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# Phlebolymphology



### Aims and Scope

***Phlebolymphology*** **is an international scientific journal entirely devoted to venous and lymphatic diseases.**

**The aim of *Phlebolymphology* is to provide doctors with updated information on phlebology and lymphology written by well-known international specialists.**

***Phlebolymphology*** **is scientifically supported by a prestigious editorial board.**

***Phlebolymphology*** **has been published four times per year since 1994, and, thanks to its high scientific level, is included in several databases.**

***Phlebolymphology*** **comprises an editorial, articles on phlebology and lymphology, reviews, and news.**


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# Content

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# Editorial

**Dear Readers,**

The current issue of *Phlebolymphology* is dedicated to "venous compression syndromes." These syndromes are not very common and may remain underdiagnosed. Besides their rarity, they may cause symptoms and sometimes debilitating complications such as deep vein thrombosis and postthrombotic syndrome. Thus, this issue aims to shed some light on these syndromes and to raise awareness, as well as to provide guidance for their diagnosis and management.

**D. BACCELLIERI** ***(Italy)***, **F. B. A. VALENTE** ***(Italy)***, **V. ARDITA** ***(Italy)***, and **M. DUMANTEPE** ***(Turkey)*** elaborate on the iliac vein compression syndrome known as May-Thurner or Cockett syndrome. They describe the currently available diagnostic imaging techniques as well as minimally invasive procedures for treatment.

**A. S. GAWEESH** ***(Egypt)*** and **M. A. ELSABBAGH** ***(Egypt, United Kingdom)***, present the pathophysiology, diagnosis, and management of thoracic outlet syndrome with venous involvement. This syndrome may also cause upper-limb vein thrombosis and postthrombotic syndrome that may affect the quality of life in young individuals. Early diagnosis and treatment remain the key points.

**M. DUMANTEPE** ***(Turkey)***, **C. ÖZTÜRK** ***(Turkey)***, **V. ARDITA** ***(Italy)***, **F. B. A. VALENTE** ***(Italy)***, **D. BACCELLIERI** ***(Italy)***, and **A. RODRIGUEZ MORATA** ***(Spain)*** provide a comprehensive review of the diagnosis and treatment of "nutcracker syndrome," which despite its rarity may be the cause of significant pathology. They present the alarming symptomatology along with the diagnostic process to confirm the presence of this syndrome and also describe potential therapeutic interventions.

**I. DROC** ***(Romania)***, **R. DANTIS** ***(Romania)***, and **R. MILLERET** ***(France)*** describe "popliteal vein entrapment," which is relatively rare and, in several cases, may exist in association with popliteal artery entrapment syndrome. It requires careful evaluation of the symptoms and appropriate selection of the diagnostic tools to confirm not only the diagnosis but also the causes, an important issue for decision-making about the appropriate treatment.

I am confident that everyone will find in this issue important information regarding the "venous compression syndromes" and an update on their diagnosis and management.

Enjoy reading!

*Co-Editor*

**Dr Athanasios Giannoukas**

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# A comprehensive review of the history, pathophysiology, diagnosis, and treatment of iliac vein entrapment syndrome, also known as May-Thurner syndrome

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## ABSTRACT

May-Thurner syndrome (MTS), also known as iliac vein entrapment syndrome, is caused by extrinsic compression of the left common iliac vein—most often by the right common iliac artery—leading to venostasis and potential development of deep vein thrombosis (DVT). Though historically underdiagnosed, its recognition has increased with the routine use of cross-sectional imaging and intravascular ultrasound (IVUS), which now serves as the gold standard for diagnosis and procedural guidance.

MTS primarily affects young women and often presents with unilateral leg swelling, recurrent DVT, or chronic pelvic symptoms. Diagnosis relies on duplex ultrasound, computed tomography or magnetic resonance venography, venography, and IVUS, which can detect subtle intraluminal abnormalities and guide precise stent placement. Endovascular treatment with dedicated venous stents has largely replaced open surgical options due to superior safety, efficacy, and durability.

Proper stent selection and IVUS-guided sizing are essential to avoid complications such as restenosis or migration. Postprocedural management includes anticoagulation and patient-specific follow-up. Ongoing research focuses on novel stent technologies, AI-enhanced imaging, and long-term outcome data from registries like the European Venous Registry. Early identification and intervention improve long-term outcomes and quality of life, underscoring the importance of clinical awareness and multidisciplinary care.

**Keywords**

chronic pelvic pain | deep vein thrombosis | iliac vein compression | IVUS | May-Thurner syndrome | obstructive venous disease | postthrombotic syndrome | quality of life | venography | venous stenting

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# Introduction

Extrinsic compression of the left common iliac vein (LCIV) by the arterial system against bony structures in the iliocaval area is commonly known as May-Thurner syndrome (MTS) or Cockett syndrome. Commonly, the LCIV is compressed between the spine and the right common iliac artery (RCIA). This condition may represent a cause of obstructive venous disease due to venostasis in the proximal venous system and unfortunately is rarely considered and diagnosed. Obstructed outflow evolving from this syndrome may progress to severe venous disorders involving the leg or pelvis or in worse cases may increase the risk of deep vein thrombosis (DVT). With increasing use of cross-sectional imaging and heightened awareness among vascular specialists, this syndrome is being diagnosed more frequently today, particularly in patients with unexplained lower-limb swelling or recurrent thrombosis.[1-2]

# History of iliac vein entrapment syndrome

The origins of this syndrome trace back to 1851, when Rudolf Virchow hypothesized that increased incidence of left-sided venous thrombosis in left lower extremities was the result of the RCIA compression by the LCIV. The latter finding was later supported by McMurrich reporting 32% of intravascular obstruction or adhesion in the LCIV in an unselected population of 107 cadavers, concluding for a congenital disease. Some years after, other authors reported the same incidence in 399 cadavers but in relationship to ''elastine and collagene'' findings inside the diseased vein, concluding for acquired diseases due to extrinsic compression over time.[3]

In 1957, May and Thurner reported a fibrous intraluminal band or ''spur'' in 22% of 430 cadavers on the LCIV, postulating this was acquired from chronic and pulsatile compression causing local trauma, inflammation, and endothelial proliferation.[4] Following this finding, Cockett in 1965 began to study the clinical implications in living patients with DVT and iliac vein compression through the use of venography, reporting typical symptoms such as swelling and pain associated with edema, hyperpigmentation, induration, and ulceration. DVT was diagnosed in young patients (mean age, 23 years old), always in the LCIV below the arterial compression after a period of immobilization. Therefore, he also concluded that compression often can be asymptomatic due to the possibility to develop collateral circulation.[4]

# Epidemiology

The true prevalence of MTS is difficult to ascertain due to the asymptomatic nature of many cases. Imaging and autopsy studies have reported LCIV compression in up to 66% of individuals, yet only a small percentage develop symptoms. Among patients presenting with left-sided lower-extremity DVT, MTS has been identified as the underlying cause in 2% to 5% of cases. Women between the ages of 20 and 40 are disproportionately affected, especially those with risk factors such as hormonal therapy, pregnancy, or prolonged immobilization.[1-4]

# Pathophysiology

Venous compression can be permissive and asymptomatic, but 3 factors may lead to the development of symptoms; these are as follows: i) chronic inflammation and fibrotic response due to persistent extrinsic trauma may cause formation of spurs, webs, channels, and diaphragms inside the vessel; ii) external inflammation may lead to increased vessel rigidity; and iii) flow alteration secondary to lower-limb reflux and loss of volume during backflow to the heart may lead to vein collapse and gradually to thrombosis.[3]

# Types of compression

Several variations have been described; nowadays, we recognize the following groups[5-7]: i)LCIV compressed by RCIA; ii) right common iliac vein (RCIV) compressed by RCIA/left common iliac artery (LCIA)/right internal iliac artery (RIIA)/right external iliac artery (REIA); iii) left external iliac vein (LEIV) compressed by left external iliac artery (LEIA); iv) right external iliac vein compressed by REIA; v) RCIV compressed by aortic bifurcation; and vi) inferior vena cava (IVC) compressed by RCIA.

# Clinical manifestation

Patients with MTS can present extreme heterogeneity of symptoms from leg swelling with persistent edema, venous claudication, symptomatic varicose veins, and phlebitis. Most rarely, in case of primary DVT presentation, phlegmasia cerulea dolens can be the first presentation.[4]

All patients with left-sided chronic venous disorders need to be investigated for MTS, particularly patients with a history of isolated or recurrent DVT. All causes of extrinsic compression need to be excluded during differential diagnosis, such as pelvic mass, iliac artery aneurysm, bladder distension, spinal lithiasis or lumbar discopathy, lymphadenopathies, and tumors.[1,4]

Clinical stages can be classified as follows: i) stage 1, asymptomatic LCIV compression; ii) stage 2, formation of intraluminal spurs; and iii) stage 3, occurrence of left iliac DVT.

# Diagnosis

Persistent narrowing of a vein compressed with stenosis of more than 50% is adequate for suspicion of MTS; other indicators include venous collaterals, identified intraluminal changes, diameters of proximal vessels, and flow patterns.[5,6]

Imaging modalities include: i) nonivasive venous imaging—such as duplex ultrasound (DUS), plethysmography, and computed tomography venography (CTV)/magnetic resonance venography (MRV); and ii) invasive venous imaging—such as venography and intravascular ultrasound (IVUS). Before being subjected to any diagnostic imaging modality, it is important that patients are well hydrated to avoid false positive results.

## Duplex ultrasound

DUS is currently the initial modality of diagnosis of all venous disorders; it's a full noninvasive, repeatable examination of the whole venous system. Although it provides high resolution and sensitivity and specificity, the abdominal ultrasound scan may present some limitations for use with compressive syndromes. The deep location of veins and standard prone position of patients can be a limitation for correct evaluation and may lead to overdiagnosis of compression.

To solve this limitation, this examination needs to be performed in supine and semi-sitting positions.

After DUS in the standing position, focused on reflux, the patient is invited to lay in the supine position, and the femoral vein evaluation is performed using a 4–7 MHz linear array transducer. In nonocclusive disease such as MTS, the flow patterns can be absolutely normal with regular phasicity of the common femoral vein, but other cases can reveal reduced phasicity of flow, reduction in amplitude, and limited response to compressive maneuvers or Valsalva maneuvers. Iliac and caval vessels need to be investigated with a 2-3–MHz probe in B mode to directly evaluate diameters and morphologic compression. Peak vein velocity (PVV) is measured in the poststenotic segment and compared with the prestenotic segment often dilated. If the PVV ratio is more than 2.5, the finding is significant. Reflux in the ipsilateral internal iliac vein is associated with proximal compression due to compensatory reversal flow.[8,9]

## Plethysmography

Air plethysmography measures the global change in volume in mL/s of the part of the calf enclosed by the cuff in response to gravitational filling on dependency (venous filling index) and drainage on leg elevation (venous drainage index). It is a volumetric tool used several years ago as a method to evaluate venous refluxes and proximal obstructions. Rapid filling and low elevation drainage are indicative of global venous incompetence and obstruction, respectively. This technique can be used to assess severity of venous symptoms, particularly in severe reflux, but is not currently recognized as a diagnostic tool for MTS.[10]

## Computed tomography/magnetic resonance venography

CTV and MRV are second-level diagnostic tools in case of suspected MTS and offer complete examination of the venous system that can also be enhanced by 3D reconstruction. CTV has some disadvantages related to radiation exposure and iodinated contrast, but it's well recognized that it provides high-quality studies and a complete evaluation of the venous anatomy. MRV is the most versatile imaging, with dynamic sequences that can provide information regarding velocity and volume while providing high-quality morphologic images of the compressed vein such as with fibrotic scarring, postthrombotic fibrosis, as well as collaterals and varicose veins (*Figure 1*).[11,12]

## Venography

Historically the gold standard for diagnosis of venous diseases, venography has recently become a useful procedure combined with IVUS and possibly with simultaneous endovascular procedures. Imaging in two or three projections is mandatory before advancing catheters or endovascular devices after any guidewire advancement in occlusive disease. Regarding MTS, venography can provide information about patency of vessels, anatomical variations, and associated reflux. It's often possible to observe the classical arterial ''shadow'' associated with the ''pancake effect'' typically present in the antero-posterior view and secondary to vein enlargement below the compression. Furthermore, venography can show hypertrophic collateral circulation, internal iliac vein branches, and ascending lumbar vein.[11,13]

## Intravascular ultrasound

IVUS has become the cornerstone imaging modality for the diagnosis and endovascular management of iliac vein compression syndromes. Offering real-time, 360-degree, high-resolution cross-sectional views from within the venous lumen, IVUS provides superior anatomical detail compared with traditional venography or static cross-sectional imaging modalities like CTV or MRV.

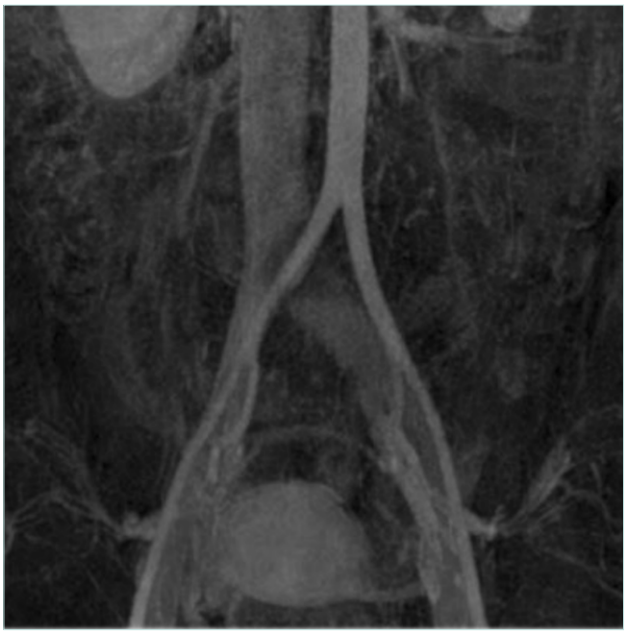

*Figure 1.* Magnetic resonance venography showing compression at May-Thurner's point.

IVUS excels in detecting subtle intraluminal abnormalities such as fibrotic spurs, endoluminal webs, and residual thrombus that may not be apparent on other imaging. Its diagnostic accuracy exceeds 95% in experienced hands and is especially useful for evaluating dynamic changes in vein caliber that may occur with respiration or body position.[14,15]

During interventions, IVUS allows precise assessment of the compressive lesion, measurement of luminal diameters, and identification of healthy vein segments both proximal

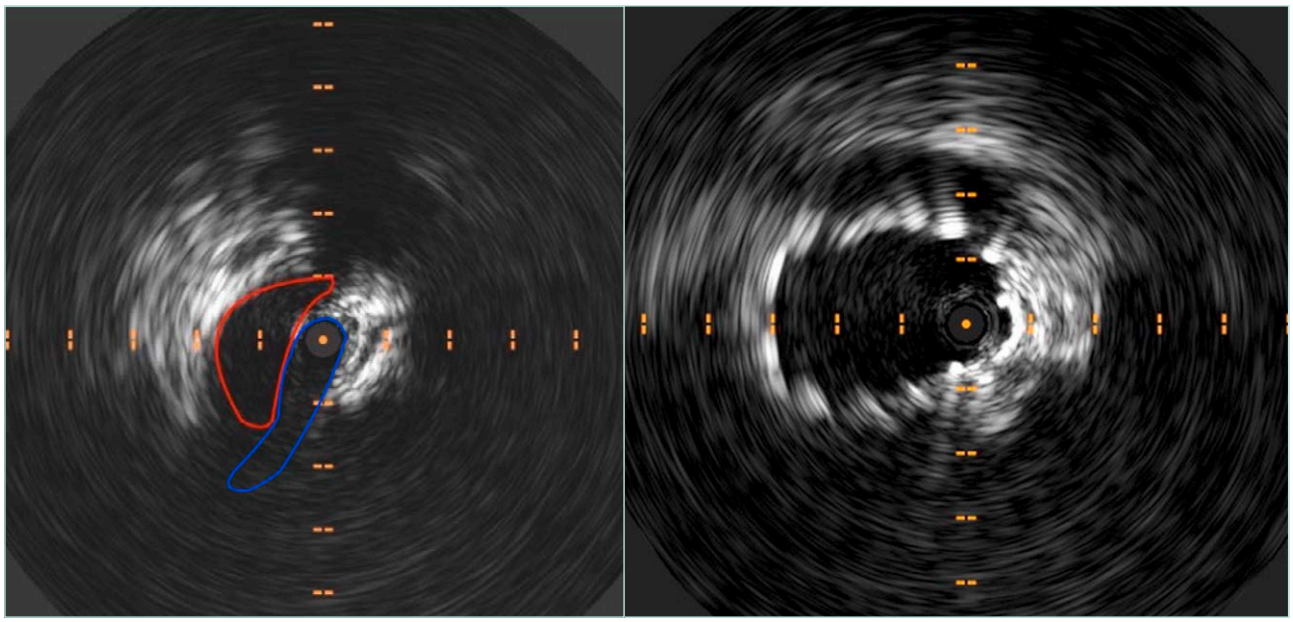

*Figure 2.* Intravascular ultrasound (IVUS) showing preoperative compression at May-Thurner's point and subsequent restored patency post stenting.

and distal to the lesion—critical for determining optimal stent length and placement. This helps avoid common complications such as undersizing, which may result in stent migration or restenosis, and oversizing, which can lead to excessive radial force, vessel wall damage, and uncontrollable back pain. After stent deployment, IVUS is used again to verify that the stent is fully expanded, well-apposed to the vein wall, and that no residual stenosis or mechanical obstruction remains. Its integration into standard practice has been shown to significantly improve patency rates and reduce the risk of reintervention.[14-16] *(Figure 2)*.

# Treatment

Treatment of asymptomatic patients, even with high-grade stenosis or occlusion, is not supported by any evidence that suggests this reduces the risk of subsequent DVT.

In case of C3-C6 CEAP (clinical-etiological-anatomical-pathophysiological) classification, interventions need to be considered. Furthermore, venous claudication (heaviness and pain during exercise) with severe swelling and persistent edema is a possible indication in young patients if associated with a debilitating quality of life.[17]

## Open surgery

Prior to the advent of endovascular techniques, management of symptomatic iliac vein compression relied on open surgical interventions, which were often technically challenging and associated with substantial morbidity. These procedures included venous bypass grafting, transposition of the iliac vein, venolysis (surgical release of the compressed vein), and patch angioplasty. In bypass procedures, the obstructed segment of the vein was circumvented using autologous vein grafts or synthetic conduits, aiming to restore venous outflow. Transposition, on the other hand, attempted to physically relocate the compressed vein segment to a position less prone to arterial impingement.[18,19]

Despite their theoretical effectiveness, open surgical approaches were limited by the deep pelvic location of the iliac vessels, which complicated access and increased the risk of injury to adjacent structures such as the ureter, bowel, and arteries. Postoperative recovery was lengthy, and the potential for thrombosis or graft failure remained significant. Moreover, because many cases of iliac vein compression were not diagnosed until after thrombosis had occurred, surgery often addressed chronic sequelae rather than providing prophylactic benefit.[20]

In select cases, such as when endovascular options are unavailable, contraindicated, or have failed, open surgery may still be considered. However, it is now largely reserved for exceptional circumstances due to the superior safety, efficacy, and durability of modern endovascular solutions. One of these exceptions is represented by extravascular stenting.

The evolution of IVUS and dedicated venous stents has made minimally invasive management the preferred first-line approach in most vascular centers.[17]

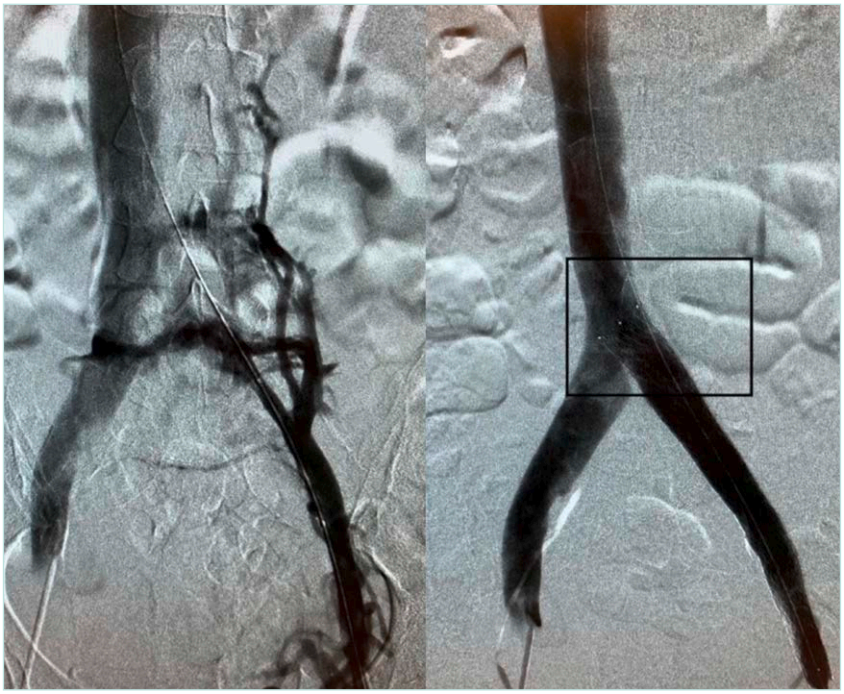

*Figure 3.* Venography showing pre (left panel) and post (right panel) recanalization of a May-Thurner syndrome patient with a long stent anchored to the origin of the common iliac vein.

### Endovascular treatment

An endovascular approach is focused on restoring patency of compressed/occluded vessels by endoluminal stent implantation. The goal of stenting MTS is to solve compression, achieving correct venous return. Multiple devices are available on the market with different features. An optimal venous stent must possess a well-balanced combination of mechanical strength, conformability, and precise deployment characteristics to address the complex anatomical and pathophysiological features of venous disease. Among the critical determinants of stent performance are radial resistive force, chronic outward force, crash resistance, and flexibility—all of which vary according to stent design.[21-23]

Radial resistive force, the ability of a stent to withstand radial compression, is typically higher in closed-cell configurations than in open-cell designs. This is due to the smaller free-cell area within the stent mesh, which enhances structural integrity and helps maintain luminal patency in the face of compressive forces. Chronic outward force, the centrifugal pressure exerted by the stent after deployment, is another essential property. This force increases as stent diameter decreases, underscoring the importance of selecting an appropriately sized stent. Significant oversizing should be avoided, as a minimally oversized stent delivers optimal circumferential stress to the venous wall, promoting endothelial integration while reducing the risk of restenosis.[24]

Crash resistance, defined as the stent's capacity to ensure unidirectional external compression—particularly from overlying arterial structures or musculoskeletal motion—is a pivotal factor in long-term patency. Stents with larger nominal diameters typically exhibit superior crash resistance, retaining shape and function even under substantial mechanical load *(Figure 3)*.[24]

Equally important is the stent's flexibility. In contrast to arterial stents, venous stents must navigate the more variable and dynamic architecture of the pelvic venous system. High flexibility allows the device to adapt to the curvatures and shifts in vessel geometry without kinking or altering its cross-sectional shape. This requirement further emphasizes the need to avoid overlapping multiple stent segments, which can lead to increased rigidity and compromise physiological motion.[24]

Taken together, these mechanical properties define the ideal stent profile for treating venous obstructions, where both durability and adaptability are essential for long-term clinical success.

According to common practice, venous stents need to be positioned using IVUS guidance based on the size of the LEIV anchoring point rather than the LCIV, as the latter may be dilated due to the compression, resulting in an increased risk of contralateral iliac DVT.[14,15]

Referral centers have different stent configurations available, so the physician can decide which stent is appropriate for implantation according to the IVC confluence anatomy. Several trials are ongoing with satisfactory results for MTS treatment and long-term results with secondary patency near 100%.[25,26]

One of the most crucial and debated issues is stent migration; this event may occur upon choosing a shorter or smaller stent. Undersizing a venous stent, particularly within the iliac vein, poses a greater clinical risk than modest oversizing. Inadequate stent diameter can lead to a fixed iatrogenic stenosis, a complication that is often difficult to reverse once established. This issue frequently arises from the incorrect assumption—borrowed from arterial stenting practice—that restoring flow and achieving patency are sufficient therapeutic end points. However, in the venous system, these goals must be accompanied by restoration of full luminal caliber. Ensuring an adequately sized stent is crucial for effective decompression and sustained relief of venous hypertension. IVUS guidance leads to the right choice of sizing and length and allows correct identification of landing zones in the external iliac vein and in the IVC confluence.[25,26]

After treatment, immediate anticoagulation with low-molecular-weight heparin is started and intermittent pneumatic compression is administered for the first 12 hours, then active mobilization is allowed. There is no evidence on postprocedural drug treatment, according to the Delphi Consensus proposed by The Imperial College of London. Direct anticoagulants seem to be the treatment of choice for MTS patients after implantation, at least for 1 month, which can be extended to 6 months; in case of previous DVT, treatment needs to be personalized according to hematological indications.[17]

## Preventive strategies and screening

Although there are no formal screening guidelines for MTS in the general population, clinicians should consider proactive assessment in high-risk individuals. This includes young women with unprovoked left-sided DVT, recurrent thrombosis, or severe chronic pelvic symptoms. An early diagnosis can prevent long-term complications such as postthrombotic syndrome or venous ulcers, which significantly affect quality of life.

Preventive strategies include prompt investigation of unilateral leg swelling or unexplained pelvic discomfort, routine DUS in patients with known hypercoagulable states and chronic venous symptoms, and multimodal imaging (CT angiography/MRV) in recurrent DVT without obvious provocation, incorporating MTS suspicion into the diagnostic workflow of vascular medicine.[2]

In institutional settings, development of a risk-stratified protocol or checklist for evaluating patients with idiopathic left-sided DVT can help guide early investigation for iliac vein compression. Raising awareness among primary care and emergency physicians can also reduce delays in referral to vascular specialists. Further research may eventually support formal screening criteria, especially as noninvasive imaging becomes more accessible and affordable.

## Research and future directions

Ongoing research in MTS is focused on improving diagnostic precision, treatment durability, and understanding the natural history of asymptomatic compression. Advanced imaging technologies—including dynamic MRV and IVUS with AI-assisted interpretation—are under investigation for their potential to detect subclinical disease and guide more individualized treatment decisions. Novel stent materials and designs, such as bioresorbable or drug-eluting venous stents, are also being evaluated to reduce restenosis and improve long-term patency.[27]

In parallel, there is growing interest in identifying biomarkers of venous injury and inflammation that could predict symptom progression or stent response. Randomized controlled trials are increasingly being designed to compare outcomes between different stent types, anticoagulation protocols, and follow-up strategies, such as in the European Venous Registry. Furthermore, development of comprehensive registries, and long-term follow-up cohorts is essential to better understand the impact of MTS treatment on quality of life, recurrence rates, and cost-effectiveness.

Ultimately, the integration of precision imaging, personalized medicine, and advanced device engineering may pave the way for earlier detection, safer interventions, and more durable outcomes in patients with iliac vein compression syndromes.

## Conclusions

Iliac vein entrapment syndrome, though historically underdiagnosed, is increasingly recognized as a significant contributor to venous pathology in young patients, particularly women. The spectrum of its clinical presentation—ranging from asymptomatic compression to debilitating venous insufficiency—underscores the importance of clinical vigilance. Advancements in diagnostic imaging, particularly IVUS, have made early detection more feasible, and the evolution of endovascular techniques has provided a reliable, minimally invasive solution for symptomatic cases.

Timely intervention can prevent severe complications, including DVT and postthrombotic syndrome, thereby improving quality of life and reducing the burden on health care systems. Clinicians should maintain a high index of suspicion in patients with unilateral leg swelling, unexplained DVT, or pelvic venous symptoms, and ensure appropriate imaging is pursued. A multidisciplinary approach involving vascular surgeons, interventional radiologists, hematologists, and primary care providers is key to successful management.

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# Venous thoracic outlet syndrome: a comprehensive clinical and therapeutic review

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## ABSTRACT

Venous thoracic outlet syndrome (VTOS) is a vascular disorder caused by extrinsic compression of the axillary-subclavian vein, leading to impaired venous drainage of the upper extremity. Compression most commonly occurs at the costoclavicular junction (CCJ) and, less frequently, at the pectoralis minor space, either independently or as part of a combined "double crush" mechanism. This venous compression may be initially asymptomatic, discovered only incidentally in high-risk populations, but it can evolve into symptomatic disease—manifesting as intermittent swelling and venous congestion, or progressing to acute thrombosis with significant morbidity. VTOS is clinically categorized into 4 subtypes: asymptomatic compression, nonthrombotic VTOS (McCleery syndrome), thrombotic VTOS (Paget-Schroetter syndrome), and postthrombotic VTOS. The diagnostic process requires a high index of suspicion and dynamic imaging under provocative conditions. Advances in duplex ultrasound, magnetic resonance venography, and intravascular ultrasound (IVUS) have improved the detection and characterization of both positional and chronic venous obstruction. Contemporary management emphasizes early thrombus removal, timely surgical decompression, and venous reconstruction in selected cases. Prompt diagnosis and intervention are critical to prevent progression to postthrombotic syndrome and irreversible functional impairment. This review offers a comprehensive overview of VTOS, including its pathophysiology, classifications, diagnostic pathways, and management algorithms, supported by current literature.

**Keywords**

catheter-directed thrombolysis · dynamic duplex ultrasound · first rib resection · McCleery syndrome · Paget-Schroetter syndrome · subclavian vein compression · venous revascularization · venous thoracic outlet syndrome

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# Introduction

Thoracic outlet syndrome (TOS) refers to a group of disorders caused by compression of neurovascular structures as they pass through the thoracic outlet—the anatomical space bounded by the first rib, clavicle, and scalene muscles. Among the subtypes—neurogenic, arterial, and venous—venous thoracic outlet syndrome (VTOS) is the second most common, less frequent than neurogenic TOS but more prevalent than arterial TOS. VTOS, comprising approximately 3% to 5% of all TOS cases, represents a complex vascular condition with potential for serious morbidity if not managed promptly and comprehensively.[1]

VTOS most frequently affects young, otherwise healthy individuals—typically athletes or those engaged in repetitive overhead arm activity. When thrombosis occurs, it is often sudden and can be dramatically symptomatic, characterized by upper-limb swelling, cyanosis, pain, and venous distention.[2]

The underlying pathophysiology stems from repeated extrinsic compression of the axillary-subclavian vein, leading to endothelial trauma, inflammation, and, in some cases, spontaneous thrombosis. If inadequately treated, VTOS may result in chronic venous hypertension, postthrombotic syndrome (PTS), and significant long-term functional impairment, especially in young patients whose livelihoods depend on physical performance.[3,4]

This review aims to offer a structured and evidence-based framework for understanding, diagnosing, and managing VTOS. Emphasis is placed on contemporary debates in treatment sequencing—including the roles of anticoagulation, thrombolysis, decompression, and venous revascularization—and the clinical decision-making paradigms that underpin these interventions.

# Anatomic zones of compression and pathophysiology

Venous compression in VTOS typically occurs at 2 critical anatomical junctions within the thoracic outlet: the costoclavicular junction (CCJ) and the pectoralis minor space (PMS).[5] Understanding these sites and the forces acting upon them is fundamental for accurate diagnosis and effective treatment planning.

## Costoclavicular junction (CCJ)

The costoclavicular junction is the most common site of venous obstruction in VTOS. The subclavian vein passes anterior to the anterior scalene muscle and posterior to the clavicle with its attached muscle (subclavius muscle), traversing a confined space above the first rib lateral to the costoclavicular ligament *(Figure 1)*.[6] Arm abduction and retroversion, particularly in muscular individuals or overhead athletes, significantly narrow this space. Contributing anatomical features that further narrow the space include: i) congenital anomalies such as cervical ribs, anomalous fibrous bands, and elongated transverse processes of the cervical vertebrae; ii) muscular hypertrophy, especially of the scalene or subclavius muscles; and iii) posttraumatic remodeling or callus formation from the clavicle or the rib fractures.[5]

## Pectoralis minor space (PMS)

Compression of the axillary vein can also occur underneath the pectoralis minor tendon, particularly during forward elevation and abduction of the arm. While less commonly isolated,

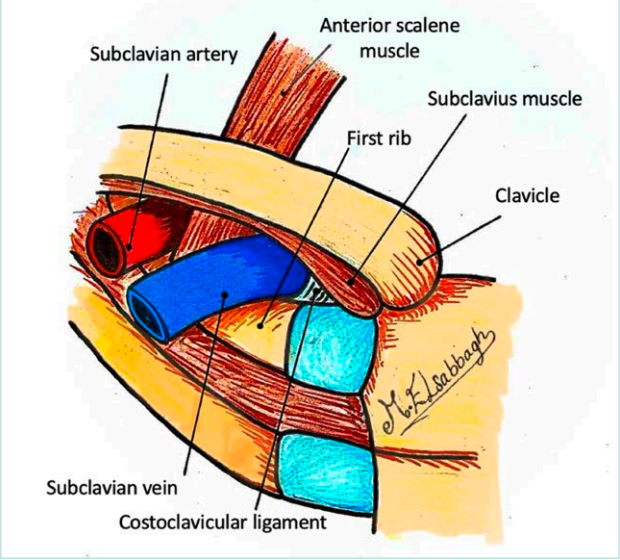


*Figure 1*. Compressing structures at the costoclavicular space.

PMS compression may coexist with CCJ compression—a phenomenon known as "venous double crush syndrome."[7] This dual pathology is increasingly recognized in overhead athletes and must be considered during surgical planning to avoid incomplete decompression.[5]

The repetitive nature of mechanical stress during overhead or hyperabduction arm movements may contribute to subtle but progressive venous damage over time that results in chronic endothelial irritation *(Figure 2)*. This microtrauma leads to mechanical endothelial injury, which initiates intimal

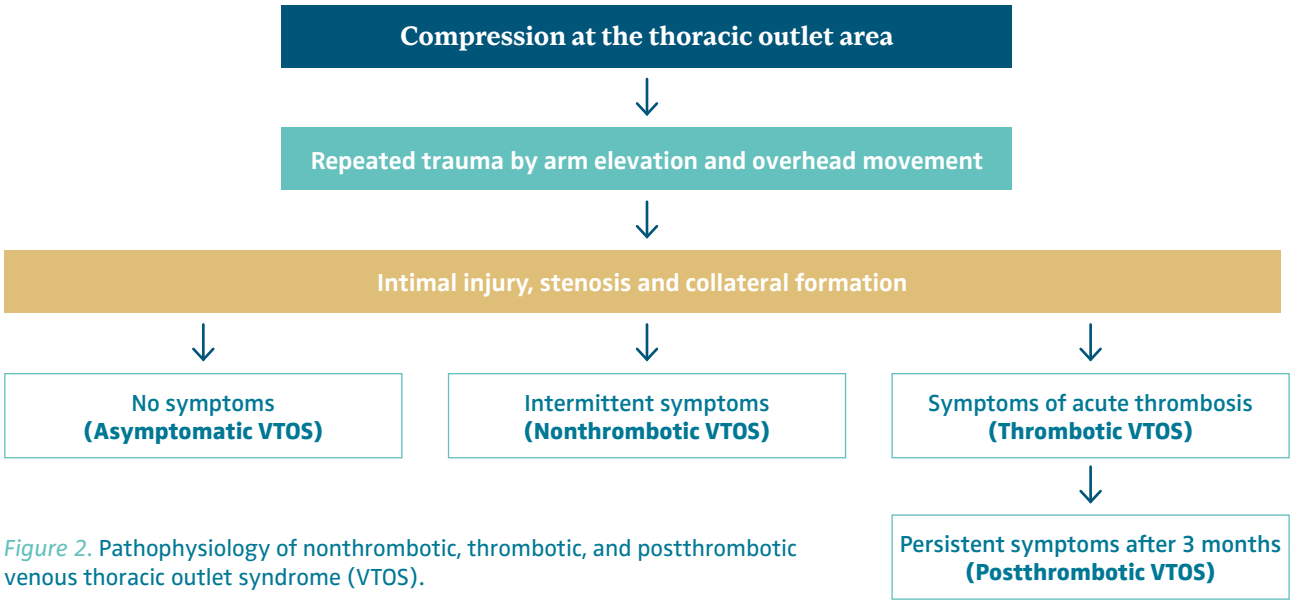


*Figure 2*. Pathophysiology of nonthrombotic, thrombotic, and postthrombotic venous thoracic outlet syndrome (VTOS).

hyperplasia, inflammatory responses, and venous scarring. If unchecked, progression to thrombosis is the expected outcome. Over time, even nonthrombotic compression can evolve into a thrombotic phenotype. Importantly, this transition may occur silently, without overt clinical warning, underscoring the need for vigilance in high-risk populations.

## Clinical spectrum and classification

VTOS presents along a clinical continuum that reflects both the degree of venous compromise and the presence or absence of thrombosis. A practical 4-tiered classification facilitates appropriate triage and management *(Figure 2)*.

## Asymptomatic VTOS

The initial phase of VTOS may be asymptomatic due to the development of collateral veins that facilitate drainage of the upper extremity.[8] This type of VTOS is usually discovered incidentally in irrelevant investigations conducted as a part of the screening of high-risk populations (eg, athletes) or discovered in relevant investigations conducted to investigate other types of symptomatic TOS, ie, patients with arterial or neurogenic symptoms. Despite that dynamic tests possibly show positional venous narrowing, this group of population does not present with symptoms or signs of VTOS. The natural history remains unclear—some remain stable, whereas others may progress to become symptomatic. The true prevalence of asymptomatic VTOS remains unknown. It is likely underdiagnosed due to the lack of symptoms and reliance on provocative imaging.

## Nonthrombotic VTOS (McCleery syndrome)

In this (nonthrombotic) subtype of VTOS, patients present with intermittent positional symptoms of swelling, heaviness, and bluish discoloration during overhead activity. These symptoms resolve with rest. The absence of objective persistent physical signs often leads to repeated medical evaluations without conclusive findings. Patients are frequently misdiagnosed with musculoskeletal or neurologic conditions. A high index of clinical suspicion is critical. The diagnosis is challenging and can often be missed without dynamic imaging using duplex ultrasound (DUS) and/or venography in both neutral and hyperabducted arm positions.

## Thrombotic VTOS (Paget-Schroetter syndrome)

Thrombotic VTOS is the most commonly diagnosed subtype of VTOS due the acute nature of its presentation related to the acute thrombosis of the axillary-subclavian vein. Typically, it occurs in young, active individuals, particularly in the dominant arm hence it is called ''effort thrombosis.'' Patients present with sudden onset of swelling, cyanosis, pain, and prominent superficial veins. Offering urgent interventions in a timely manner to restore the venous patency and prevent chronic sequelae is of paramount importance, particularly in those with severe symptoms who do not respond to medical treatment. In the absence of timely treatment, it can potentially progress to phlegmasia cerulea dolens, pulmonary embolism, or irreversible postthrombotic changes. Early thrombus removal by thrombolysis or percutaneous thrombectomy followed by surgical decompression is increasingly being advised to prevent long-term sequelae.

## Postthrombotic VTOS

Postthrombotic VTOS represents the chronic phase, more than 3 months, following an axillary-subclavian vein thrombosis episode. In addition to the preexisting extrinsic compression impeding the venous outflow, it can also be associated with venous scarring that causes luminal narrowing related to the postthrombotic changes leaving residual synechiae on the inner venous wall. Patients usually present with a clear

history of prior upper-limb deep vein thrombosis (DVT) for which they were treated with anticoagulation, or sometimes with no history of previous DVT and they present for the first time with venous insufficiency symptoms and signs (chronic limb swelling, heaviness, fatigue, bluish discoloration, prominent venous collaterals on the shoulder and the chest wall and reduced functional capacity). It should be noted that in some cases recanalization can mask the presence of significant luminal narrowing in resting position using DUS or even venography *(Figure 3)*. However, with arm hyperabduction, it becomes clearly visible *(Figure 4)*. Also doing a balloon test in these cases can help detect a masked venous stenosis *(Figure 5)*.[9]

Postthrombotic VTOS can significantly impair quality of life particularly if the dominant arm is affected; in a systematic review, the rate of PTS can be as high as 46% in patients treated with anticoagulation only.[10] Advanced imaging and multidisciplinary evaluation are essential to guide appropriate intervention.

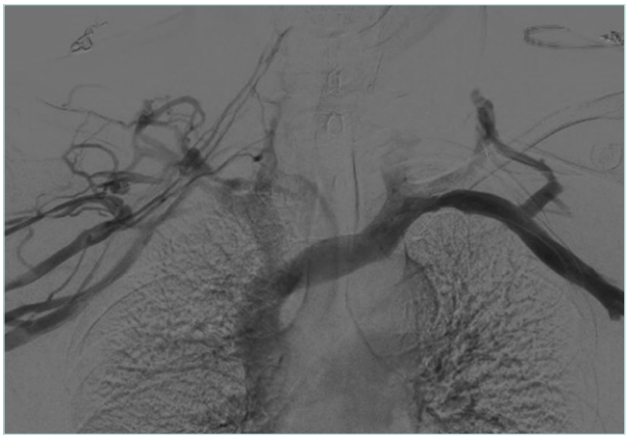

*Figure 3.* Venogram of arms in neutral position with postthrombotic syndrome (PTS) on the right side and no venographic signs of venous obstruction on the left side.

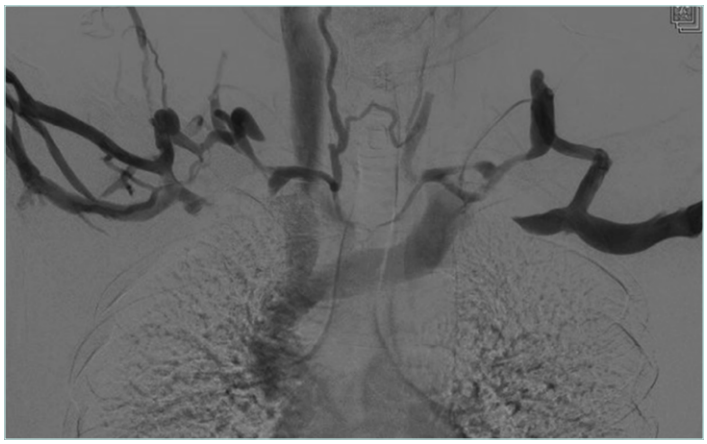

*Figure 4.* Venogram for arms in abduction position showing subclavian vein compression on both sides.

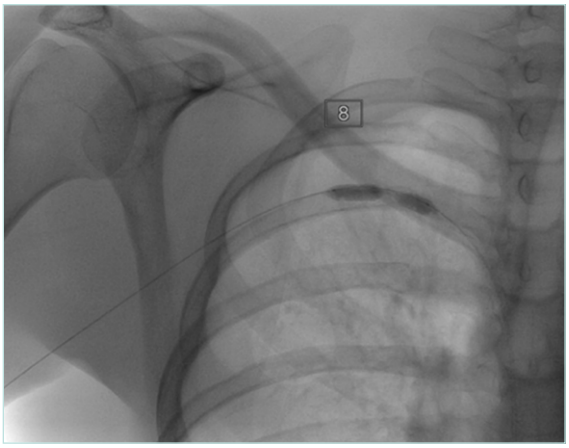

*Figure 5.* Balloon test for the right side with postthrombotic syndrome (PTS) with visible waist of the balloon denoting significant venous stenosis.

# Diagnostic approach

A successful diagnostic strategy for VTOS requires a high index of suspicion and integrating clinical evaluation with dynamic imaging. The diagnostic process must account for the episodic nature of symptoms and the need to evaluate venous function under provocative conditions. Provocative testing is crucial—static imaging may miss dynamic compression.

## Clinical evaluation

The clinical assessment begins with a detailed history that explores occupation, sports participation, prior trauma, and the timing of symptom onset. Patients with VTOS often report upper extremity swelling, heaviness, fatigue, or discoloration, which may be intermittent or persistent. Intermittent symptoms that occur during overhead activity and resolve at rest are more suggestive of nonthrombotic VTOS (McCleery syndrome). Constant or persistent symptoms raise suspicion for acute thrombosis (Paget-Schroetter syndrome) or postthrombotic sequelae. Physical examination should document visible arm swelling, cyanosis, or prominent venous collaterals over the shoulder and chest wall. Provocative maneuvers (eg, arm abduction or hyperabduction) may elicit visible venous congestion or reproduce symptoms. Palpation and percussion over the thoracic outlet may reveal tenderness or fullness due to venous engorgement.

## Imaging modalities

### *Duplex ultrasound*

DUS is a primary, noninvasive modality and the initial imaging

test of choice in suspected VTOS. A standard venous DUS may miss the diagnosis if performed only in the neutral position. Therefore, a comprehensive dynamic DUS is essential. This entails examining the axillary-subclavian vein in both neutral and provocative positions, such as with the arm abducted, elevated, or placed in military brace posture. The dynamic scan assesses for the following: i) positional compression with loss or reduction in venous waveform phasicity *(Figure 6)*; ii) retrograde flow or cessation of flow in abduction; iii) visualization of thrombus, echogenic webs, or wall thickening; and iv) presence of prominent collaterals.

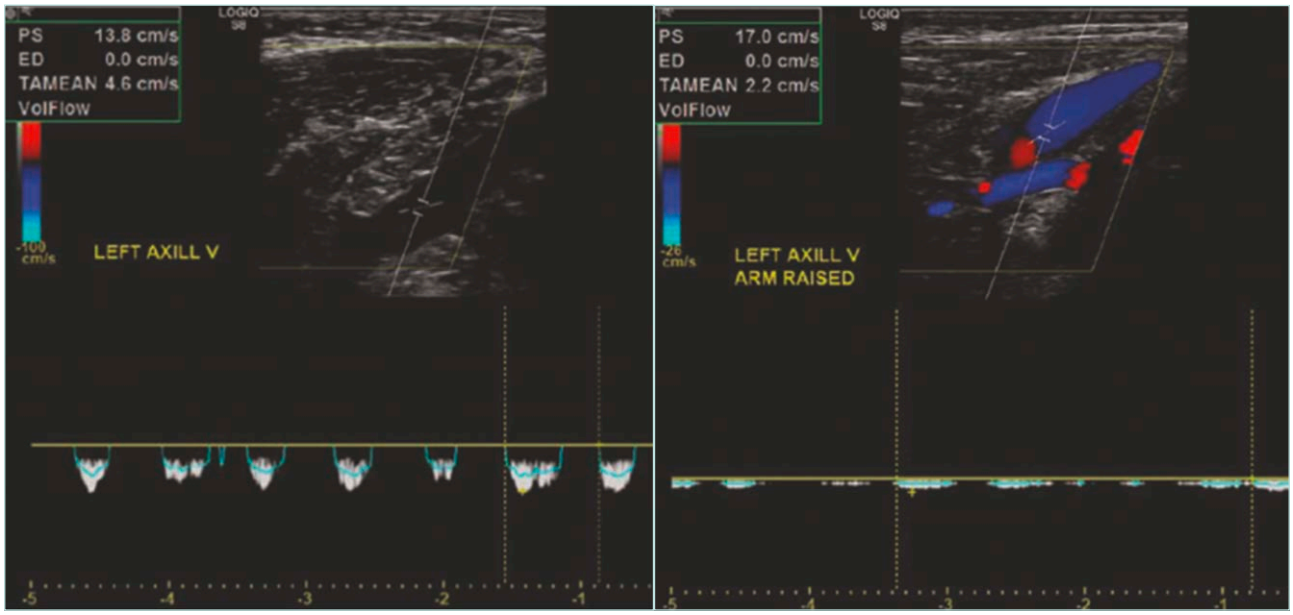


*Figure 6.* Presence of respiratory phasicity in the spectral wave of the axillary vein in the neutral position (left image) and loss of the respiratory phasicity in the abduction position (right image).

Dynamic DUS is operator-dependent and must be interpreted with care. Its sensitivity for detecting acute thrombosis is high, but its ability to assess external compression hinges on precise positioning, patient cooperation, and real-time visualization. High-resolution probes and color Doppler enhancement improve diagnostic yield.

### *Computed tomography (CT) and magnetic resonance (MR) venography*

These modalities offer a comprehensive view of the thoracic outlet and associated musculoskeletal structures. CT venography is particularly useful for identifying bony anomalies, whereas MR venography provides better soft tissue resolution. Both are vital for preoperative planning. MR venography has a sensitivity for detecting stenoses and obstructions of 100% with a specificity of 97%.[11]

### *Catheter-based venography*

Catheter-based venography is considered the gold standard for dynamic assessment. Performed with the arm in neutral

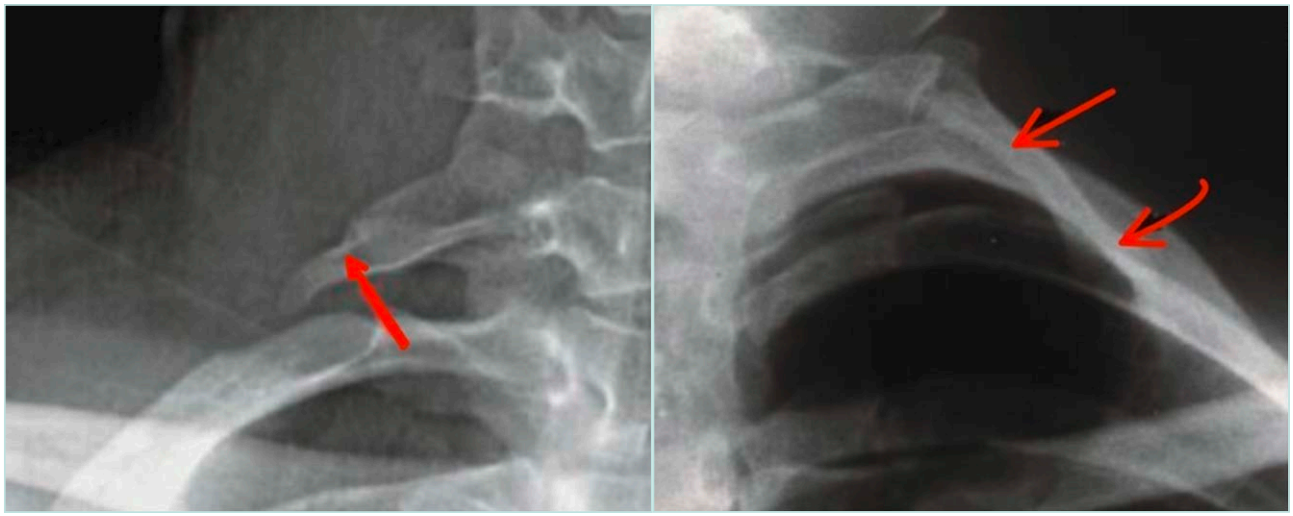

*Figure 7.* X-ray with elongated transverse process (right image) and complete cervical rib (left image).

and abducted positions, it can reveal positional stenosis, intraluminal webs, and collaterals *(Figures 3 and 4)*. However, it may underestimate intimal abnormalities or early fibrosis.

### *Intravascular ultrasound*

Intravascular ultrasound (IVUS) is increasingly used for detailed intraluminal evaluation. It detects subtle wall thickening, fibrosis, and residual thrombus better than venography.[12] IVUS also guides interventions such as patch venoplasty and stenting.

### *Plain radiography*

Plain radiography is used adjunctively to detect cervical ribs, elongated C7 transverse processes, or posttraumatic bone healing that may alter thoracic outlet anatomy. It is not definitive but is often a useful first step *(Figure 7)*.

# Management strategies

The management of VTOS must be individualized based on the patient's clinical presentation, symptoms' severity and duration, underlying anatomy, and degree of thrombotic involvement. Four interdependent pillars form the foundation of VTOS treatment, as follows: i) anticoagulation; ii) thrombus removal (thrombolytic, pharmacomechanical, or mechanical); iii) surgical decompression; and iv) venous revascularization (as needed).

## Anticoagulation

Anticoagulation[13] is the standard of care in all patients with thrombotic VTOS. It aims to prevent thrombus extension and embolization, stabilizes the acute event, and serves as a bridge to the definitive intervention. Anticoagulation needs to be initiated immediately upon diagnosis of axillary-subclavian DVT (Paget-Schroetter syndrome).

Patients offered early thrombus removal usually need to continue therapeutic anticoagulation even if the thrombus removal was successful. Prescribing prophylactic anticoagulation to protect against developing axillary-subclavian DVT also plays an important role in the nonthrombotic and postthrombotic cases after decompression surgery and revascularization. Anticoagulation is not indicated in nonthrombotic VTOS (McCleery syndrome).

Historically, low-molecular-weight heparin (LMWH) and vitamin K antagonists (VKAs) were the only approved anticoagulants for venous thrombosis. Now, there is established evidence supporting the use of direct oral anticoagulants (DOACs) as an alternative anticoagulation due to their fixed dosing and safety profile where routine monitoring is not required. Furthermore, in a recently published meta-analysis it was shown that treatment of patients with upper extremity DVT with DOACs might be associated with lower PTS rates than treatment with other anticoagulants.[14]

The principal treatment phase of Paget-Schroetter syndrome is 3 to 6 months; however, an extended phase of anticoagulation can be considered in patients with non-recanalized thrombus, venous stents, and those known with thrombophilia. The duration of the extended phase is variable and can be lifelong in confirmed thrombophilia.

## Thrombus removal: thrombolysis vs mechanical options

Early thrombus clearance is critical in acute Paget-Schroetter syndrome. Successful intervention restores venous patency, reduces inflammatory damage, and potentially reduces the risk of progression to PTS. For optimum outcome, a thrombus removal strategy needs to be offered in the first 14 days of DVT onset for patients with confirmed axillary-subclavian DVT and a threatened limb (painful, swollen, and cyanotic limb) particularly for those who show poor response to the initial anticoagulation. In a previous retrospective study, patients with the worst outcomes, when offered decompression and revascularization at a later stage, were those patients who had persistent symptoms despite anticoagulation.[9]

### *Methods of thrombus removal*

***Catheter-directed thrombolysis (CDT):*** This technique involves infusion of tissue plasminogen activator (tPA) via multi-side-hole catheter inserted within the thrombus over 12 to 24 hours. During this time, the patients require one-on-one care in a high dependency unit (HDU) or intensive treatment unit (ITU) bed *(Figures 8 and 9)*.

***Pharmacomechanical thrombectomy (PMT):*** This technique combines the local thrombolytic infusion with mechanical clot fragmentation and aspiration (eg, AngioJet catheter) using lower doses of r-tPA over shorter duration (short procedure time) to reduce the bleeding risk.

***Mechanical thrombectomy (MT):*** This technique offers pure mechanical clot retrieval without infusion of any thrombolytic material, it is particularly useful in patients with contraindication to thrombolytics, eg, allergy, recent surgery, bleeding disorder, etc.

After thrombus removal, immediate completion venography with or without IVUS is recommended to confirm the flow restoration; detect any residual webs, stenosis, or intimal hyperplasia; and to guide decisions about the need for additional decompression or revascularization procedure *(Figure 10)*.

Studies show that thrombus removal should be followed by surgical decompression for definitive treatment of VTOS.

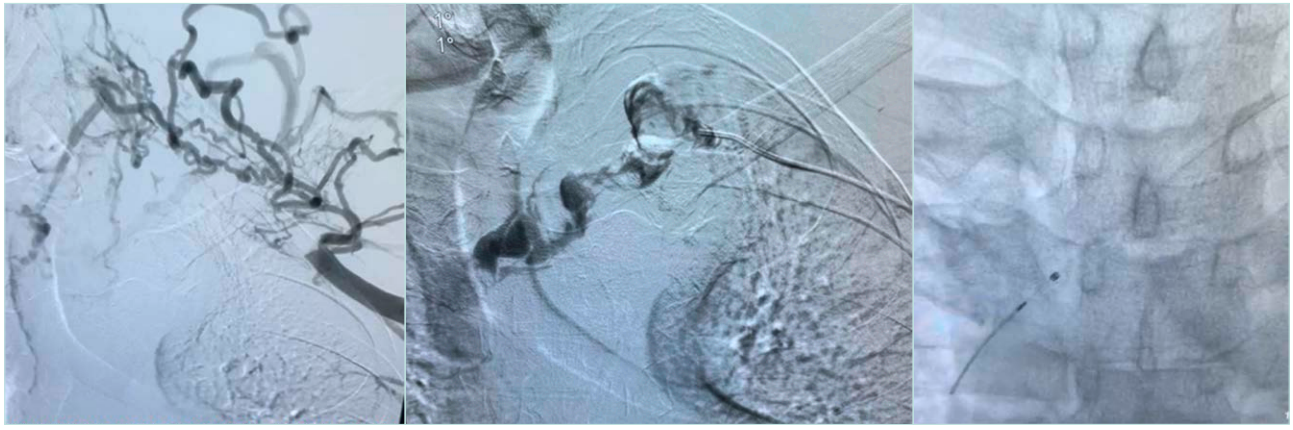

*Figure 8.* Initial venogram shows thrombosed axillary-subclavian vein (left image), selective venogram beyond the thrombus (middle image), and fluoroscopic picture confirming location of the tip of the infusion catheter distal to the thrombus (right image).

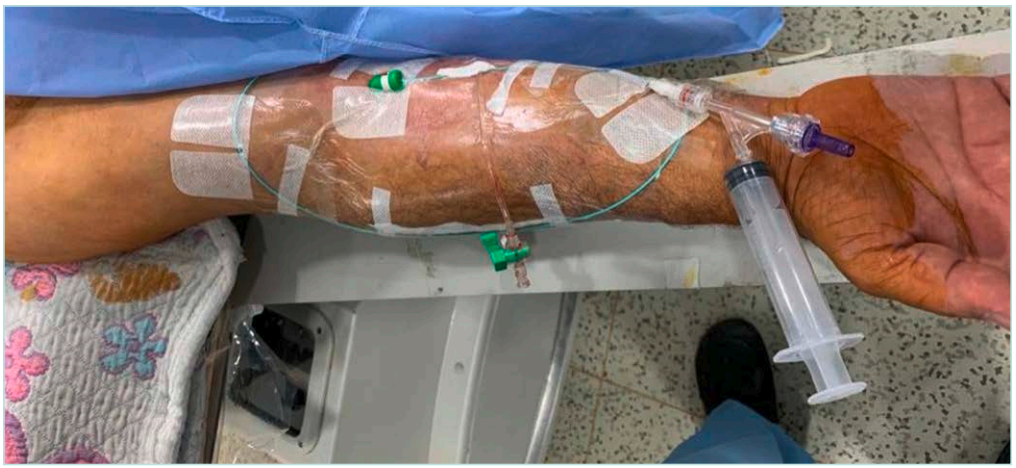

*Figure 9.* Multi side-hole catheter inserted through 6-French sheath in the basilic vein.

The primary 5-year patency of the axillary-subclavian vein in patients who undergo thrombolysis followed by surgical decompression is 84%.[15] Thus, there is a growing consensus that early diagnosis and early thrombus removal followed by operative first rib resection (FRR) produces the most desirable long-term outcome. Therefore, an early thrombus removal strategy should always be considered as a temporizing measure that enables definitive decompression.

## Surgical decompression

Surgical decompression is the cornerstone of definitive VTOS therapy. It is indicated in all symptomatic types, the thrombotic (Paget-Schroetter syndrome) after thrombus removal, the nonthrombotic (McCleery syndrome) with severe disabling symptoms, and the postthrombotic type with persistent disabling symptoms. Resection of the first rib eliminates the anatomical cause of venous compression, reduces recurrence risk, and improves long-term functional outcomes. In a systematic review and meta-analysis, the clinical improvement after surgical decompression of TOS was 90%.[16] Decompression is not indicated in asymptomatic VTOS or if the symptoms are mild.

### *Surgical techniques for first rib resection (FRR)*

***Transaxillary approach:*** This is the most widely performed approach, cosmetically appealing due to the hidden scar in the axilla. It facilitates complete resection of the first rib; however, it provides limited vascular exposure and control, therefore open surgical revascularization cannot be performed from this approach.

***Infraclavicular approach:*** This approach has been gaining popularity in recent years due to its versatility. It allows both the decompression facilitating partial FRR with its associated costoclavicular ligament and subclavius muscles and the revascularization by venous patching or endovenectomy. Furthermore, it gives the advantage of avoiding dissection near the brachial plexus and thoracic duct, reducing the risk of injuring these structures; on the other hand, it may not allow complete rib resection.

***Paraclavicular approach:*** This approach combines the supra- and infraclavicular incisions; it allows complete resection of the first rib but with more risk of nerve or thoracic duct injury. It is usually reserved for complex cases requiring extensive neurovascular decompression.

There is lack in the literature of the direct comparison between the infraclavicular approach and the other approaches; most studies compare the transaxillary approach to the paraclavicular one (supra- +/- infraclavicular) or to the minimally invasive video-assisted thoracic surgery (VATS).

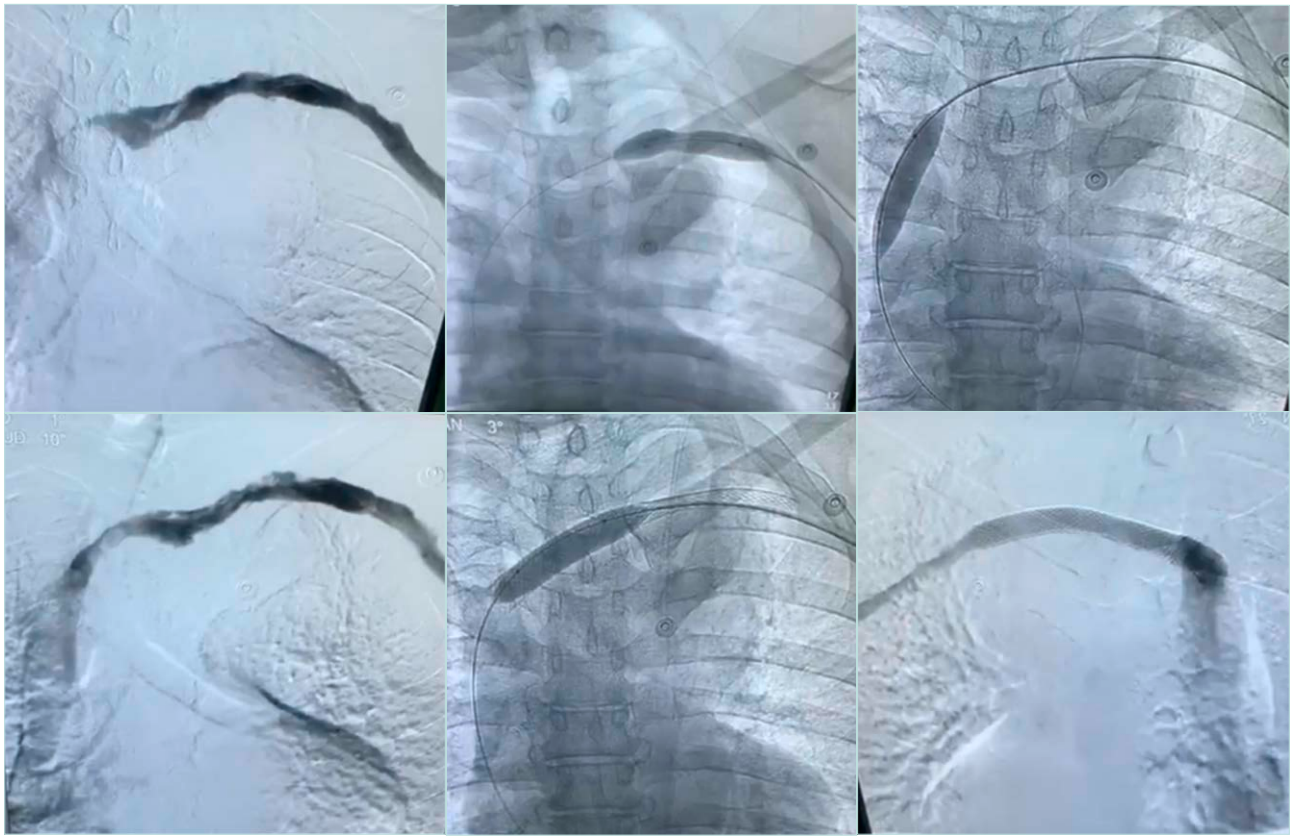

*Figure 10.* Post-lysis venous stenosis was persistent after balloon venoplasty, treated with venous stent.

In a prospective study, the FRR using the infraclavicular approach showed similar technical success and clinical improvement when compared with the paraclavicular approach, however, with a trend toward less morbidity.[9]

### *Rib-sparing decompression*

This novel strategy advocates decompressing the subclavian vein by excising the soft tissue elements contributing to the compression without excising the first rib, such as division of hypertrophied subclavius muscle, resection of the fibrous band and the scalene muscle (scalenectomy). This strategy is an emerging alternative for nonthrombotic VTOS; however, its long-term durability remains uncertain.[17]

Paget-Schroetter syndrome patients who undergo a thrombus removal procedure can be offered decompression surgery **early** (within 2 weeks from the thrombus removal procedure) or **delayed** (4-6 weeks after the thrombus removal procedure). Early decompression offers the advantage of dissection in a field free of fibrosis or scarring, and it enables patients to restore their limb function sooner. Delayed decompression allows the inflammation to resolve, potentially reducing the bleeding and the technical difficulty; however, it carries a risk of recurrent thrombosis while awaiting the decompression surgery.

Retrospective studies favor earlier decompression, showing better symptom resolution and long-term patency. However, optimal timing remains debated and must consider patient-specific factors.

## Venous revascularization: when decompression alone is not enough

Despite effective decompression, some patients—particularly those with chronic postthrombotic VTOS—may continue to exhibit residual venous narrowing or functional obstruction. This can result from long-standing intimal fibrosis, wall thickening, or anatomical webs. In these cases, adjunctive venous revascularization becomes necessary to restore adequate flow and optimize long-term symptom control.

The most common indication of revascularization after decompression is the persistent significant venous stenosis (due to incomplete lumen restoration or intimal damage and scarring) confirmed intraoperatively by IVUS or completion venography. If neither venography nor IVUS are employed in the same sitting of the decompression, the persistence of significant disabling symptoms after the decompression can be indicative of flow limitation despite anatomic release and hence an indication for revascularization.

### *Revascularization modalities*

*Open surgical revascularization:* This can involve **patch venoplasty** and/or **endovenectomy**.

Patch venoplasty can be performed either through the infraclavicular or the paraclavicular approach. It involves longitudinal venotomy and patch augmentation with autologous, biologic, or synthetic material and is suitable for segmental strictures and severely fibrotic veins.

The endovenectomy involves surgical removal of intimal webs, the adherent thrombus, and/or the fibrotic tissue. It is often combined with patch closure, and it is technically demanding, requiring high-level surgical expertise.

***Percutaneous revascularization:*** This can involve **balloon venoplasty** and/or **venous stenting**.
Balloon venoplasty can be performed in the same sitting of the decompression surgery if venography is employed or be performed in a later stage after the decompression surgery. It is usually effective; however, recoil is common in chronic cases.

Venous stenting is reserved for cases of recurrent or refractory stenosis where open repair is not feasible. The long-term durability is uncertain, especially in young, active individuals. The risks associated with venous stent include stent fracture, compression, migration, and in-stent restenosis due to thoracic outlet mobility.

In retrospective studies, the venous reconstruction in Paget-Schroetter syndrome was done by either venous patch through the infraclavicular approach or by balloon venoplasty with or without venous stent and showed significant symptoms improvement (98.9%) with overall secondary venous patency rate of 98.5% and freedom from reintervention of 89.9% over an average follow-up of 23 months.[18]

# Integrated treatment algorithm

The algorithm in *Figure 11* is a clinical type-specific framework that allows individualized, stepwise escalation of therapy while minimizing unnecessary interventions.

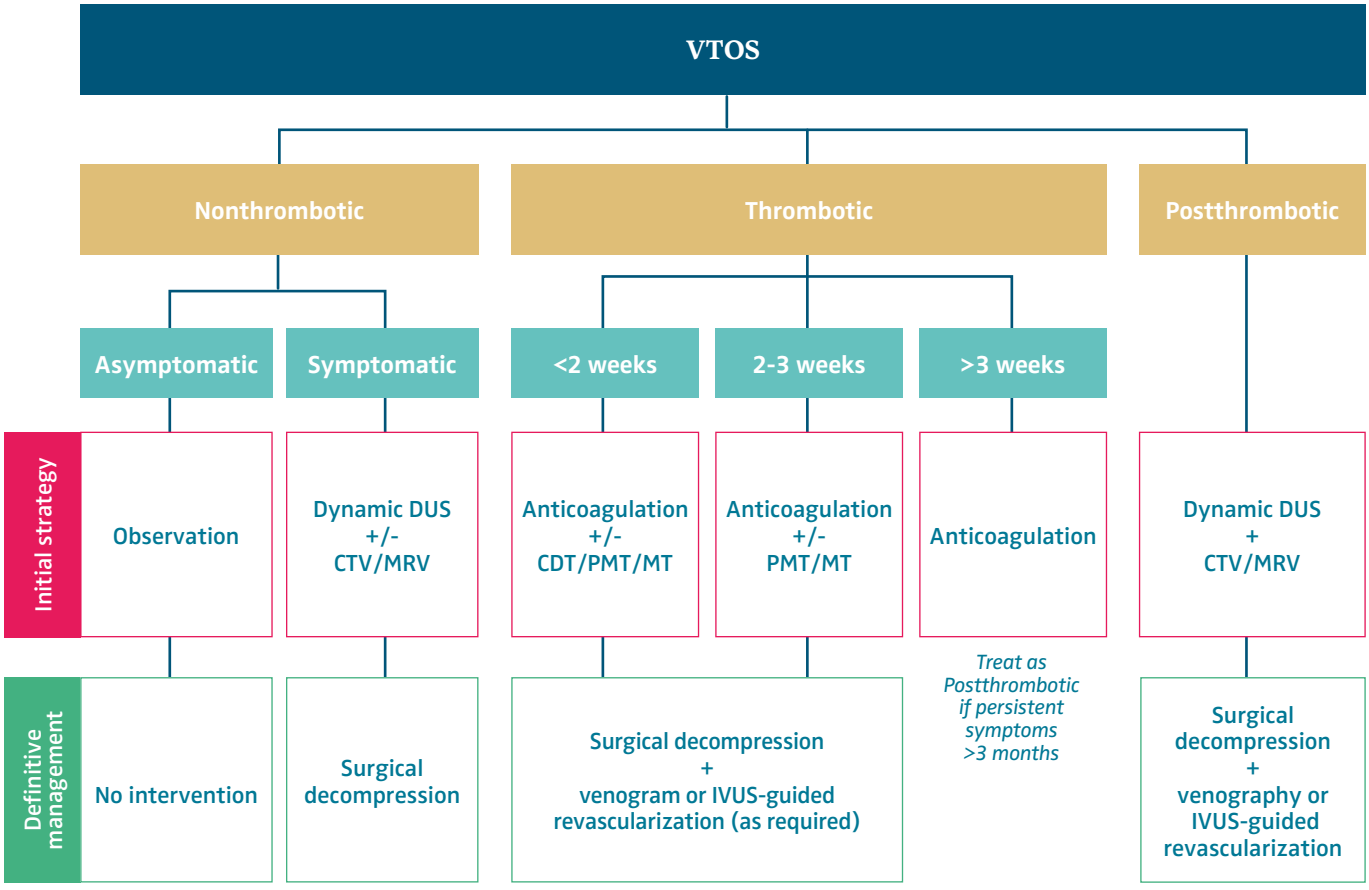


*Figure 11.* Treatment algorithm for different forms of venous thoracic outlet syndrome (VTOS).

AC, anticoagulation; CDT, catheter-directed thrombolysis; CTV, computed tomography venography; DUS, duplex ultrasound; FRR, first rib resection; IVUS, intravascular ultrasound; MRV, magnetic resonance venography; MT, mechanical thrombectomy; PMT, pharmacomechanical thrombectomy; PTS, postthrombotic syndrome.

# Conclusion

VTOS represents a complex, under-recognized vascular disorder with considerable functional consequences if left untreated. Although historically less emphasized than neurogenic forms, VTOS is increasingly identified in young, active individuals and demands a proactive, multidisciplinary treatment strategy.

Timely diagnosis is crucial, relying on a combination of clinical suspicion and provocative imaging. Dynamic DUS, complemented by advanced modalities such as MR venography and IVUS, plays a pivotal role in determining both the presence and nature of the venous lesion.

Management requires more than anticoagulation. In acute cases, thrombolysis or thrombectomy restores venous patency and enables decompression. Surgical decompression, most commonly via transaxillary or infraclavicular FRR, addresses the mechanical cause. When decompression alone is insufficient, venous revascularization—particularly patch venoplasty and endovenectomy guided by IVUS—provides a path toward functional recovery. Stenting remains a controversial but occasionally necessary adjunct.

As treatment paradigms evolve, areas ripe for future research include the following: comparative outcomes of rib-sparing versus rib-resecting approaches, the optimal timing of decompression, durability of venous reconstruction, and the long-term safety of thoracic outlet stenting.

VTOS, when approached systematically, is highly treatable. Structured evaluation, tailored intervention, and vigilant follow-up can restore limb function, prevent recurrence, and dramatically improve patient outcomes. This shift from underdiagnosis to protocol-driven care marks the next frontier in modern venous practice.

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# A comprehensive review of the diagnosis and treatment of nutcracker syndrome

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## ABSTRACT

Nutcracker syndrome (NCS) describes the symptomatic compression of the left renal vein between the aorta and superior mesenteric artery. It causes a series of clinical symptoms including hematuria, proteinuria, flank pain, postprandial abdominal discomfort, and pelvic symptoms in women such as dysmenorrhea or dispareunia. Long-standing venous compression can encourage collateral drainage pathways through gonadal and pelvic veins, which may explain reported symptoms, and the syndrome may overlap with the pelvic congestion syndrome. Although it may be associated with substantial morbidity, the diagnosis can be challenging and variable, frequently involving a combination of Doppler ultrasound and cross-sectional imaging. For most centers, it appears that surgery remains the first-line treatment; however, endovascular alternatives are rapidly evolving in the field with favorable outcomes. This article reviews current concepts on NCS with a particular focus on diagnosis and contemporary surgical and endovascular treatment methods and their outcomes.

**Keywords**

abdominal compression syndrome | chronic pelvic pain | Doppler ultrasound | IVUS | nutcracker syndrome | pelvic vein disorder | renal vein compression | renal vein stenting | renocaval bypass | venography

# Introduction

Nutcracker syndrome (NCS) describes symptomatic compression of the left renal vein (LRV) between the aorta and superior mesenteric artery (SMA).[1] The SMA typically arises from the aorta at a right angle, proceeding ventrally before curving caudad, usually preventing LRV entrapment. When the SMA arises at a more acute angle or the LRV follows a high course, compression may result. NCS refers to symptoms caused by venous hypertension in the left kidney due to mesoaortic compression of the LRV. The term "nutcracker phenomenon" indicates anatomical LRV compression without clinical symptoms. Asymptomatic compression is often seen on imaging, but NCS patients may present with hematuria, orthostatic proteinuria, flank or pelvic pain, dyspareunia, dysmenorrhea, and fatigue.[2]

The anatomical feature was first described by Grant in 1937: "the left renal vein, as it lies between aorta and superior mesenteric artery, resembles a nut between the jaws of a nutcracker."[3] In 1950, El Sadr and Mina described LRV compression by the aorta and SMA.[4] Though "nutcracker" appeared in 1971, De Schepper coined "nutcracker syndrome" in 1972.[5]

NCS prevalence is unclear due to variable symptoms and lack of diagnostic consensus. However, unexplained hematuria is common, and NCS is diagnosed by Doppler ultrasonography (DUS) in 40% of such cases.[6] It can affect all ages but peaks in the second and third decades, aligning with vertebral growth.[7] Though once thought more prevalent in females, recent studies show equal gender distribution.[8]

# Anatomy and pathophysiology

There are 2 main anatomical configurations of NCS. The most common, anterior NCS, refers to compression of the LRV between the abdominal aorta and SMA. In some cases, the third portion of the duodenum also lies between the aorta and the SMA, in front of the LRV. Therefore, anterior NCS may rarely occur with superior mesenteric artery syndrome (compression of the duodenum by the SMA, ie, Wilkie's syndrome).[9] The less common variant is posterior NCS, in which the LRV is compressed between the aorta and the vertebral body. NCS can also occur from other causes, such as malignancy, lymphadenopathy, severe lordosis, intestinal malrotation, pregnancy, and rapid weight loss.[10]

The normal aortomesenteric angle ranges from 38° to 65°.

According to Shin et al, to diagnose NCS, the angle between the SMA and the aorta needs to be less than 45° when measured in the sagittal plane specifically, an angle less than 35° is sufficient for a definitive diagnosis.[7] In most of the symptomatic NCS patients, this angle is reduced to less than 22°, causing collapse of the LRV.

From a pathophysiological point of view, sustained elevation of pressure in the LRV causes venous hypertension with retrograde transmission toward perirenal and pelvic venous plexuses. This can lead to orthostatic proteinuria due to glomerular hyperfiltration secondary to venous congestion, hematuria due to rupture of submucosal calyceal venules, and flank pain due to renal capsule distension.[11]

# Clinical manifestations

The exact prevalence of NCS is unknown, due to the absence of definitive diagnostic criteria and the variability in symptomatic presentation, and therefore probably underdiagnosed. Common symptoms include hematuria (micro or macroscopic), proteinuria, left flank pain, postprandial abdominal discomfort, and pelvic symptoms in women such as dysmenorrhea or dyspareunia. In a study of 112 patients, hematuria occurred in 79%, left flank pain in 38%, varicocele in 36%, proteinuria in 31%, and anemia in 13%.[12] In men, it may appear as a left-sided varicocele unresponsive to conventional treatment. Elevated pressure in the stenosed LRV is thought to cause venous reflux and hypertension, leading to varices between the renal pelvis and ureter, manifesting as micro- or macrohematuria.[13]

Orthostatic proteinuria is another feature, believed to result from increased LRV pressure, subclinical immune injury, and altered renal hemodynamics on standing. These changes may trigger excessive angiotensin II and norepinephrine release.[14] However, orthostatic proteinuria is relatively common in the pediatric population, affecting 2% to 5% of children and young adults, usually with a benign course.[15] Whereas some patients experience persistent symptoms, others, especially children, may remain asymptomatic.

The LRV communicates with the left gonadal vein and lumbar plexus, which often dilate to compensate for venous outflow. In severe cases, ovarian vein dilatation and reflux may lead to PCS,[16] characterized by noncyclic chronic pelvic pain or heaviness due to gonadal vein reflux and dilation.[17]

NCS should be distinguished from other causes of hematuria (eg, lithiasis, nephritis), abdominal pain (Wilkie's syndrome, SMA syndrome, endometriosis), idiopathic varicocele, or isolated pelvic congestion. It may also coexist with other compression syndromes such as median arcuate ligament syndrome (MALS) and May-Thurner syndrome (MTS).

# Diagnosis

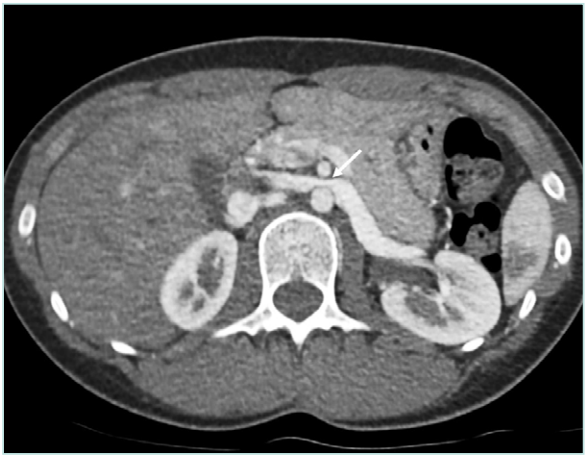
The diagnostic approach for suspected NCS depends on clinical severity, comorbidities, and the need to exclude other conditions. Diagnosis is challenging due to symptom variability and lack of definitive criteria. Imaging—including DUS, computed tomography angiography (CTA), magnetic resonance imaging (MRI), venography, and intravascular ultrasound (IVUS)—is essential, but clinical correlation is crucial for management.

# Doppler ultrasonography

DUS is the preferred initial imaging for NCS, with sensitivity of 69% to 90% and specificity of 89% to 100%.[18] It assesses LRV collapse, blood flow velocity, and the aortomesenteric angle. Multiplanar imaging is essential, with patients hydrated and ideally fasted for 6 to 8 hours. Positional changes (supine, prone, upright) affect results.[19] Ratios are often elevated in the upright position due to gravity worsening LRV compression.

DUS must exclude mass lesions and assess the SMA angle. The LRV diameter is measured at both proximal and distal sites of compression, with peak velocities recorded. Diagnostic DUS findings include a velocity >100 cm/s at the compressed site, >70% luminal narrowing, and a $V_{max}/V_{mean}$ ratio >4.5 between the narrowed and hilar segments.[20]

# Computerized tomography angiography



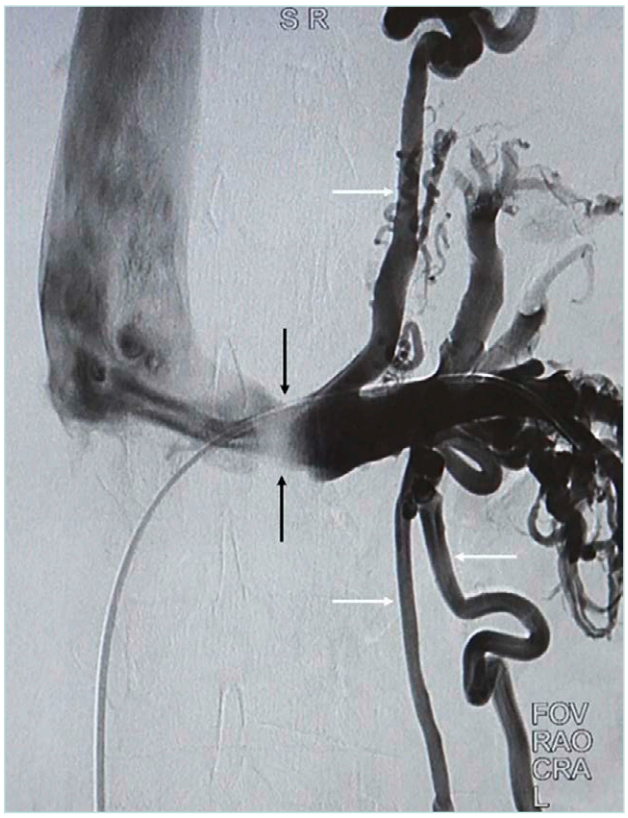
CTA provides high-resolution images of renal vasculature and adjacent structures without being invasive,[21] though it lacks flow data. Sensitivity and specificity are 92% and 89%, respectively.[22] CTA identifies LRV compression by comparing the diameter at the renal hilum and narrowed segment, and by evaluating the SMA–aorta angle. Normally 45° to 90°, an angle ≤35° suggests NCS.[23] On axial images, the "beak" sign—an abrupt narrowing of the LRV—has a sensitivity of 92% and specificity of 89% *(Figure 1)*.[23] Since absolute diameters vary, the hilar-to-compressed diameter ratio is more reliable, with sensitivity of 67% and specificity of 100%.[23,24]

*Figure 1.* **Axial CTA image shows compressed left renal vein between aorta and SMA and characteristic "beak" sign with abrupt narrowing of the LRV at the SMA level (white arrow).**
CTA, computed tomography angiography; LRV, left renal vein; SMA, superior mesenteric artery.

# Magnetic resonance imaging

MRI avoids ionizing radiation and is thus preferable in children and pregnant individuals. It evaluates vein diameter ratios and the "beak sign" similarly to CTA. MRI offers superior soft-tissue contrast and comparable sensitivity and specificity.[25] Specialized sequences allow non-contrast-enhanced imaging.

# Venography and intravascular ultrasonography




If imaging remains inconclusive, venography with pressure gradient measurement or IVUS is considered. Though invasive, they remain the diagnostic gold standard.[26] Direct measurement of the LRV to vena cava pressure gradient is considered the definitive diagnostic test for NCS, although it is usually unnecessary. A renocaval gradient >3 mm Hg confirms NCS. In healthy individuals, the gradient is usually 0 to 1 mm Hg.[27]

Venography is best reserved for preoperative planning. It demonstrates LRV narrowing, collaterals, and venous reflux *(Figure 2)*. Pressure readings further aid diagnosis.[27] However, some normal individuals may exhibit >3 mm Hg gradients, and patients with collaterals may show normal pressures.

IVUS assesses LRV diameter and can be done during venography.[28] An ultrasonic catheter is introduced through femoral access and slowly withdrawn from the LRV through the SMA and into the inferior vena cava (IVC). IVUS is essential for sizing and confirming proper stent placement.[28]

*Figure 2.* **Venography demonstrates maximal compression and poor opacification of the aortomesenteric level of LRV (black arrows) with preferential collateral flow via the splenic venous plexus and gonadal veins (white arrows).**
LRV, left renal vein.

# Treatment

The treatment of NCS remains controversial due to inconsistent diagnostic criteria and the lack of consensus on the optimal treatment modality. Management is symptom driven. By consensus, the asymptomatic nutcracker phenomenon does not require treatment.[1,2,29]

Guidelines from the European Society for Vascular Surgery recommend 6 months of conservative therapy for adults with mild symptoms, and 24 months for children aged 18 or younger.[2,30]

# Conservative management

Conservative treatment is often effective, especially in children. Most pediatric cases resolve spontaneously, likely due to increased intra-abdominal and retroperitoneal fat growth and fibrous tissue accumulation near the origin of the SMA, which relieves compression on the LRV. Collateral venous development also lowers LRV pressure.[19] These mechanisms explain the complete symptom resolution in up to 75% of younger patients over 24 months.[31]

Angiotensin-converting enzyme inhibitors, especially alacepril, are widely used in pediatric patients to manage orthostatic proteinuria and hypertension. Aspirin may be added to improve renal perfusion.[32]

Elastic compression stockings can reduce pelvic or flank pain. Underweight or low-normal body mass index patients may benefit from weight gain, which resolves symptoms in up to 30% of such cases.[33]

# Surgical treatment

Surgery is indicated to prevent chronic glomerulopathy, impaired renal function, permanent gonadal vein dilation, and renal vein thrombosis. Due to higher morbidity, open surgery is reserved for patients with persistent symptoms like hematuria, proteinuria, severe pain, autonomic dysfunction, renal failure, or varicocele. Common procedures include renal vein transposition, gonadal vein transposition, renocaval bypass, venous bypass, renal autotransplantation, and endovascular stenting.[34]

# Open surgical treatment

**Transposition of the LRV:** Renal vein transposition is the standard of care for patients with non-remitting symptoms and is the most common invasive intervention for anterior NCS, with excellent immediate and long-term symptom control. This procedure was first described in 1982 and quickly became the standard surgical approach to NCS and between 80% and 100% of patients reported relief of flank pain and hematuria following renal vein transposition.[2,34] Hartung et al reviewed 42 cases presenting with NCS managed surgically; 83.3% of patients reported successful resolution of symptoms, demonstrating the important role of open surgery in the management of this condition.[35] LRV transposition entails excision of the vessels at the IVC junction with reimplantation distal to the SMA. It is carried out through a midline transperitoneal approach. For patients who have an LRV with a permanent distortion caused by long-term compression or those in whom the LRV is excessively tensioned after transposition, the great saphenous vein can be used as a patch or extension graft, respectively. Although renal vein transposition or bypass is a relatively low-risk procedure, reported complications include paralytic ileus, small bowel adhesion, retroperitoneal hematoma formation, and LRV restenosis.[30,24]

**Renocaval bypass:** A considerable number of patients undergo restenosis and occlusion of the transposed vein and require reintervention. The renocaval bypass technique employs the great saphenous vein to construct a bypass and does not require transposition of the LRV. The saphenous vein is anastomosed proximally to the IVC, below the LRV, and distally to the LRV. Both anastomoses are performed with partial clamping so that they have little effect on venous hemodynamics. The advantages of this operation are the short period of renal ischemia and few anastomoses and no need to ligate the lumbar veins, the gonadal vein, or the LRV if they are not refluxing, since they do not affect the anastomoses. However, owing to the risk of shortening, restenosis, or collapsing of the saphenous vein graft because of the aorta, the renocaval bypass with prosthetic graft is the preferred technique in adult patients with significant collaterals and unfavorable anatomy. For this purpose, ringed reinforced polytetrafluoroethylene (PTFE) grafts are used to connect the LRV to the IVC with a C-Shape *(Figure 3)*. Deser et al report successful use of a PTFE prosthetic graft for renocaval bypass in a patient with posterior NCS.[36] Furthermore, Morata et al reported over 40 procedures and more than 6 years of follow-up with PTFE graft renocaval bypass.[29] Severe thrombotic or stenotic complications occurred in only 11% of these patients. They also highlighted that it is essential to cover the bypass graft with an omental flap (epipoplasty) to prevent duodenal fistula risk. The advantages of this operation are the short period of renal ischemia and few anastomoses, with high rates of symptomatic resolution, especially for complaints of hematuria and flank pain, and it is considered the gold standard treatment for NCS.[29,34,35]

**Renal autotransplantation:** This is also relatively common, though more invasive, as it involves relocating the kidney to the iliac fossa. The technique was first reported by Hardy et al following ureteral injury.[37] It is considered a complete procedure because it effectively normalizes LRV pressure levels and corrects any possible posterior renal ptosis, offers excellent results, and is associated with low morbidity. Shokier et al reported cessation of hematuria in patients with CT-diagnosed NCS in all patients who underwent autotransplantation, with individuals remaining asymptomatic at 1-year follow-up.[38]

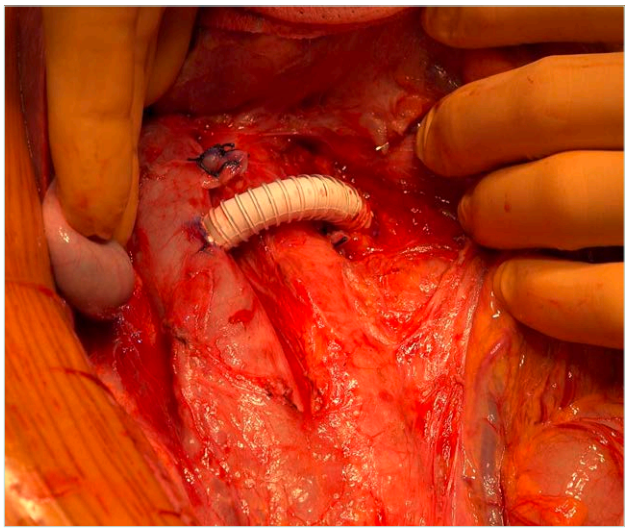


*Figure 3.* Renocaval bypass using ringed reinforced prosthetic polytetrafluoroethylene (PTFE) graft with transperitoneal approach.

Despite being invasive, renal autotransplantation may be more efficacious at normalizing LRV pressures. However, as a more invasive procedure compared with LRV transposition, renal autotransplantation does carry additional risks including increased renal ischemia time, a more extensive surgical dissection, and a total of 3 anastomoses (artery, vein, and ureter) with consequent possible complications at any of these sites.

**Transposition of the left ovarian vein:** In well-selected patients, left ovarian vein transposition (LOVT) for NCS reliably relieves left renal venous hypertension by redirecting left renal venous outflow through the LOVT into the common iliac vein or IVC, reducing pelvic venous congestion and its attendant symptoms. It avoids a large open abdominal procedure, the use of prosthetic materials, and stents. The morbidity of the procedure is limited, patients recover quickly, and they experience sustained relief of symptoms.[39] The retroperitoneal approach for LRV decompression requires minimal manipulation of the ovarian vein, provides access to treatment of the symptomatic pelvic varicose veins, and avoids the subsequent risks of intra-abdominal problems *(Figure 4)*. It provides an alternative for failed renal vein transposition or renal vein stents.[40] Cosmetically, the incision is smaller and less apparent, which is of importance to the many young women affected by NCS.

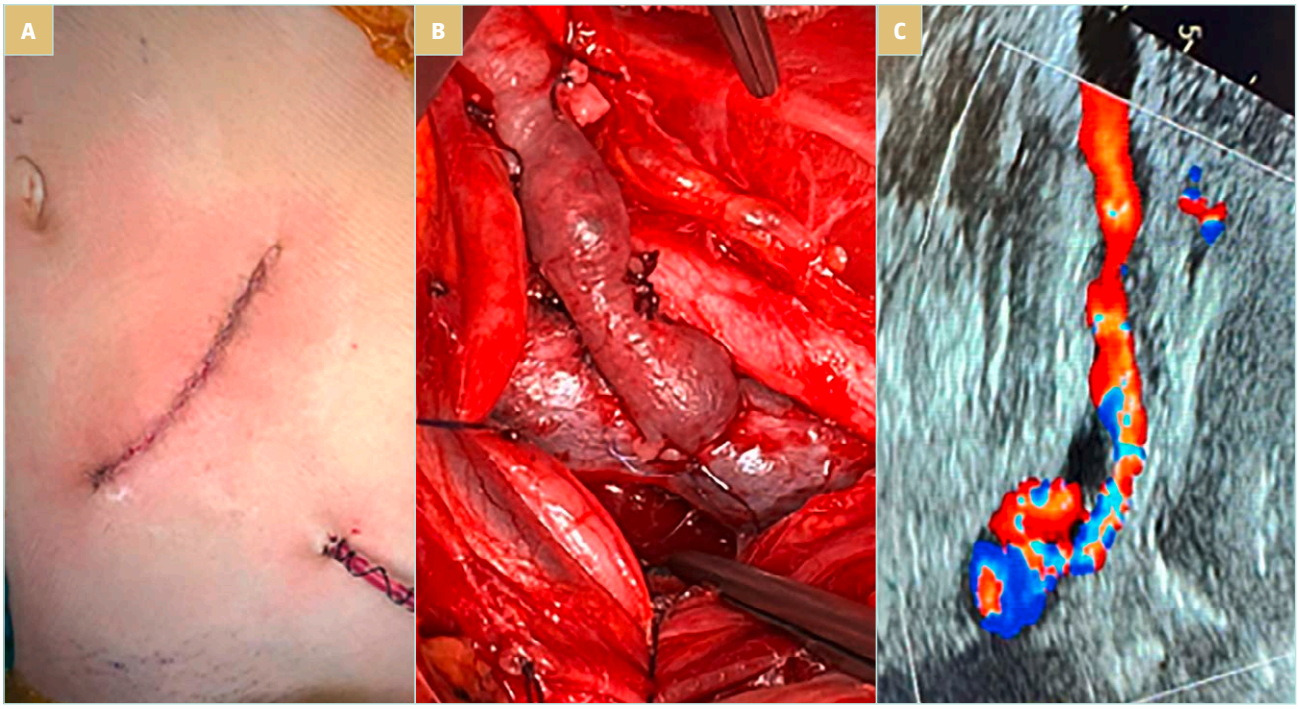



*Figure 4.* (A)The oblique incision for retroperitoneal approach to the ovarian vein for transposition. (B) Left ovarian vein to common iliac vein anastomosis. The proximity of the veins permits the construction of a well configured anastomosis. (C) Follow-up duplex ultrasonography shows sufficient left ovarian vein flow at 1 year.

**Laparoscopic surgery:** Minimally invasive approaches with laparoscopic or robot assisted–laparoscopic techniques reduced recovery times and are increasingly becoming standard practice.[41] Nevertheless, reintervention rates have been reported to be up to 68%, mostly for restenosis of the LRV.[42] The literature on laparoscopic surgery in NCS is largely limited to case reports or small series. However, the outcomes of laparoscopic procedures reported in the literature are comparable with those of open procedures; these include laparoscopic spleno-renal venous bypass and laparoscopic LRV-IVC transposition, with the latter avoiding complications to the spleen from ischemia and tears, as it bypasses the portal venous circulation where pressure is higher than central venous pressure, hence maintaining LRV hypertension. Hartung et al reported successful outcomes at 12-month follow-up following laparoscopic transposition of the LRV into the IVC for a 40-year-old lady where disabling pain in the left lumbar region and hematuria resolved, and on duplex ultrasound the reconstruction remained patent.[43] Experience with robotically assisted laparoscopic LRV transposition has also been limited to case reports. Wang et al report a case with no postoperative complications and hematuria resolved in 1 month.[44] Thaveau et al report the use of robotically assisted LRV transposition followed by left ovarian vein embolization with DUS performed at 6-month follow-up revealing a competent LRV.[45] Further studies are required to assess the long-term outcomes and cost-effectiveness of this procedure with robotically assisted LRV transposition.

# Endovascular treatments

**Endovascular stenting:** This approach is gaining popularity due to its minimally invasive nature, despite the lack of stents specifically designed for the renal vein. Currently available venous stents with high radial force and flexibility have proven effective. A retrospective analysis reported 96.7% symptom improvement in 59 of 61 patients at 6 months, with no significant restenosis at 66 months.[46] Wang et al found pressure gradient reduction and symptom regression in 29 of 30 patients within 6 months.[47] In a comparative study, all 15 patients treated with stents became asymptomatic, though one required surgery for stent migration.[48] Over 150 successful endovascular cases have been documented; however, long-term data remain limited, especially in younger patients.[49]

The most used stents are self-expanding and should be 60 to 80 mm in length, placed near the LRV's first division. Oversizing by 20% is advised to prevent migration. Complications include incorrect placement, migration (7.3% rate), partial or complete displacement into the IVC or renal hilum, and rare cases of embolization, thrombosis, restenosis, or fracture.[47-49] Migration is linked to cardiac motion, early activity, mismatched sizing, or poor positioning.[30,48] A study with 75 patients and 55-month follow-up showed a 6.7% migration rate, without clear correlations to stent size or placement.[50] In a review of 18 cases, 2-year patency was 85.2%, but stenting after LRV transposition showed limited benefit, with 3 of 5 patients still symptomatic.[50,51]

**Hybrid treatment:** To mitigate stent migration at the aortomesenteric level, hybrid treatment combines conventional endovenous stenting with transfixing polypropylene stitches (*Figure 5*).[52] This laparoscopic or open surgical fixation method stabilizes the stent and reduces migration risk. Hybrid procedures are emerging as promising, especially for young patients with high-risk anatomy.

**Embolization of the LGV:** Patients with or without hematuria may experience gonadal vein insufficiency, resulting in varicocele in men and pelvic congestion in women. The ovarian vein connects to the gonadal, uterine, gluteal, and vulvoperineal venous plexuses, which may contribute to pelvic symptoms. Embolization of the LGV is the gold standard for treating pelvic congestion due to ovarian or pelvic vein insufficiency. Treating LRV compression may not sufficiently address gonadal reflux. Embolic agents include foam, glue, plugs, liquid sclerosants, and coils. The decision to treat should be based on the presence of renal or pelvic symptoms, reflux severity, and varicose anatomy. Clinical expertise should guide embolization in conjunction with anatomical and functional assessments.[53,54]

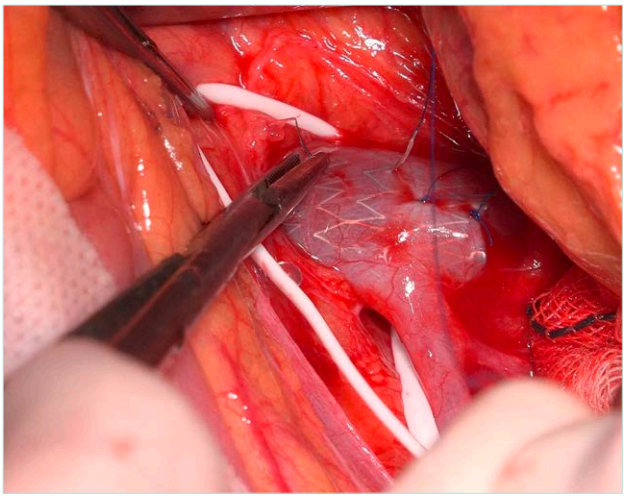


*Figure 5.* Peroperative view of hybrid treatment shows transfixing polypropylene stitch through the renal vein wall and the stent meshes after endovascular venous stenting.

# Conclusions

Patients with NCS may experience a wide spectrum of symptoms. Early recognition and treatment of those with significant pain and hematuria are essential. Clinical judgment and a high index of suspicion are critical, particularly in patients without prior imaging. Multiple surgical options exist, and only solid theoretical and technical expertise ensures proper selection. LRV transposition and autotransplantation remain the mainstay treatment. However, laparoscopic techniques are gaining ground due to lower postoperative morbidity. Further research is needed to refine diagnostic protocols, assess long-term outcomes of treatments, and create consensus guidelines.

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Phlebolymphology Vol 32 | No. 2 | 2025

# Popliteal compression syndrome

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## ABSTRACT

Popliteal entrapment (compression) syndrome is a rare disease affecting principally young people, without atherosclerotic involvement. It is due to extrinsic compression of the neurovascular bundle at the popliteal fossa. There is no consensus or guidelines for the diagnosis or management, especially for functional popliteal entrapment. Compression of the popliteal vein manifests itself symptomatically in dynamic situations, such as prolonged standing or physical exercises. These symptoms are not specific, and clinical examination does not identify specific signs either. The ultrasound (US), in supine position, is usually nondiagnostic. Actually, a normal US in patients who complain of symptoms, related to venous insufficiency, should evoke venous compression as a possible diagnostic. Dynamic imaging by US is the key to visualizing the conflict between veins and anatomical structures. If a surgical treatment is considered, magnetic resonance imaging and/or dynamic phlebography are necessary. Nonsurgical procedures for light or mild cases include stretching exercises and botulinic toxin, under US-assisted injection. In more symptomatic patients, and depending on the etiology of compression, several surgical options can be offered: direct decompression through popliteal fossa dissection, aponeurectomy, isolated or combined with lengthening of gastrocnemius and soleus muscles. An often-overlooked syndrome is the chronic venous insufficiency described by Dijkstra and colleagues in patients with morbid obesity: weight loss is able to stabilize or improve venous return without direct vascular interventions and even allows healing of chronic ulcers.

**Keywords**

dynamic phlebography | functional venous and arterial compression | gastrocnemian muscle | popliteal arterial entrapment | popliteal vein entrapment | Silfverskiold test | tiptoe test

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# Introduction

Popliteal entrapment syndrome is an uncommon disease of the lower limbs, mainly affecting athletes or military personnel (generally young patients without any atherosclerotic risk factors). It is due to compression of the popliteal artery, popliteal vein, or tibial nerve in the popliteal fossa by surrounding musculoskeletal structures.[1,2]

Popliteal artery entrapment syndrome (PAES) is a rare pathology, but by far the most common entrapment that could lead to arterial insufficiency in young and physically active persons.[3,4]

Compression of the popliteal vein was considered less frequent than popliteal artery entrapment, until ultrasound (US) became widely available.[5] Most authors considered venographic findings of venous compression as a benign situation without pathologic consequences.

The implication of vein compression in symptomatic venous insufficiency was pointed out in 2000, when Rajuand Neglen[6] published a study of 30 patients who underwent operation to free the popliteal vein, where 82% were significantly improved.

Attention to this problem was awakened, new diagnostic and therapeutic solutions were devised, but popliteal vein compression remains underdiagnosed and undertreated.

# Anatomy

Different anatomical variations may be involved. A first condition is compression by an aberrant insertion of the lateral head of gastrocnemius; this is the most frequent situation, often associated with fibrous bands and/or fibrotic perivascular tissue; but also, a more lateral insertion of the medial head of gastrocnemius muscle to the femoral condyle can compress the vein. Another etiology is hypertrophy of the upper part in gastrocnemius and soleus muscles, with shortening of the sural triceps: type 6 in the Whelan and Rich classification.[7] Obese people often present with this pattern. *Figure 1* illustrates the anatomy of popliteal fossa and the classification of popliteal entrapment syndrome (into 4 types), showing common variants responsible for arterial entrapment.[8] A new classification into 6 types (by Levien) added type V where both popliteal artery and vein are compressed and type VI, functional entrapment: no visible anatomical anomaly, but symptoms appear during exercise due to muscle hypertrophy.[9]

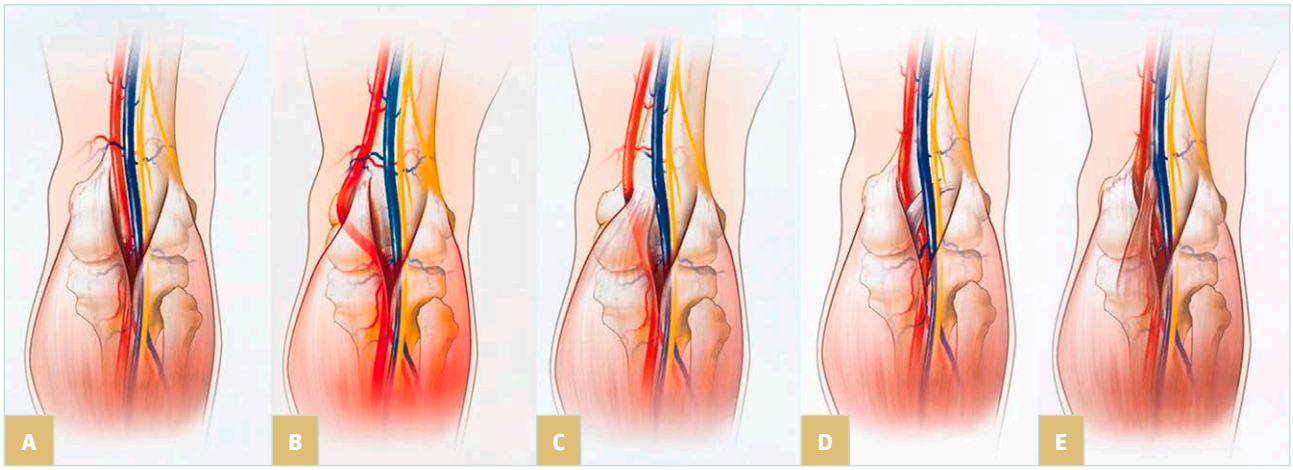



*Figure 1.* Illustration of the anatomy of popliteal fossa and the classification of popliteal entrapment syndrome. Graphic illustrations show normal anatomy of popliteal fossa and common variants responsible for arterial entrapment. A) Normal popliteal artery is adjacent to and lateral to medial head of gastrocnemius muscle, which is normally attached just superior to medial femoral condyle. B) Type I. Popliteal artery takes abnormal course medial to normally attached medial head of gastrocnemius muscle. C) Type II. Abnormal embryologic development results in medial head of gastrocnemius attached more laterally than is normal. D) Type III. Popliteal artery and gastrocnemius are normally positioned, but fibrous band is responsible for entrapment. E) Type IV. Popliteal artery courses beneath popliteus muscle.

# Dynamic popliteal vein compression

## Pathophysiology

The compression can be limited to upper, medial, or lower popliteal vein. In aberrant insertions of the medial gastrocnemius and in hypertrophy of the muscle it is usually medial. Upper compression is related to a stenosis at femoral canal level, whereas low compression is related to the soleus ring.

Dijkstra and colleagues[10] measured popliteal compartment pressure in obese patients and found a significant increase in pressure when body mass index (BMI) was more than 35.

In athletes, a compartment syndrome may be an association, or it can be the main problem.

Intrafascial pressure measurements help in diagnosis, but the procedure is invasive and not available in many labs.

## Symptoms and signs

Symptoms reported by the patients are nonspecific: swelling at ankle level, heavy legs, cramps after standing for a long time or keeping the knee extended. Pain when exercising is mainly experienced by athletes. Inspection may show dilatation of calf muscles. Visible varicose veins are seen mainly in patients who experience recurrence after surgery. Popliteal fossa perforators feeding nonsaphenous varices should raise a flag. Though popliteal fossa perforators are a frequently encountered finding, they would be considered a warning sign mainly in patients who show early recurrence of varicose veins after small saphena ablation.

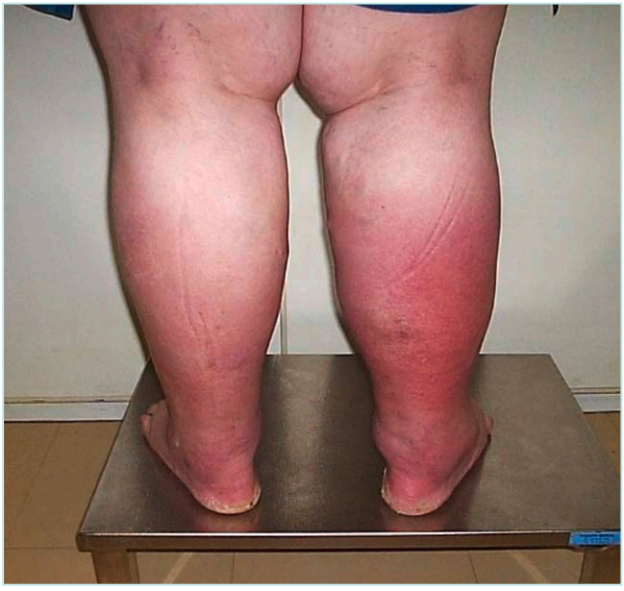
At a later stage, lipodermatosclerosis appears, often misdiagnosed as superficial venous thrombosis. On the other hand, dynamic compression has been identified as a possible cause of deep vein thrombosis (DVT); for instance, in long distance flights due to prolonged sitting.[2]

## Ultrasounds

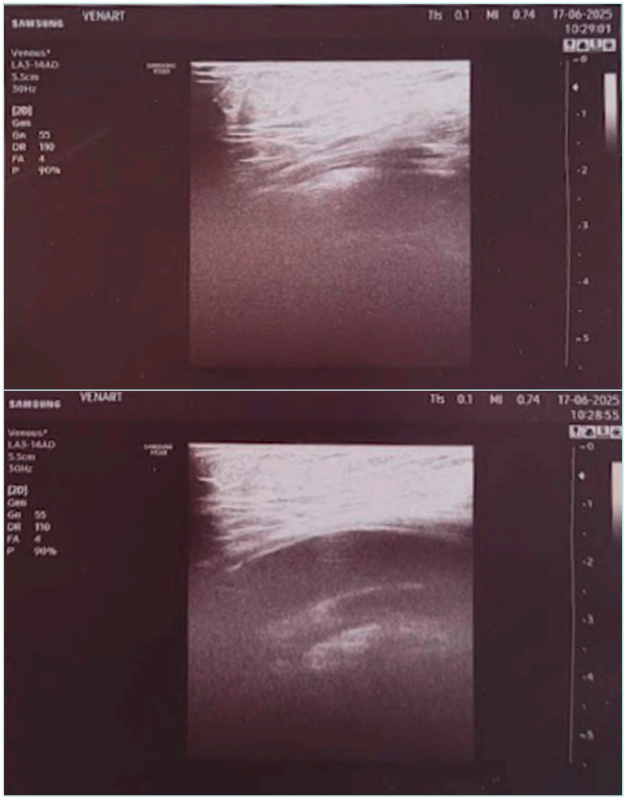
If there is no superficial venous insufficiency associated, in a supine patient, US can appear as normal (*Figure 2*).

When symptoms of venous insufficiency are documented, dynamic tests must be added to confirm or eliminate the diagnosis of popliteal vein compression.

In the tiptoe test, the patient is standing, preferably on a phlebologic stool, with only the anterior part of his feet on the edge. The US probe is placed longitudinally on the popliteal fossa to identify the popliteal vein. The patient is asked to slowly move up and down: compression of the vein by muscular structures of the sural triceps is confirmed by flow restriction in color or power Doppler mode. We consider that clinically significant compression implies a positive test in both extension and flexion of the foot *(Figure 3)*.



▲ *Figure 2.* Obese patient with normal non-dynamic venous duplex ultrasound and popliteal venous compression.




▶ *Figure 3*. Ultrasound image from the tiptoe test. Upper image) foot extended. Lower image) foot in neutral position.

## Other imaging studies

Other imaging studies are performed if an intervention is planned.

Angio-magnetic resonance imaging (MRI) and computed tomography (CT) scans are not very informative because dynamic testing takes a lot of time and can only be done on a supine patient.[11] Standing MRI and CT scan are rarely available.

Our reference test remains dynamic phlebography.[2] The examination is performed on a tilting table at 60° angle, with 3 manual injections of contrast agent: in neutral, foot extension, and foot flexion positions.

The surgeon should be in the room during the phlebography, for better evaluation of the anatomical pattern of the compression and to ask for more incidences as needed. In recurring varicose veins after small saphenous ablation, the surgeon can map the tributaries and perforators, which act as a spontaneous bypass over the compression (*Figure 4* shows ascending phlebography: vein compression in the 3 positions of the foot; *Figures 5 and 6* show ascending phlebography: spontaneous bypass of a venous popliteal compression).

Hall and colleagues[12] used intravascular US (IVUS) in patients diagnosed with popliteal artery entrapment. The investigators found a popliteal vein compression in 100% of patients with arterial entrapment and consider IVUS to be superior to angiograms. But the cost is a limiting factor.

Popliteal venous compression and compartment syndrome are related entities: they can provoke similar symptoms and be associated in the same patient.

Intrafascial pressure measurements are helpful to rule out the compartment issue but are not available in many vascular laboratories.

Sport medicine specialists should be consulted in case of doubt before deciding for a surgical procedure.

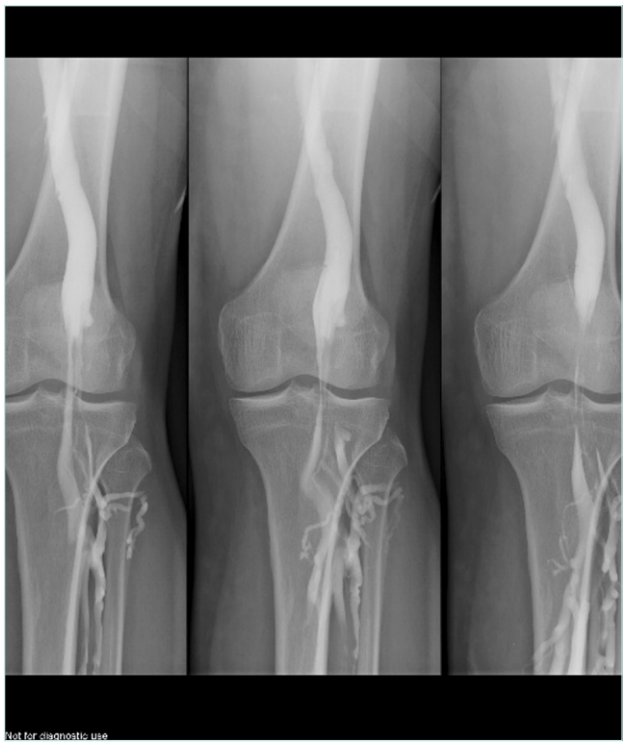



*Figure 4.* Ascending phlebography: vein compression in the 3 positions of the foot.

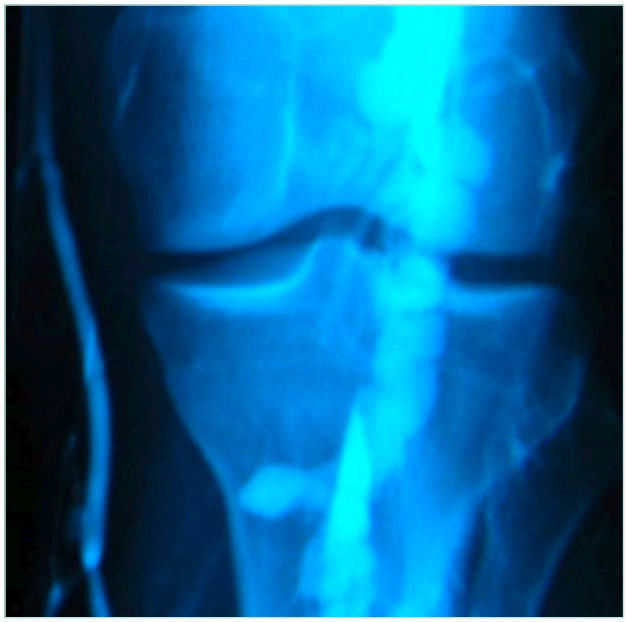


*Figure 5*. Ascending phlebography: spontaneous bypass of a venous popliteal compression.

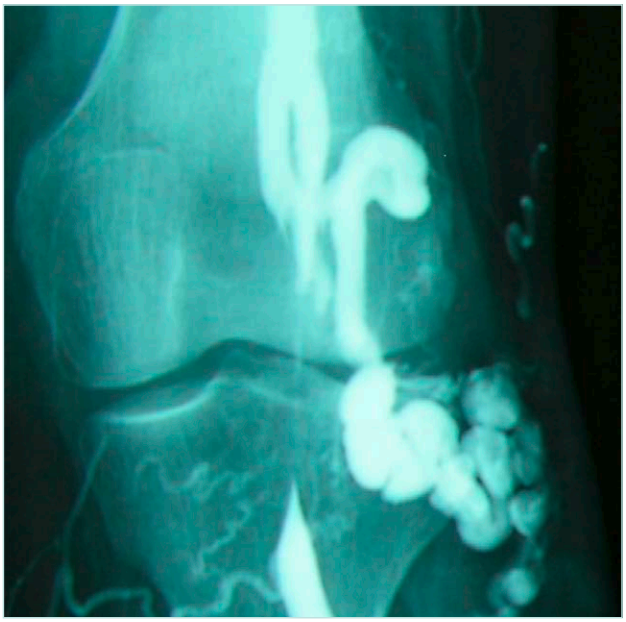


*Figure 6.* Ascending phlebography: spontaneous bypass of a venous popliteal compression.

# Differential diagnosis

As dynamic compression of the popliteal vein is a common situation (27% of a ''normal'' population according to Raju and Neglen[6]), and often coexists with other pathologies, the problem is mainly to evaluate its relevance in the symptoms related by the patient.

In young active patients, leg pain can be related to tendinomuscular pathologies.

Obesity impairs venous return not only at popliteal level; retroperitoneal hyperpressure caused by fat deposits and respiratory insufficiency are cofactors.[10]

Some patients have varicose veins; others, postthrombotic syndrome.

Air plethysmography can help but is rarely available. Spáčil[13] performed US and photoplethysmography in 61 patients (116 limbs). He found reduction in maximum venous outflow when the limb was fully extended in 50 patients.

# Treatment

Conservative options are proposed in most cases.

## Kinetotherapy

Kinetotherapy consists of elongation exercises every day with a tilting board or against a wall.

When symptoms appear during sport activities, in cooperation with the coach, the training can be adapted to limit the shortening and bulging of the sural triceps.

Wearing high heels is discouraged, and the patient is asked to progressively reduce their height while continuing the elongation program.

A 6-month medical treatment with good compliance is necessary before any invasive therapy is considered.

## Botulin toxin

Botulin toxin US-assisted injections are efficient and minimally invasive. Gandor and colleagues described the first series in 2014[14] and obtained good results in 80%. Isner-Horobeti and colleagues[15] published a case report in 2015 with 3 years of follow-up and normalization of the US tests, with no more symptoms. We observed similarly good results for our own patients.

Unfortunately, this technique is not widely used by vascular surgeons because in most countries use of botulinic toxin is restricted to some specialties only.

We refer our patients to a physical medicine specialist who is an expert in treating spasticity in neurological patients. Eighty percent of them report an improvement of their symptoms after 2 sessions with 6-month interval, which is in line with published data. If the result is not good enough, we inform the patient about surgical options.

## Surgery

Surgery can be direct or indirect.

Direct surgery implies dissection of the vein in the popliteal fossa section of any abnormal muscular fiber and fibrous tracts compressing the vein. Superficial aponeurosis is not sutured in order to relieve pressure in the popliteal fossa.

Indirect surgery is indicated mainly when patients present with a hypertrophic and/or shortened gastrocnemius muscle bundle.

A Silfverskiold positive test is mandatory to select a surgical option. This test measures the insufficiency of passive dorsal ankle flexion and can be performed without specific equipment. Lengthening of the medial gastrocnemius bundle by section of the white aponeurotic fibers is minimally invasive surgery, and there is no risk of nerve damage. It is ambulatory, performed under regional and local anesthesia.

Recently, an incisionless gastrocnemius release technique performed with a needle under echoguidance has been described[16]; we have not tested it yet.

After gastrocnemius recession, a specific rehabilitation program must be followed during 4 to 8 weeks.

In summary, dynamic compression of the popliteal vein is multifactorial, with nonspecific symptoms. The knowledge of sport medicine and physical therapy specialists is very useful to evaluate the significance of venous compression in the clinical presentation: we often rely on multidisciplinary consultations before proposing a treatment plan, which should always begin by noninvasive options.

Randomized studies are missing and needed now because efficient and minimally invasive treatments are available.

The influence of dynamic popliteal compression in the development of leg varicose veins deserves to be studied; this hemodynamic disturbance should be suspected in cases of recurring varices in the popliteal fossa.

# Permanent popliteal vein entrapment

Permanent popliteal vein entrapment is less common than arterial compression. It is often part of the type V popliteal compression classification. It may also be present as recurrent DVT in young patients without risk factors.

DVT is rarely associated with popliteal artery entrapment syndrome (PAES). Nowadays, 10% to 15% of PAES are involved in popliteal vein thrombosis.[17] These patients should be treated with anticoagulants. Surgical intervention with myotomy with or without venous thrombectomy should be performed.

Popliteal venous compression may be associated with popliteal artery aneurysm. The aneurysm size is usually moderate (between 2 and 3 cm); a bigger aneurysm can produce popliteal vein thrombosis.[18] The single clinical symptom may be calf swelling, which can vary with the patient's leg position.[18] This cause of extrinsic compression of the ipsilateral popliteal vein should be included in the differential diagnosis of the unilateral leg swelling, without DVT. The treatment of the popliteal aneurysm is surgical or endovascular.

The technique in surgical repair is aneurysmal exclusion or resection and arterial bypass with interposition of a reversed saphenous vein graft or a synthetic polytetrafluoroethylene (PTFE) graft, via a medial approach (most used) or posterior approach.

In the endovascular repair of this region with a lot of mobility, questions about durability arise.

We should have landing zones 20 mm proximal and distal and at least 2 distal vessels that are patent.

*Figure 7* shows the type of grafts used for proximal to distal popliteal bypass.

Another rare cause of venous compression is proximal tibial artery aneurysms or pseudoaneurysms, especially when the first clinical sign is leg swelling in young patients without atherosclerotic involvement. A similar case, a popliteal artery pseudoaneurysm was reported by Kim and colleagues[19] in 2023. The treatment was surgical, a posterior approach with pseudoaneurysm resection and interposition of a reversed saphenous vein graft.

Here, we present a case of a 42-year-old man presenting with swelling of the right calf and pain at this level on exercise, with normal peripheral pulses. Duplex ultrasonography revealed vein compression by a pulsatile mass, filled with blood during the systole. The angio-CT suggests the diagnosis of pseudoaneurysm, which originates at the origin of the tibial posterior artery. *Figure 8* shows the surgical repair by medial approach with pseudoaneurysm excision and vessel repair with autologous vein patch.

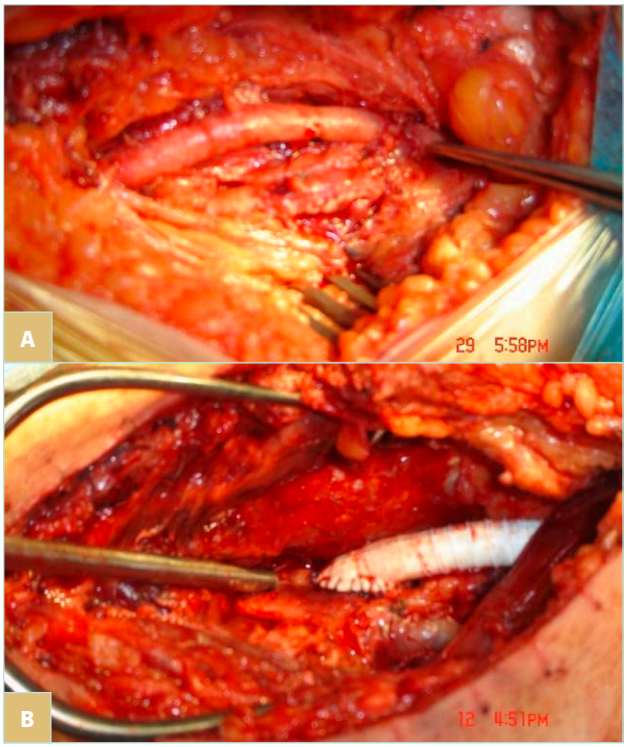



*Figure 7*. The type of grafts used for proximal to distal popliteal bypass. A) Vein graft (recommended whenever available). B) Polytetrafluoroethylene (PTFE) graft.

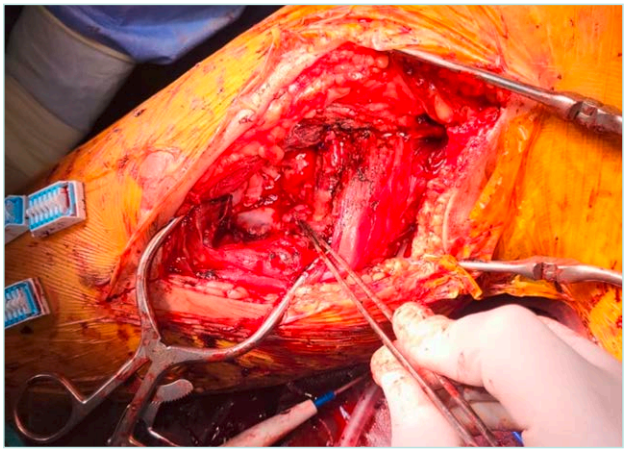


*Figure 8*. Intraoperative view of surgical repair of proximal tibial artery pseudoaneurysm treatment with a saphenous vein patch.

# Popliteal artery entrapment syndrome (PAES)

PAES was first described by Stuart in 1879. Its incidence is 0.17% to 3.5% of the general population in the United States.[20] This embryological development anomaly reveals an aberrant relationship of the popliteal artery with the surrounding myofascial structures.

This is considered a progressive disease because of the repetitive compression that can determine progressive arterial damage ending with arterial occlusion.

Clinical signs of PAES are intermittent claudication in young patients, apparent without signs of atherosclerotic involvement. The median delay between symptoms and diagnosis of PAES is 12 months. Arterial occlusion represents 24% of cases; poststenotic dilatation or aneurysm formation, 13.5%. The median age is 32 years old with 83% of cases being male.

It is important to keep in mind that distal pulses (tibial anterior and posterior) are normal in the absence of severe popliteal artery stenosis. Investigation should continue if PAES is suspected.

## Diagnostic

We have at our disposal multiple imaging modalities. The risk of delay in making a diagnosis can raise the risk of arterial injury.

First line is US, which reveals arterial stenosis or occlusion.[21] **Angio-CT** confirms the diagnostic and shows the arterial bed proximal and distal from the popliteal stenosis. **Subtraction angiography** should be performed only in special situations, but it remains the gold standard, especially associated with provocative maneuvers (eg, ankle plantar flexion).[22] **MRI** of the knee reveals the anatomical cause of the compression.

Early diagnosis should be desired in order to detect the popliteal artery stenosis before complete occlusion of the artery, the treatment strategy being different in these two situations.

## Treatment

The goal of the treatment is surgical decompression of the vessel with or without thrombectomy or reconstruction. There are a few cases reported in the literature from different parts of the world (Korea, USA, Japan, Turkey, etc).[17,23-25]

We can begin by medical treatment: vasodilators and antiplatelet drugs should be started from the onset of symptoms.

Surgical treatment remains the gold standard. Usually, the posterior approach should be performed, with resection of the head of the gastrocnemius muscle that is responsible for the extrinsic compression. After the dissection of the popliteal artery, if the artery is occluded, we can perform a short bypass or interposition using an ipsilateral saphenous vein graft.[26] If there is only a stenosis, we can make a longitudinal incision of the artery and suture a venous enlargement patch. The postoperative treatment should be an association of an antiplatelet drug and a vasodilator (pentoxifilinum, for example).

Another option is endovascular treatment but because of the mobility of the region and the spiral forces of the popliteal artery, the outcomes are not favorable (stent fracture, thrombosis).

# Functional PAES

Functional PAES (FPAES) was not described until 1985 when noninvasive diagnostic modalities like US were largely used.[27] In FPAES, the popliteal artery is compressed by the calf muscles during exercise, leading to leg pain and atypical claudication usually in active young adults. These patients have normal anatomy at rest.

It is difficult to diagnose; in many cases, angiography and even MRI do not identify the entrapment. It would be useful to perform diagnostic tests with provocative maneuvers (like active plantar flexion).

The "gold standard" in the identification of abnormal popliteal fossa myofascial anatomy related to PAES is MRI because of its great sensitivity.[3]

A new protocol for diagnosis has been proposed by the University of Wisconsin School of Medicine, consisting of the following: i) ankle brachial index (ABI) with exercise; ii) arterial Doppler US with plantar flexion and standing; and iii) magnetic resonance angiography with plantar flexion.[27]

Also in the United States, the team of Boniakowski[28] has proposed the use of IVUS as an adjunct to angiography. The advantage is that it can provide not only the exact location of the compression but also the quality of the vessel wall, indicating whether or not arterial repair is needed. It is a new tool, but the procedure has adjunctive costs.

A new treatment is US-guided botox injection—a nonsurgical treatment option.[29] Botulinum toxin A (BTX A) could reduce the volume and tonus of gastrocnemian muscles in patients with FPAES. Isner-Horobeti and colleagues reported a case of bilateral FPAES treated with success after a failed surgical intervention, with maintenance of the result during a medium-term follow-up.[15]

Hislop and colleagues reported on a larger cohort (27 patients), of which 59% of patients had good results (improvement of symptoms maintained at 1 year), 22% a mixed response (the improvement reduced over the 1-year period of the survey), and 19% a poor response.[29]

# Conclusions

PAES is a rare vascular pathology affecting young patients. The diagnostic is difficult and often requires an interdisciplinary team. Symptomatic patients require treatment, often surgical. Until now, there are no guidelines for this entity.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