamic imaging.

Keywords
- angiography
- athletes
- popliteal artery
- popliteal vessels
- sports injuries

Introduction

Performance-related musculoskeletal injuries can be classified according to the mechanisms producing them into collision-related acute injuries, chronic repetitive stress, or shearing force-related injuries.[1] In elite athletes, accurate diagnosis and subsequent management of the musculoskeletal ailment is paramount in deciding its prognosis and, in turn, time to return to play.

Musculoskeletal radiologists are traditionally trained to identify even the most subtle of musculoskeletal injuries. However, identifying appropriate neurovascular structures and qualifying and quantifying neurovascular abnormality may serve as potential areas of satisfaction in the search for a musculoskeletal radiologist. In general, interventional radiologists generally manage vascular complications in the general population and elite athletes. Hence, the musculoskeletal radiology literature on sports-related vascular

article published online
November 23, 2023

DOI https://doi.org/10.1055/s-0043-1777014.
ISSN 0971-3026.

Thieme Medical and Scientific Publishers Pvt. Ltd., A-12, 2nd Floor, Sector 2, Noida-201301 UP, India

complications in extremities is lacking. Performance-related pressure always remains critical for an elite athlete, and missing vascular complications such as arterial or deep venous thrombosis (DVT), traumatic pseudoaneurysm, and entrapment syndromes may result in a potential limb-threatening ischemia costing a career to the athlete in addition to a significant medicolegal challenge to the radiologist. Hence, the musculoskeletal radiologist must approach imaging of an athlete with a new-onset limb pain with a high index of suspicion to diagnose vascular complications. Differentials should include musculoskeletal as well as nonmusculoskeletal diagnoses in such cases.

Traumatic involvement of the lower limb vessels ranges from acute high-velocity injuries from falls and collisions leading to crushing/penetrating injuries or contact sports, causing nonpenetrating/blunt trauma. The latter affects the popliteal artery most commonly, followed by the common femoral artery, superficial femoral artery, and anterior tibial arteries in decreasing order of frequency.[2] Conversely, nontraumatic vascular complications are fundamentally different from their traumatic counterparts in clinical examination and diagnostic workup apart from imaging and subsequent management; their detailed discussion is beyond the scope of this article. Therefore, we have summarized clinical findings and work up of traumatic and nontraumatic knee injuries in ►**Table 1**.

In this pictorial review, we shall discuss the pathogenesis of various sports-related vascular complications, both traumatic and nontraumatic, and their imaging appearances.

Pathogenesis of Popliteal Artery Complications in Athletes

Traumatic

Popliteal artery injury is a well-documented complication of knee dislocation and open knee injuries in 30 to 50% of cases.[3] Contact sports, high-velocity trauma such as motorbike racing and cycling, track-and-field events such as high-jump and long-jump and dashboard injuries in motorsports are the most common causes of knee dislocations with concomitant popliteal artery injuries in athletes. A relatively fixed course of the popliteal artery between the adductor hiatus and the soleus arch predisposes it to sustain various types of trauma, including intimal injury (►**Fig. 1**), avulsion, occlusion, or aneurysm formation (►**Fig. 2**). Arterial shear forces and chronic repetitive microtrauma can result in pseudoaneurysms, rarely arterial thrombosis (►**Fig. 3**) and emboli.

Venous thrombosis is another known complication following appendicular trauma. According to Virchow's triad, three important factors are responsible for DVT—blood flow, blood components, and blood vessels. Trauma can have varying elements of Virchow's triad of hypercoagulability, endothelial injury, and venous stasis. The predominant component of traumatic DVT is the exposed thrombogenic subintimal layer following blunt intimal injury.[4]

Nontraumatic

Nontraumatic lower limb vascular complications in athletes are less apparent on imaging and require a high index of suspicion as the athlete may be asymptomatic at rest. The symptoms are only reproducible with vigorous exercise. Researchers have postulated various muscular, ligamentous, and vascular adaptations such as external iliac artery endofibrosis following rigorous training regimes with or without background variant anatomy as causative factors for such complications.[5,6]

Popliteal artery entrapment syndrome (PAES) has various anatomic etiologies. Six types of PAES (►**Fig. 4**) are described in the literature[7,8] based on aberrant vascular or muscular anatomy or functional cause (type VI). Type III PAES is the most common type caused by an accessory muscular slip of the medial head of the gastrocnemius compressing the popliteal artery.

Popliteal Artery Injury in Knee Dislocation

Popliteal artery injuries are common with knee dislocation (►**Fig. 3**) and open knee injuries following high-velocity injuries or falls. When the knee is imaged as part of the polytrauma computed tomography (CT), evaluating the knee joint and assessing the patency of the popliteal artery and possible vascular injuries are essential. CT angiography (CTA) is the gold standard investigation in acute settings to diagnose the exact site, length of the injured arterial segment, and associated complications such as acute extravasation, pseudoaneurysm or aneurysm formation, for which ultrasound is often the initial imaging modality of choice. Digital subtraction angiography (DSA) can provide advanced diagnostic and therapeutic to confirm the diagnosis.[9,10]

Popliteal Artery Entrapment Syndrome

PAES is a vascular compression syndrome caused by an aberrant course of the popliteal artery or an accessory muscular slip (type I through V) compressing the artery (►**Fig. 5A** and **B**) or hypertrophied medial gastrocnemius compressing the popliteal artery on a functional basis (type VI) (►**Fig. 6**). Caution must be exercised as narrowing of the popliteal artery during ankle dorsiflexion and plantar flexion may also occur in the general population, and it is vital to correlate the patient's symptoms before diagnosing PAES. In a symptomatic patient, the disappearance of the pedal pulse following exercise with the development of symptoms and corresponding imaging appearances described below should alert the clinicians for PAES.

On Doppler ultrasound, PAES is diagnosed by popliteal artery stenosis, increased velocity and resistance, and decreased peak systolic velocity, especially after exercise (►**Fig. 6**).[11]

CTA, in PAES, demonstrates narrowing of the popliteal artery behind the knee and can also provide multiplanar and volumetric reconstructions to delineate anatomy better. It may require three separate contrast bolus and scan with the foot in dorsal flexion, plantar flexion, and neutral position for functional evaluation of the artery.[7] We recommend scanning both lower limbs because of the high incidence of bilateral disease.

Magnetic resonance angiography (MRA), like CTA, is a noninvasive imaging technique. It is usually indicated in cases

Table 1 Demographics, clinical features, investigations, and management of sport-related popliteal artery complications in athletes

Pathology	Demographics	Clinical features	Investigations including imaging	Management
Popliteal artery injury in knee dislocation	Younger patients <30 years, male predominance, higher BMI	History of high-velocity or significant trauma, dislocated knee, stigmata of vascular ischemia in the leg beyond the knee joint, Reduced ankle-brachial pressure index	Plain radiographs—features of knee dislocation MRI—comprehensive assessment of multiligamentous injury CTA or MRA—CTA is preferred due to faster acquisition and its MIP and volumetric reformatting capabilities DSA—narrowing of the popliteal artery lumen at the level of knee dislocation or fracture (intimal injuries—more common) or complete lack of distal filling (complete occlusion—less common)	Combine surgical approach involving orthopaedic and vascular teams Popliteal artery intimal injury with normal distal pulses is usually observed for 48 to 72 hours Those with features of limb ischemia require arterial reconstruction
PAES	Younger patients <30 years, male predominance (M:F—15:1), bilateral in 22–67%	Claudication, exercise-induced leg pain (up to 90% patients) Symptoms of limb ischemia—paresthesias, rest pain, tissue loss Loss of ankle pulses on ankle plantar or dorsiflexion ABPI—normal at rest and decreased during exercise	Doppler ultrasound—increased velocity, decreased peak systolic activity CTA or MRA—CTA is better in advances cases of PAES with thrombosis, while MRA provides better soft tissue contrast and delineates anatomy better DSA—narrowing of the popliteal artery during stress maneuvers, additional findings: medial deviation, ectasia, aneurysmal dilatation and vessel wall irregularities, and distal arterial emboli detection	For acute thrombosis—catheter-mediated thrombolysis Definitive treatment for PAES type I through V—resection of the gastrocnemius muscle ± vascular reconstruction
Cystic adventitial disease of the popliteal artery	Male predominance (M:F—5:1), 40–50 years, active and sedentary people—affected with same frequency	Loss of pedal pulses with knee flexion (Ishizawa's sign)	MRI—multiple cysts along the popliteal artery MRA or Doppler ultrasound with waveform analysis of the popliteal artery	Cyst aspiration, evacuation with removal of the cyst wall, vein graft, vein patch and grafting
CECS	Females affected more than males, bilateral in 70% of patients	Symptoms depend upon affected compartment Anterior—foot drop or paresthesias of the dorsal foot Superficial posterior compartment—weak plantar flexion and paresthesias of the lateral foot Deep posterior compartment—reduced toe flexion and ankle inversion with paresthesias of the plantar foot	ICP measurements—at rest and after exercise: gold standard Normal ICP: 5–10 mm Hg ICP increase after exercise: within 40 mm Hg of SBP or within 20 mm Hg of DBP MRI complimentary to ICP measurements—increased signal intensities in affected compartment muscles on T2-weighted images	Conservative management—rest for 2–3 months with gradual return to play If conservative management fails, surgical decompression via open or subcutaneous fasciotomy
Effort-induced DVT (Paget-Schroetter syndrome)	More common in upper extremities In distance runners and skiers – lower extremities affected	Lower extremity swelling, decrease sensation, impaired sports performance Asymmetrical circumference, pitting edema, discoloration Homan's sign—pain on passive ankle dorsiflexion	Doppler ultrasonography—gold standard Complete blood profile with coagulation studies, factor V Leiden mutation and hereditary thrombophilia evaluation	Anticoagulants vein graft

Abbreviations: ABPI, ankle brachial pressure index; BMI, body mass index; CECS, chronic exertional compartment syndrome; CTA, computed tomographic angiography; DBP, diastolic blood pressure; DSA, digital subtraction angiography; DVT, deep venous thrombosis; ICP, intracompartmental pressure; MRA, magnetic resonance angiography; MRI, magnetic resonance imaging; PAES, popliteal artery entrapment syndrome; SBP, systolic blood pressure.

Fig. 1 Popliteal artery intimal injury and dissection: A 29-year-old male ice hockey player presented with posterior knee pain. Coronal proton-density fat-suppressed image showing an intimal flap (curved yellow arrows) in the popliteal artery at the level of the popliteal fossa apex.

where conventional MRI fails to demonstrate structure causes or in suspected functional PAES cases. Its advantages include lack of radiation, excellent soft-tissue contrast resolution aiding diagnosis of aberrant musculature and its multiplanar acquisition. MRA usually suffers from an underestimation of stenosis when the vessel is narrowed by less than 50% and volume averaging[12] (►**Fig. 5C**). However, recently developed three-dimensional T1-weighted spoiled gradient echo sequences exploit short time-to-repeat and echo time and are ideal for multiphasic vascular studies. Using gadolinium-based contrast media provides excellent spatial resolution, high signal-to-noise ratio, and reduced flow-related artifacts. Subtraction techniques also improve contrast resolution where “mask images” of background tissues are acquired before contrast bolus and are subtracted from post-contrast images. Various trigger or bolus tracking methods are used to obtain optimum vascular opacification. We use the fluorotrigger method at our institute where the radiographer triggers the post-contrast once the contrast bolus opacifies the popliteal artery to a certain extent (►**Table 2**). Alternatively, the time-resolved MRA acquisition method is generally used for suspected PAES where multiple acquisitions are performed over successive time points scanning a single volume, for example, the entire course of popliteal arteries from mid-thighs to mid-calves in different ankle positions.[13]

DSA remains the standard method of imaging with therapeutic advantages. It can diagnose popliteal artery narrowing with the ability to capture dynamic images during stress maneuvers and also depict vessel wall irregularity, aneurysm formation and thrombosis.[14]

Cystic Adventitial Disease of the Popliteal Artery

It is a rare disease most commonly involving the popliteal artery in male subjects in their 40s. Thought to be of

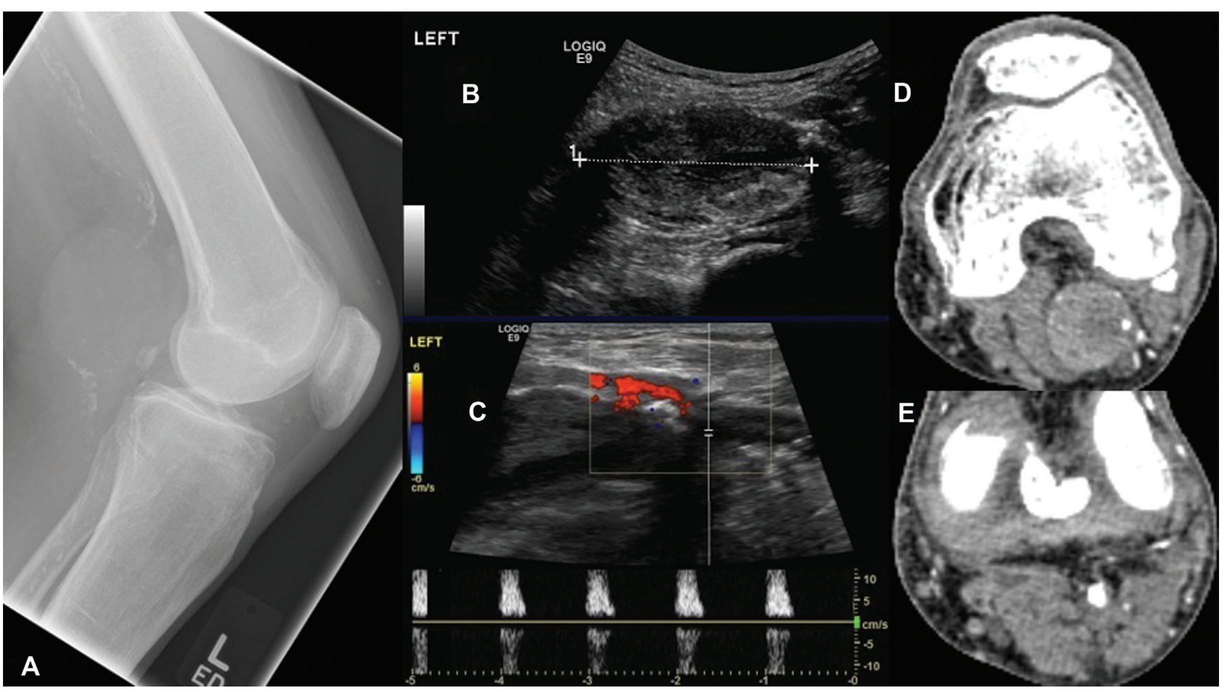

Fig. 2 Popliteal artery aneurysm: The lateral knee radiograph (**A**) showing vascular calcification and globular aneurysmal shadow inseparable from the popliteal artery shadow. Grayscale (**B**) and color Doppler (**C**) ultrasound image showing a heterogenous popliteal artery aneurysm with partial thrombosis, confirmed on axial computed tomography angiogram images (**D**, **E**) showing near-completely occluded popliteal artery aneurysm.

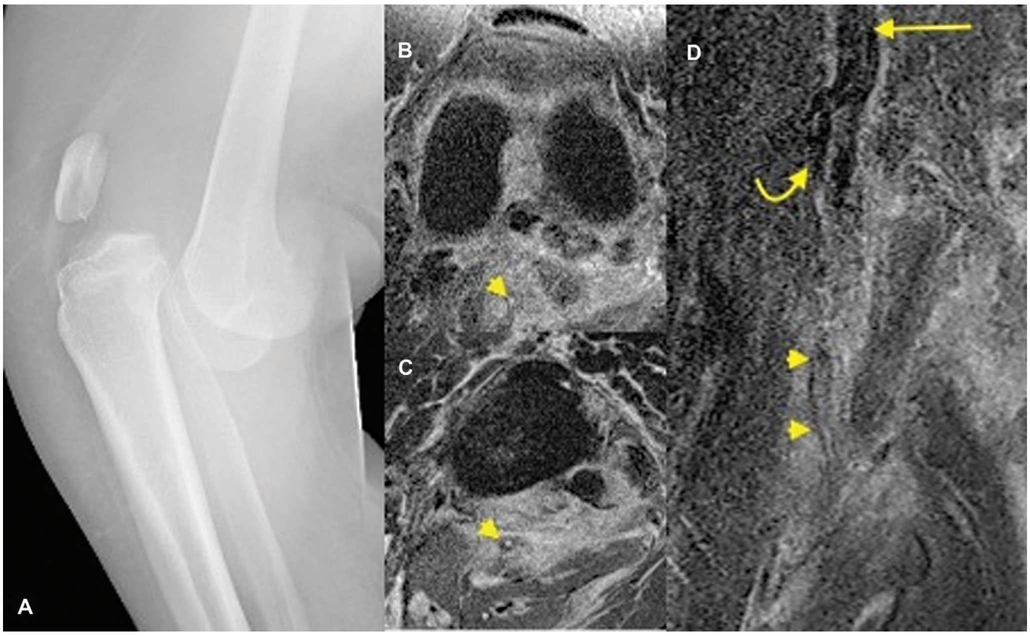

Fig. 3 Popliteal artery thrombosis following injury related to the posterior knee dislocation: The lateral knee radiograph (**A**) showing high-grade posterior knee dislocation. T2-fat-suppressed (T2-FS) axial images at distal femoral condyle (**B**) and proximal tibiofibular joint (**C**) showing loss of popliteal artery flow void (arrowheads) consistent with thrombosis. The coronal T2-FS image (**D**) showing a long-segment popliteal artery thrombosis (arrowheads) compared with a normal popliteal artery (curved arrow) in the popliteal fossa apex. The popliteal vein (straight arrow) is also patent.

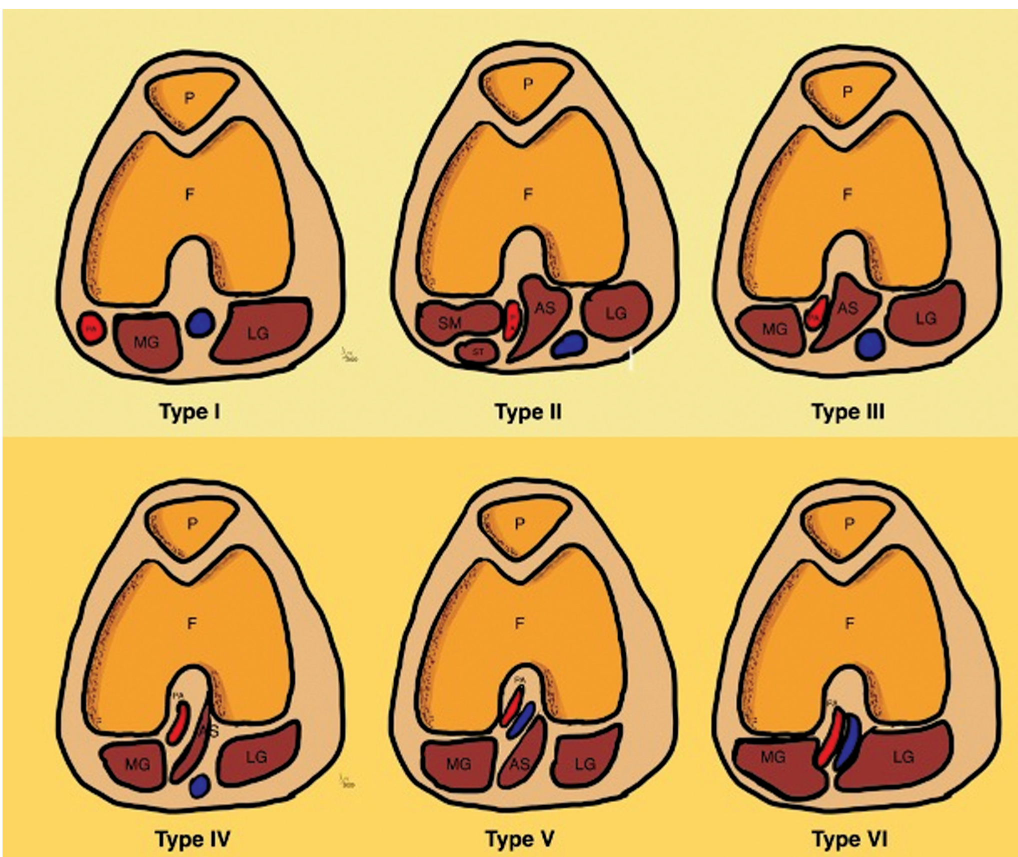

Fig. 4 Schematic representation of various types of popliteal artery entrapment syndrome (PAES): Type I—aberrant medial course of the popliteal artery. Type II—the normal course of the popliteal artery but more laterally attached medial head of gastrocnemius/functional accessory sling morphology. Type III—an accessory myotendinous slip of the medial head of the gastrocnemius. Type IV—popliteus acting as an accessory slip or fibrotic band in the popliteal fossa trapping the popliteal artery. Type V—like type IV, traps both the popliteal artery and vein. Type VI—hypertrophied gastrocnemius causing function PAES (fPAES). AS, accessory slip used describe all fibrotic band, medial gastrocnemius or popliteus depending upon the type of PAES; F, femur; LG, lateral gastrocnemius; MG, medial gastrocnemius; P, patella; PA, popliteal artery; PV, popliteal vein.

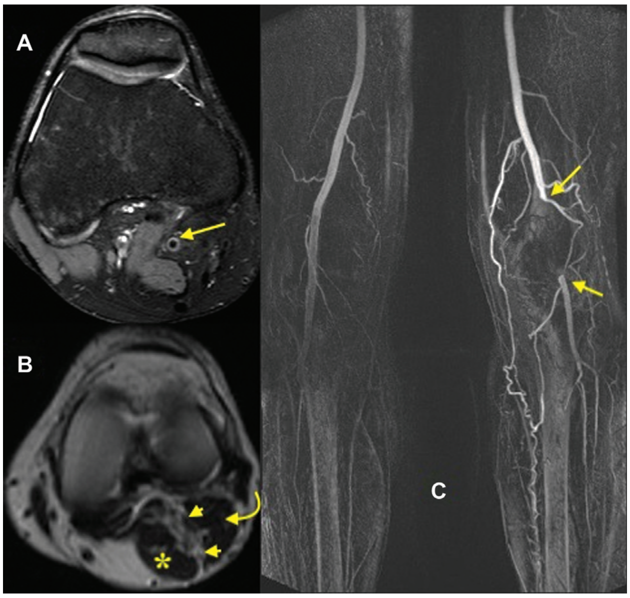

Fig. 5 Popliteal artery entrapment syndromes in two patients: T2-fat-suppressed axial image (**A**) in a patient with claudication symptoms on exertion showing an accessary muscle slip. The popliteal artery (straight arrow) lies between the accessory muscle slip and the native muscle, consistent with Type III popliteal artery entrapment syndrome. In a different patient, Proton-density weighted axial image (**B**) showing a large accessory muscle slip (asterisk) encasing the popliteal artery and vein (arrowheads) with it and native muscle (curved arrow) consistent with type V. Curved multiplanar reconstruction image of the noncontrast magnetic resonance angiography (**C**) in the same patient showing long-segment popliteal artery occlusion.

embryological origin,[15] the cystic adventitial disease is characterized by multiple mucoid cyst formation in the arterial wall compressing its lumen during knee flexion resulting in symptoms of claudication in subjects with no features of premature atherosclerosis.[16]

Grayscale ultrasound may demonstrate multiple cysts along the artery's anatomical course, and Doppler ultrasound may demonstrate arterial occlusion. Conventional angiography/DSA may appear normal or uncommonly demonstrate characteristic scimitar or hourglass signs.[17] On CT, cysts appear as hypoattenuating structures in the arterial wall compressing its lumen, which show peripheral rim enhancement owing to enhancing wall and nonenhancing mucoid material.[18] On MRI, cysts appear as hyperintense structures on T2-weighted images, which return variable signals on T1-weighted images depending upon mucoid content[19] (►**Fig. 7**). Occasionally, cysts communicate with the synovial membrane of the knee joint.

Compartment Syndromes

Acute traumatic compartment syndrome is a clinical diagnosis aided by intracompartmental pressure measurement. Rarely, cross-sectional imaging, MRI in particular, can be performed in equivocal cases demonstrating edema, hematoma, vascular injury, and soft tissue inflammation (►**Fig. 8**) or any other precipitating secondary cause increasing the volume of an affected muscular compartment. However,

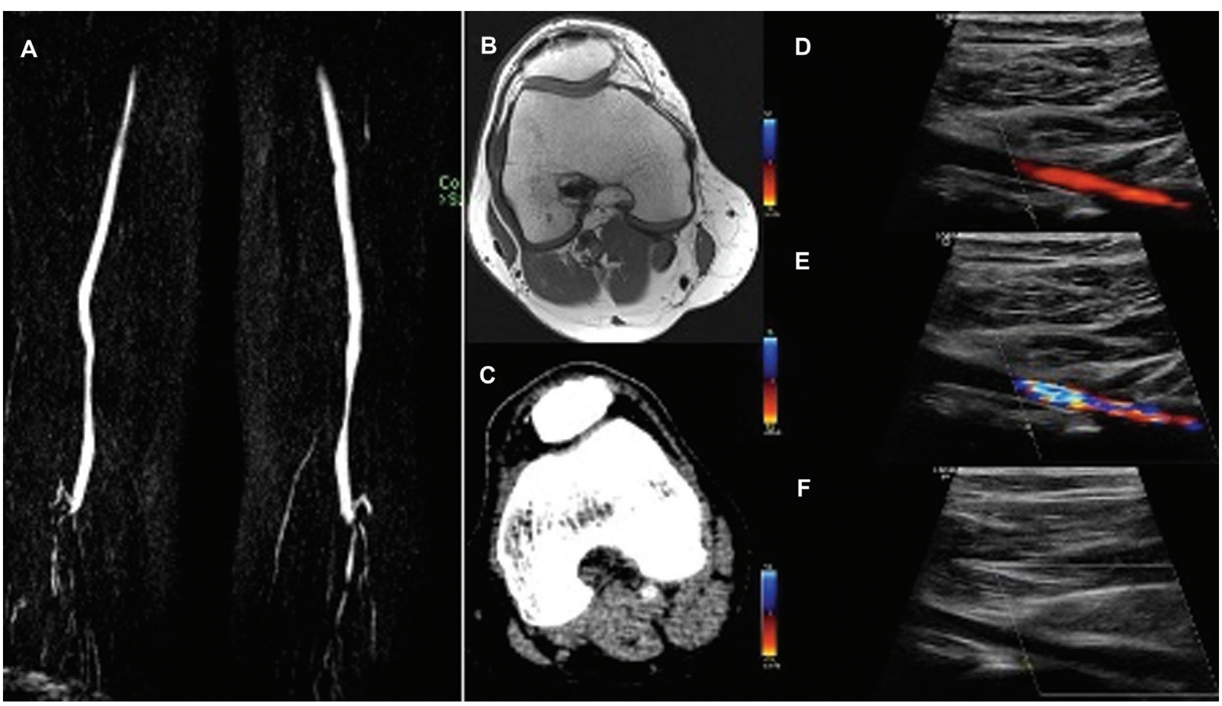

Fig. 6 Functional popliteal artery entrapment syndrome (fPAES, type VI): The patient was referred to the hospital with an ultrasound diagnosis of bilateral PAES. However, the patient was symptomatic on the left side only. Noncontrast magnetic resonance angiography curved maximum-intensity projection image (**A**) showing patent popliteal arteries at respective popliteal fossa floors. T1-weighted axial image (**B**) and axial computed tomography angiogram (**C**) showing no occlusion or aberrant muscle compressing onto the popliteal artery. The conundrum was solved by the use of dynamic ultrasound reproducing exertion. Long-axis color Doppler image of the popliteal artery approximately 4 cm proximal to the anterior tibial artery in resting position (**D**) showing no occlusion, during plantar flexion (**E**) showing mild flow resistance evident by flow turbulence and mild reduction in arterial diameter. There was a complete lack of popliteal artery flow during resisted forced plantar flexion (**F**) consistent with functional PAES.

Table 2 Sample contrast-enhanced MRA protocol for suspected popliteal artery entrapment syndrome

Coil: Knee and body array, 1.5-T scanner	
Patient position: Feet first, supine	
Sequences	**Slice position**
Localizers *MSK protocol—individual knees (use knee coil)* T1 axial (high resolution) PD coronal 3 mm PD sagittal 3 mm *Relocalize both knees together (use body array)* (MRA sequences) The mask in each FT post-contrast sequence serves as a pre-contrast sequence for the particular position. Contrast in two separate boluses. Injection rate: 1.5 ml/second Use Gadovist in one line with a saline chaser. 1st bolus: "Ankles in plantar flexion" (please put block so the patient can push against) 2nd bolus "Ankles in dorsiflexion" Inject half of the Gadovist for the first run and half for the second. Inject with a 15-second delay.	Position same as MSK knee joint Craniocaudal coverage: insertion of Quadriceps tendon to the tibial tuberosity Anteroposterior coverage: mid-patella to back of vessels up to skin *Coverage and monitoring*: Mid-thigh to mid-calf

Abbreviations: FT, fluorotrigger; MRA, magnetic resonance angiography; MSK, musculoskeletal; PD, proton density.

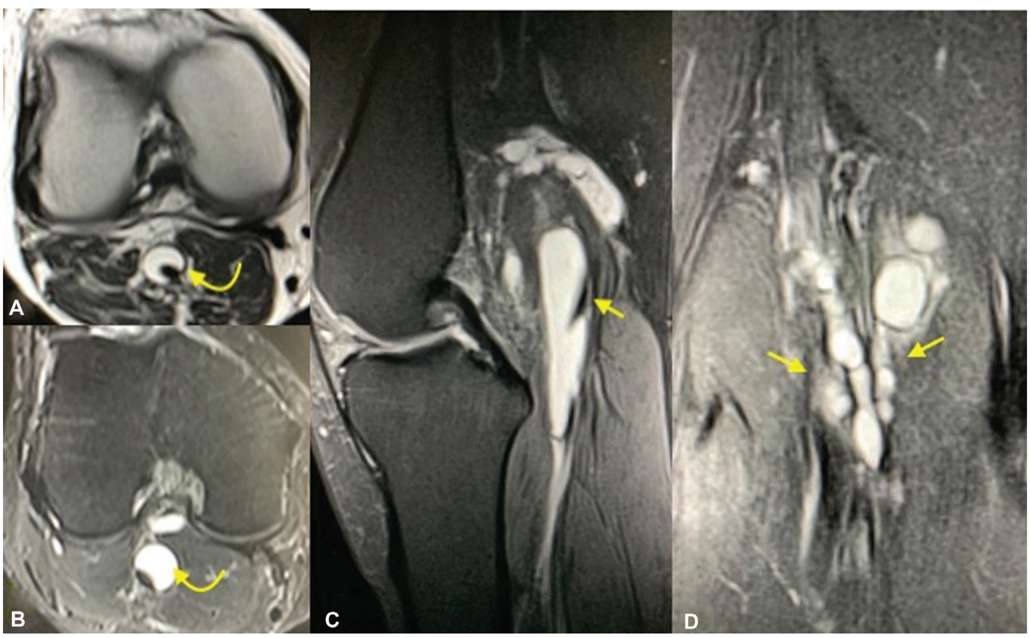

Fig. 7 Cystic adventitial disease of the popliteal artery: T1-weighted axial (**A**), T2-fat-suppressed (T2FS) axial (**B**), sagittal (**C**), and coronal (**D**) images showing multiloculated cysts arising from popliteal artery wall (straight arrows). They appear hyperintense on T1-weighted and T2FS images (curved arrows), suggesting high mucoid content.

such imaging appearances are nonspecific for compartment syndrome when not correlated with the clinical history.[20] Fasciotomy is the mainstay of treatment.

Chronic exertional compartment syndrome is one of the common causes of lower extremity pain in athletes, characterized by exercise-induced increase in compartment pressures. Intracompartmental pressure measurement and clinical examination findings are diagnostic, as described in ►**Table 1**. MRI may show compartment-specific muscle edema correlating with clinical features. Treatment is conservative, consisting of prolonging rest for 2 to 3 months followed by a gradual return of activity.

Venous Thrombosis Mimicking Popliteal Artery Thrombosis

Venous thrombosis in athletes can either be due to a traumatic event or can be effort-induced (Paget-Schroetter syndrome). Traumatic DVT most commonly occurs in the popliteal, posterior tibial, and peroneal arteries. Risk factors associated with

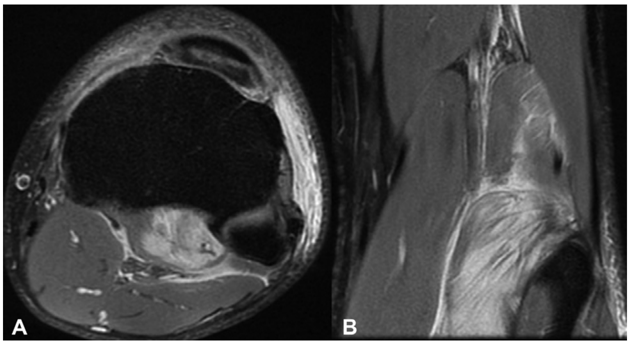

Fig. 8 Popliteus and soleus muscle injury with clinical features of the compartment syndrome: Proton-density fat-suppressed axial (**A**) and coronal (**B**) images of the knee showing edematous and injured popliteus and medial soleus muscles. The muscles are bulky with profound fascial edema. The patient was monitored for intracompartmental pressure due to symptoms and the close nature of the injury. It showed developing compartment syndrome.

increased chances of DVT in nontraumatic settings include immobilization, coagulopathy, intense exercise, dehydration causing hemoconcentration and polycythemia, and anabolic steroid abuse. Doppler ultrasound remains the preferred investigation for detecting DVT, although conventional angiogram and CT venogram can be used for troubleshooting.[21]

Conclusion

Popliteal artery related-complications are a common occurrence in athletes hampering their professional abilities. They mimic various musculoskeletal ailments and may be challenging diagnoses to the musculoskeletal radiologist as one has to think outside the box for a vascular diagnosis. However, detailed knowledge of normal and variant anatomy and sport-induced physiological changes in lower limb muscles and vessels enables reporting musculoskeletal radiologists to diagnose them early, potentially improving or saving the athlete's career.

Funding
None.

Conflict of Interest
None declared.

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