Original Article

Phlebology

Phlebology
2025, Vol. 0(0) 1–9

DOI: 10.1177/02683555251386701
journals.sagepub.com/home/phl
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Dynamic duplex ultrasound for the evaluation of venous circulation in the lower limbs: A pilot study using a portable device

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Abstract

Introduction: Venous color Doppler ultrasound, it is the gold standard for diagnosing venous insufficiency and deep vein thrombosis (DVT), guiding therapeutic decisions, and monitoring post-treatment outcomes. This article explores the indications, methodology, clinical relevance, and interpretation of a new modality of execution of DUS: the dynamic test.
Materials and Methods: Five adult volunteers with confirmed CVD CEAP class C0s were enrolled after informed consent. A portable wireless ultrasound probe with B-mode, color and pulsed Doppler capabilities was used. The probe was mounted on the patient's lower limb using a dedicated support harness, which provided stable probe positioning without restricting limb mobility. The probe was placed over the small saphenous vein (SSV) in the proximal of the leg in the posterior region, just below the popliteal fossa. The examination was conducted while the patient was walking.
Results: In one patient, a variation in the diameter of the SSV could be observed at the end of the test. In all cases, it was possible to observe a lower amplitude (msec) of the systolic peak (SP) during walking, if compared with that obtained after calf compression maneuvers. There were no differences in the systolic velocity peak between the examination conducted with activation maneuvers and the dynamic one. Reflux during dynamic movement was detected in 2/5 patients (40%) in the SSV that was not observed in static assessments.
Conclusions: Dynamic color Doppler ultrasound (D-DUS) using a portable probe enables real-time assessment of lower limb venous flow during physiological motion. This approach may reveal pathological reflux not evident in static examinations, offering a valuable addition to conventional venous diagnostics.

Keywords

calf muscle pump function, chronic venous insufficiency, Doppler ultrasound, duplex ultrasound

Introduction

Venous disorders of the lower extremities, including chronic venous insufficiency (CVI) and deep vein thrombosis (DVT), represent common and potentially serious health problems. Early diagnosis and appropriate treatment of venous insufficiency are crucial to avoid progression to skin changes and ulceration. Early diagnosis and treatment of venous thrombosis will reduce complications such as pulmonary embolism or post-thrombotic syndrome. Chronic venous disease (CVD) affects up to 25%–40% of adults in Western countries and represents a significant public health burden.[1,2] The venous color Doppler ultrasound (VCDU) has emerged as the first-line imaging modality owing to its safety, accessibility, cost-effectiveness, and diagnostic accuracy. Duplex ultrasonography is considered the gold standard for assessing venous function, particularly reflux and obstruction.[3] Venous Doppler ultrasound combines three key technologies: B-Mode, Color-Doppler and Pulsed-wave Doppler. B-mode (brightness mode) imaging provide the anatomic visualization of veins. Color Doppler to visualize the direction and velocity of blood flow. Pulsed-wave Doppler to measure the velocity of flow and assess reflux or obstruction. These modalities provide both morphological and functional information about the venous system, essential for identifying valvular incompetence, thrombosis, compression, and venous flow abnormalities.[4]

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Table 1. Patients' symptomatology assessed with Aberdeen Varicose Vein Questionnaire (AVVQ) and Chronic Venous Insufficiency Questionnaire (CIVIQ-20).

Identification number	Age	Gender	CIVIQ-20 questionaire (Time 0)	Aberdeen questionaire (Time 0)	CIVIQ-20 questionaire (post-therapy)	Aberdeen questionaire (post-therapy)
#1	39	F	33	13	30	11
#2	38	M	30	12	29	10
#3	61	F	24	11	22	10
#4	37	F	36	14	32	11
#5	59	M	25	11	24	10

The venous system of the lower limbs is composed of three main groups: deep vein system, superficial vein system and perforator vein system. Understanding venous anatomy and hemodynamics is essential to detect abnormalities during Doppler assessment. The patient should be examined in the standing or reverse Trendelenburg position to promote venous filling. A high-frequency linear transducer (7–12 MHz) is typically used. The main evaluations and procedures performed during the venous DUS study are the following: morphological evaluation, compressibility test,

Figure 1. Positioning of the Clarius probe with the Usono support at the level of the popliteal region. Posterior view.

vessel filling evaluated with the color function, the evaluation of spontaneous and phasic flow, augmentation maneuver and reflux testing with PW (Pulsed Wave) mode. Compressibility test consists in the collapse of the vein during the compression exerted under the probe. Non-compressibility suggests thrombosis. Normal veins demonstrate respiratory phasicity and spontaneous flow. The presence of continuous or absent flow is suggestive of venous obstruction.[5] Among the various augmentation maneuvers, squeezing the calf is the most frequently performed. With Valsalva maneuver or distal compression, such as squeezing of the calf, the presence of a retrograde flow longer than 0.5 s in superficial veins indicates valvular incompetence. Dynamic maneuvers like forefoot elevation (lit Mendoza) and Dependency Maneuver (Lattimer, Mendoza)[6] open new horizons and brought the discussion on reflux duration to be considered as pathological, proposing at least 1 s as cutoff for reflux (Mendoza, Habenicht, etc.).[7] However, conventional Doppler assessments are typically conducted with the patient in static positions—supine or standing for deep veins, whereas superficial vein diseases have mandatorily to be investigated in standing position, or at least in sitting.[4,8–11] These static positions limit physiological relevance to dynamic conditions, such as ambulation during the investigation.

Recent advances in portable ultrasound technology have enabled the development of real-time imaging during motion. This study explores the feasibility and potential diagnostic advantages of dynamic color Duplex ultrasound (D-DUS) using a handheld ultrasound device (Clarius®, Clarius Mobile Health, Canada) secured with a dedicated support system (USONO® B.V. part of Medacc Holding B.V.) to evaluate lower limb venous hemodynamics during active patient movement.

Materials and methods

Study design and population

This was a prospective observational pilot study conducted in accordance with the Declaration of Helsinki. Five adult volunteers (three female, two males; age range 37–59 years) with confirmed chronic venous disease (CVD) CEAP class C0s were enrolled after informed consent. The patients presented symptoms of heaviness, heavy pain, restlessness and/or night cramps in the lower limbs. All presented a greater localization of symptoms at the calf level. All patients underwent a clinical and instrumental evaluation. None presented varicose veins, ectatic reticular veins or evident telangiectasias. No patient presented any condition of edema or skin discoloration. On Duplex Ultrasound of the lower limbs none presented superficial venous reflux in standing position. During the examination several maneuvers were performed to highlight a possible reflux. In the specific, in accordance with current guidelines regarding DUS investigation, we performed the following maneuvers: distal compression–release (manual augmentation) and active muscle pump maneuvers (toe-tip standing and forefoot elevation).[10] The distal compression–release maneuvers consist in the rapid calf or foot squeeze distal to the probe followed by sudden release. For the toe-tip standing maneuver the patient rises onto the forefoot (maximal plantarflexion), contracting the calf muscles and activating the calf muscle pump. This expels venous blood from the

Figure 2. Positioning of the Clarius probe with the Usono support at the level of the popliteal region. Lateral view.

deep calf veins toward the proximal segments. The forefoot elevation maneuver was also performed. For this test, the patient rocks back on their heels (ankle dorsiflexion), relaxing the calf muscles and allowing venous refilling from the superficial veins to the deep veins.

At the end of the visit, two questionnaires were administered to the patients: Aberdeen Varicose Vein Questionnaire (AVVQ) and Chronic Venous Insufficiency Questionnaire (CIVIQ-20). The questionnaires demonstrated the presence of symptoms attributable to mild venous insufficiency. The results are reported in Table 1.

Ultrasound device and mounting system

A Clarius L7 HD (Figure 1) portable wireless ultrasound probe (Clarius Mobile Health, Canada) with color and pulsed Doppler capabilities was used. The probe was mounted on the patient's lower limb using a Usono support harness, which provided stable probe positioning without restricting limb mobility. With the patient in standing position, the device was positioned at the proximal calf, just below the popliteal fossa. Under ultrasound guidance, the Small Saphenous Vein (SSV) was located and used as a central landmark to fix the probe with the Usono support. Once the probe was positioned, it was checked that it was stable, had good contact with the skin whilst, however, exerting the "least" compression effect to the veins (Figure 2).

Dynamic protocol

Patients were asked to perform a series of lower limb movements: Tiptoe raises, active dorsiflexion, walking in place (marching) and squats. The probe was placed over the small saphenous vein (SSV) in the proximal calf, just below the popliteal fossa. The probe was placed on the leg where the patient was most symptomatic. Each dynamic sequence was monitored and recorded using the Clarius app and exported for offline analysis.

Evaluation criteria

Flow patterns, reflux duration, and venous compressibility were assessed during rest and motion. A reflux time longer

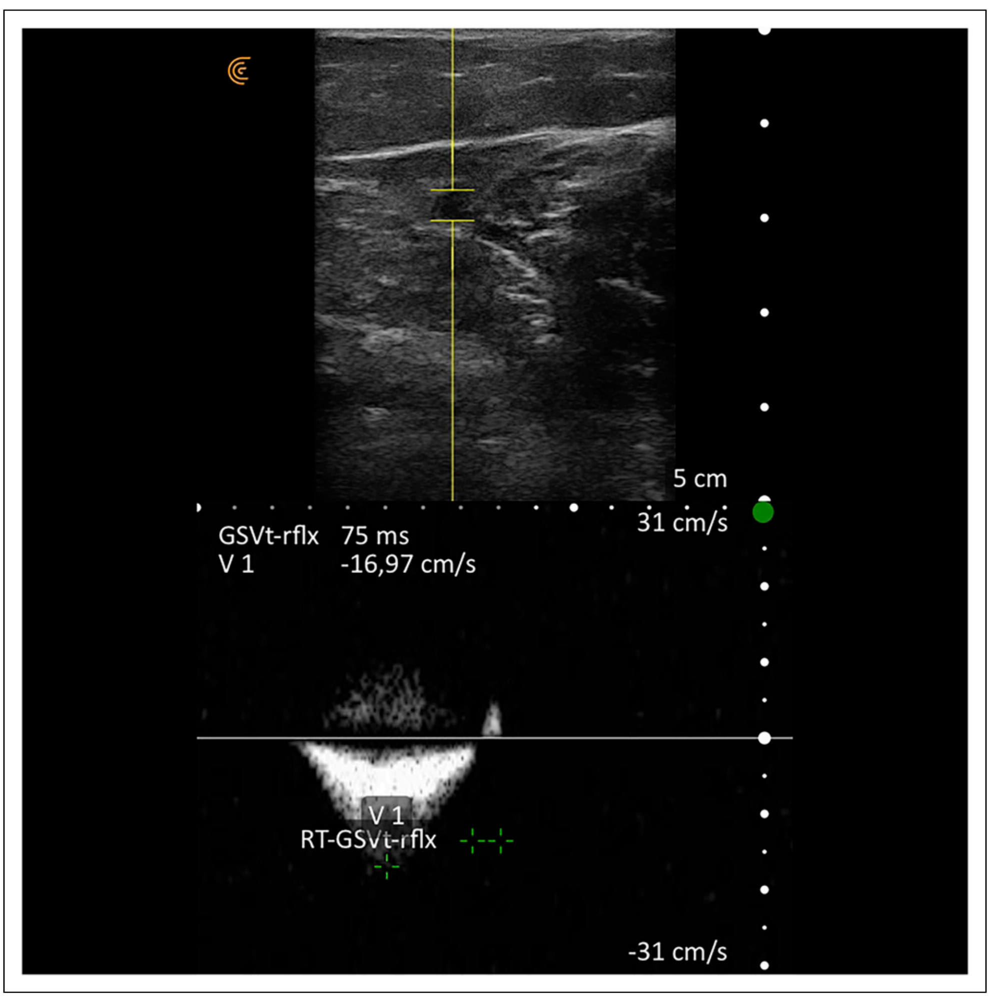

Figure 3. Static evaluation of SSV (Reflux Time 75 msec, Systolic Peak Velocity: 16.97 cm/sec).

than 0.5 s was considered pathological per guidelines.[8,9] A moderate non-hemodynamic reflux was considered when the retrograde flow time was between 0.25 and 0.5 s. Negative when it occurred with a duration below 0.25 s. Dynamic changes in veins diameter and Doppler velocity profiles (systolic peak velocity or SPV) were also analyzed.

Results

All five subjects completed the protocol without adverse effects. The Usono support ensured consistent probe placement during dynamic activities. Venous compression artifacts were minimal due to secure fixation. Flow augmentation with calf muscle contraction was clearly visualized in all cases. During active muscular contraction, the popliteal vein appeared nearly completely compressed in all subjects (mean compres-sion >50% of the area). The gastrocnemius veins consistently disappeared from view due to total muscular obliteration of the venous lumen. All veins reappeared during muscle relaxation, confirming transient functional compression. In all cases, a rhythmic contraction of the SSV due to contraction within the muscle fascia could be observed during walking. In one patient, a variation in the diameter of the vein could also be observed at the end of the test. In all cases, it was possible to observe a lower amplitude (msec) of the systolic peak (SP) during walking, if compared with that obtained after calf compression maneuvers. There were no differences in the systolic velocity peak between the examination conducted with activation maneuvers and the dynamic one. Reflux during dynamic movement was detected in 2/5 patients (40%) in the SSV that was not observed in static assessments (Figures 3 and 4). Reflux duration time in the moving condition was almost doubled compared to the standing compression maneuver. Table 2 shows the highest values (time) obtained during the execution of the static and dynamic test.

Vasoactive therapy with Bioflavonoids and Coumarin (Vasodren ®) were then prescribed for 30 days to the pa-tients. At the end, a new clinical and instrumental evaluation was performed. The CIVIQ and AVVQ questionnaires administered demonstrated an improvement in symptoms.

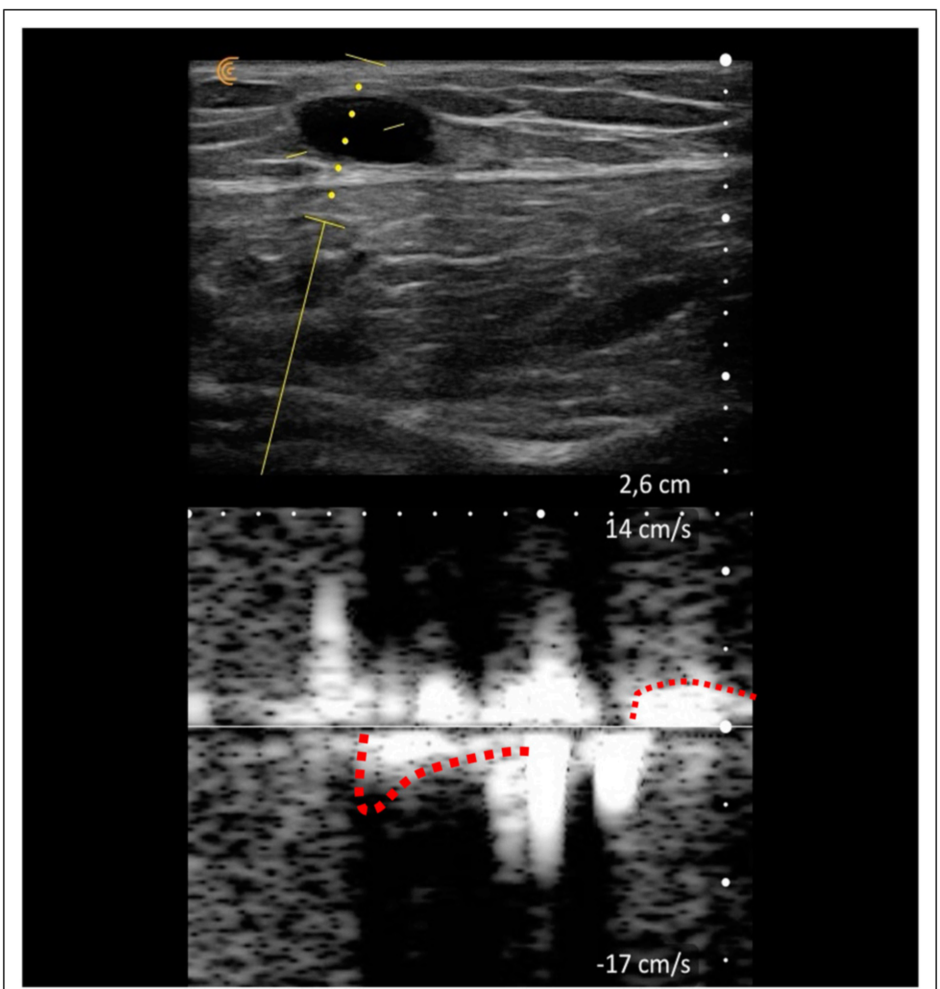

Figure 4. Dynamic evaluation of SSV (Reflux Time 500 msec, Systolic Peak Velocity: 17 cm/sec).

Table 2. DUS measurement: Diameter and reflux time.

Identification number	SSV diameter static (mm)	SSV diameter dynamic (mm)	SSV reflux time static DUS (msec)	SSV reflux time dynamic DUS (msec)
#1	5.1	5.2	75	500
#2	3.4	3.3	70	70
#3	2.6	2.8	50	80
#4	3.4	3.4	90	450
#5	3	4.5	80	90

No difference was observed from the instrumental point of view (Table 2). May these findings support the hypothesis that dynamic evaluation (d-DUS) may unmask occult venous reflux not observed in standard static protocols? Furthermore, the pilot study suggests that the good response of CEAP C0s patients to vasoactive therapy may be explained by the presence of unrecognized venous reflux.

Discussion

To date, there are no duplex studies that have investigated the venous circulation with a dynamic test. Dynamic Doppler ultrasonography with a portable device offers novel insights into venous physiology under real-world functional conditions.

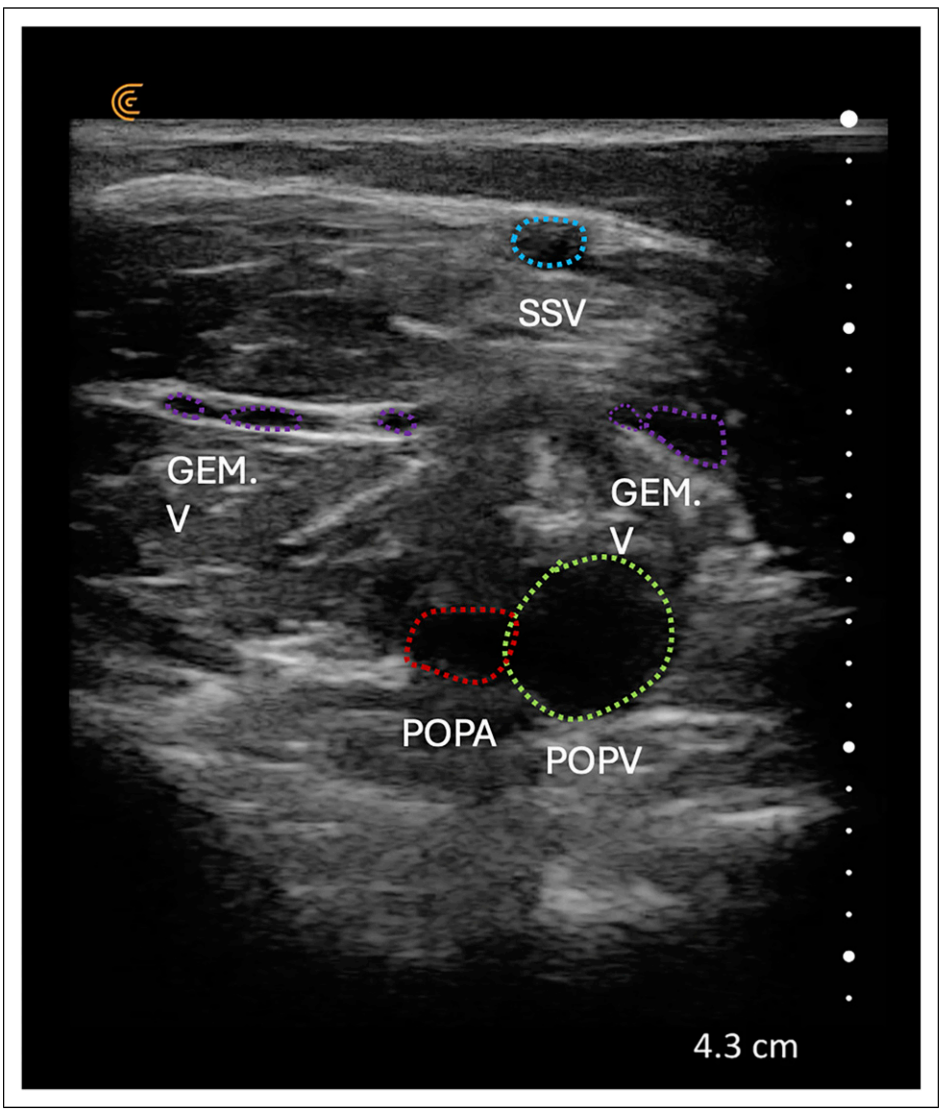

Figure 5. Dynamic venous DUS of popliteal fossa. Diastolic phase.

Venous blood progresses towards the right atrium thanks to venous pressure and thanks to the pressure difference between the peripheral circulation and the heart. However, in orthostatic conditions, gravity exerts a force against venous return, making it more difficult. Hence the need for the venous circulation to possess an additional "ventricle", capable of generating a propulsive effect on the blood outflow with its contraction. This "peripheral heart" exists, and it is the muscle pump. Therefore, each movement generates a muscle contraction and consequently squeezes the walls of the deep venous circulation. The cyclic repetition of this phenomenon generates a surge in the blood flow. Since today we have not had the possibility to study by ultrasound the activity that the muscular pump exerts on the vessels present in the popliteal fossa. Specifically, their compression, the flow velocities, the amplitude of the systolic and diastolic flows during the walk. What we were able to record with the dynamic DUS examination was the almost complete compression of the popliteal vein during the muscular propulsive phase (systole), the complete disappearance of the gemellar veins due to total compression and a dilation of the small saphenous vein (Figures 5 and 6). The latter, receiving reflux blood generated by a lesser muscular compressive action, increases its dimensions. For this reason, even modest valvular incompetence can be highlighted more easily during this phase, with the dynamic DUS examination. This was the reason that pushed us to carry out this study, in those patients with symptoms attributable to venous insufficiency but who did not present reflux with standard maneuvers. While static ultrasound is

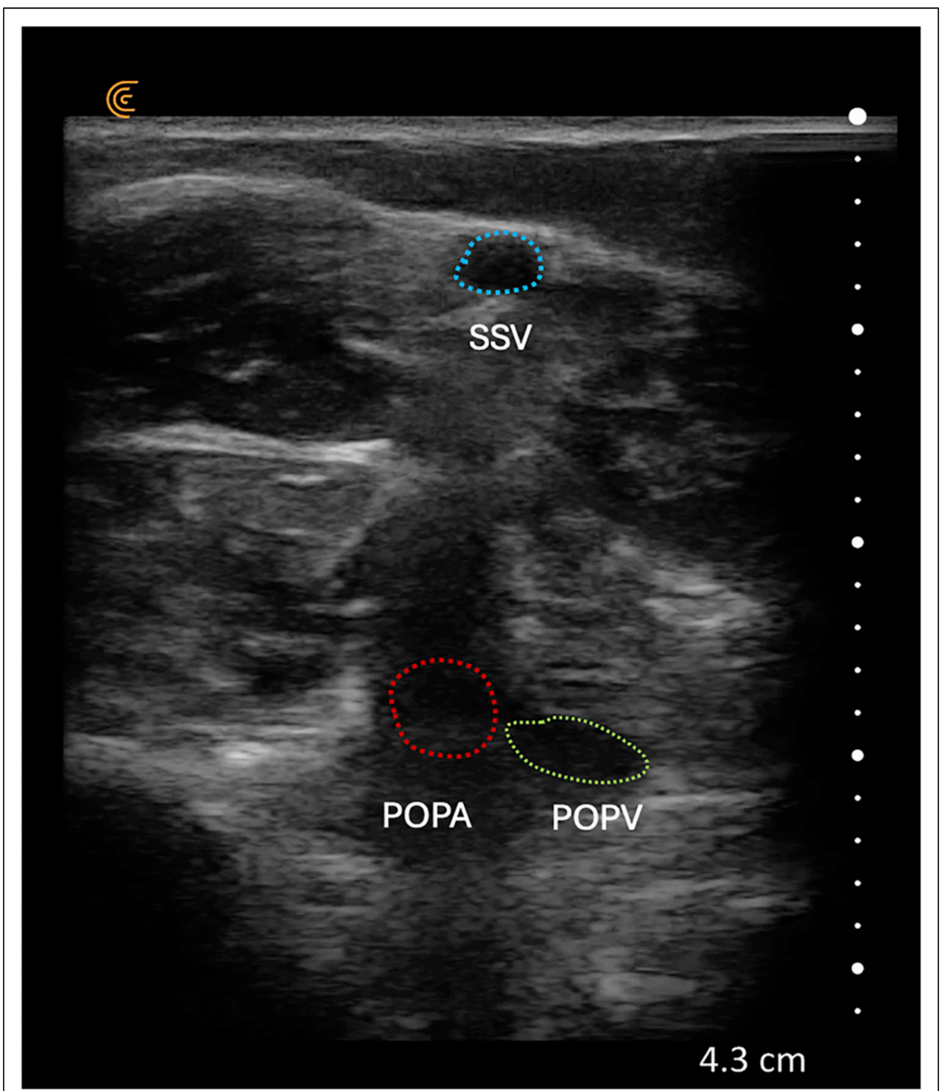

Figure 6. Dynamic venous DUS of popliteal fossa. Systolic phase. It is possible to observe a reduced caliber of the popliteal vein and the complete disappearance of the gemellar veins (due to compression exerted by the muscular contraction). Furthermore, slight increase in caliber of the small saphenous vein (due to reception of retrograde flow and consequent valve closure).

effective in many cases, it may miss episodic or positional reflux that only occurs during muscular contraction or gait-related motion.[12] These findings emphasize the dynamic nature of venous return mechanisms. The near-complete obliteration of the popliteal vein as well as gastrocnemius veins during active contraction illustrates the powerful mechanical effect of the calf muscle pump. The disappearance of the gastrocnemius veins reflects their intramuscular course and compressibility. These results have implications for the timing of venous evaluations, particularly in the context of chronic venous insufficiency. Static assessments may miss functionally relevant changes evident only during activity. Dynamic V-DUS could therefore aid in diagnosing subtle outflow abnormalities or muscle pump dysfunction.

Our study suggests that handheld ultrasound devices, when combined with stabilization systems like Usono, provide a feasible and reliable method for in-motion scanning. This method may enhance diagnostic sensitivity for early-stage venous insufficiency and improve the understanding of vein competence under load-bearing conditions. Furthermore, this type of examination can help us identify muscular dysfunctions as a cause of venous insufficiency and can facilitate the understanding of the effects of physical exercise on the possible improvement of venous insufficiency. Limitations of this study include the small sample size. Future larger-scale studies should aim to validate these preliminary findings. In this pilot study, the pressure exerted by the support on the tissues was not measured with the Pico Meter. With future studies it will also be possible to evaluate this parameter to exclude a possible influence on the test determined by the compression of the tissues induced by the support.

Conclusions

Venous color Doppler ultrasound of the lower limbs remains a cornerstone in vascular medicine. Its ability to provide real-time, dynamic, and detailed images of venous anatomy and hemodynamics makes it indispensable for diagnosing and managing a wide range of venous disorders. Mastery of technique and interpretation is vital for ensuring high diagnostic accuracy and optimal patient outcomes. Dynamic color Doppler ultrasound using a portable probe enables real-time assessment of lower limb venous flow during physiological motion. This approach may reveal pathological reflux not evident in static examinations, offering a valuable addition to conventional venous diagnostics. It will also be possible to evaluate how much physical exercise can influence venous return or how a muscular deficit can be the cause. Further trials with larger population sample are needed to confirm these findings and establish the efficacy and the real impact in the patient management.

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Luca Palombi conceived of the presented idea.
Luca Palombi and Monica Morelli performed the study.
Luca Palombi wrote the manuscript with support from Monica Morelli.
Erika Mendiza revised the manuscript.
All authors contributed to the final manuscript.
Luca Palombi, Monica Morelli and Erika Mendoza contributed to the final version of the manuscript.
All authors read and approved the final version of the manuscript.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Guarantor

Luca Palombi.

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