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# Calf volume changes with venous occlusion air plethysmography in assessment of patients after deep venous thrombosis

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***Background:*** **This is an analysis of the hemodynamic response of post-thrombotic legs to a sustained thigh compression and quick-release maneuver. This is an integral part of the investigation of venous occlusion plethysmography that has been promoted as a way of assessing the venous return. The aim was to quantify the venous volume changes in patients after deep venous thrombosis (DVT) and to determine whether refluxing legs differed from obstructed legs.**

***Methods:*** **The inflow and outflow air plethysmography tracings of 332 of 519 legs were examined retrospectively. These tracings from 192 patients were performed between 1989 and 1999. The median age was 51 (17-89) years; 65% of the patients were men, and 52% were left legs. The retrospective clinical class distribution (%) by the Clinical, Etiologic, Anatomic, and Pathologic (CEAP) classification was as follows: $C_0 = 5.4$, $C_2 = 3.3$, $C_3 = 68.4$, $C_4 = 13$, $C_5 = 3.6$, $C_6 = 6.3$. Inclusion criteria were a history of DVT and a duplex ultrasound examination documenting the site and type of deep venous disease. Ascending phlebography was performed in 28% of patients to complement duplex ultrasound in assessing the site of disease. Reflux was defined as reverse flow (>1 second) and obstruction as luminal narrowing, wall irregularity, or luminal echogenic material. Air plethysmography was performed in the supine position. After calibration with 100 mL of air, a thigh cuff was inflated to 80 mm Hg, and the resulting increase in calf volume was recorded by the sensor calf cuff with an ink trace on graphic paper. At the volume plateau, the thigh cuff was deflated suddenly to record the decrease in calf volume.**

***Results:*** **Reflux alone was identified in 19.6% of limbs and obstruction alone in 42.2%. Iliofemoral involvement was identified in 56.6%. The thigh compression/release maneuver caused a significant median (interquartile range) net reduction in calf volume by 9 (5-15) mL (*P* < .0005, Wilcoxon). The outflow volume was significantly greater than the inflow volume overall and also when legs were separated into categories on the basis of their site and type of disease (*P* < .0005, Wilcoxon). There was no significant difference in calf volume change in legs with iliofemoral involvement compared with those with distal disease. However, pure refluxing legs had significantly greater inflow and outflow volumes compared with legs with pure obstruction (*P* < .0005), with a median (interquartile range) reduction in calf volume of 13 (8-18) mL (reflux group) vs 7 (2-13) mL (obstruction group) (*P* < .0005, Mann-Whitney).**

***Conclusions:*** **Thigh compression significantly improves the venous return in patients after DVT evidenced by a greater absolute reduction of calf volume. This change was significantly greater in pure refluxing legs than in those with obstruction alone. (J Vasc Surg: Venous and Lym Dis 2014;2:416-23.)**

Venous occlusion plethysmography (VOP) after deep venous thrombosis (DVT) has been used for more than six decades as a way of quantifying the venous return. The early experiments used water VOP, but this apparatus was cumbersome and prone to leakage, and it required highly specialized equipment.[1] The introduction of air plethysmography (APG) for DVT in 1989 made the apparatus lightweight and user-friendly, when it became an accepted investigation for the assessment of venous obstruction.[2] This resulted in the worldwide dissemination of the technique of APG.[3-5] However, the use of VOP in the diagnosis of venous outflow impairment remains highly controversial.

The test of VOP requires the inflation of a thigh cuff to 80 mm Hg in a supine subject at rest. Once the resulting increase in calf volume plateaus, the thigh cuff is suddenly deflated to record the venous outflow (decrease in calf volume). Surprisingly, publications on the analysis of the resulting outflow curve have not highlighted the fact that the inflow or congestion volume is invariably less than the outflow or drainage volume. This implies that the effect of a thigh compression results in a net reduction in the volume of the calf after the thigh cuff has been deflated. There are many theories as to why this happens, which include opening up of the drainage pathways by the temporary

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occlusion and vasoactive mediators released as a result of postobstruction hyperemia.[6]

Because the assessment of venous return is of prime importance as a noninvasive technique in patients before and after venous stenting, this study aims to provide a detailed analysis of the inflow and outflow tracings in patients after DVT. The purpose is to determine whether patients with reflux or obstruction can be discriminated on the basis of the characteristics of their VOP tracings.

## METHODS

**Study design.** This was a retrospective study of prospectively acquired data of the VOP tracings obtained between 1989 and 1999 on all patients presenting with a suspected or proven DVT or follow-up of a DVT at a single tertiary referral center. The archived files included private as well as public health patients. The following documentation was reviewed: clinical referral letters, notes on patient history and clinical signs, onset and age of DVT, duplex ultrasound and phlebography reports, and summary letters and written information from the treating clinician. The charts consisted of routinely performed investigations collected as part of the PhD thesis of one of the authors. At that time there was no requirement for institutional review board (IRB) approval or consent for routine clinical material collected and used subsequently for publication. Although the Clinical, Etiologic, Anatomic, and Pathologic (CEAP) classification did not exist at the time, prospective data on the presence or absence of varicose veins, swelling, skin changes, and ulceration were recorded directly on the investigation sheets by two of the current investigators (E.K., G.G.). The inclusion criteria of the tracings that were analyzed were a proven DVT on duplex ultrasound or phlebography and the documentation of both the site and type (reflux, obstruction, or both) of disease.[7] The exclusion criteria were all the tracings from the legs that were studied for suspected DVT but did not have DVT. Patients with a non-DVT pathologic process were likewise excluded. All studies were performed in the same leg as the leg with a prior DVT. Contralateral "normal" legs were not included in the study. If patients had bilateral DVT or caval involvement (two patients), both legs were included.

Reflux (detected on an Ultramark 9 color duplex scanner with a 5-MHz linear probe; Advanced Technology Laboratories, Bothell, Wash) was defined as reverse flow >1 second after a manual calf compression and release maneuver in a standing patient. Obstruction was defined by duplex ultrasound as luminal narrowing (partial compressibility), wall irregularity, intraluminal echogenic material, or noncompressibility of the affected vein segment. Obstruction was defined on contrast phlebography as luminal narrowing (stenosis) or an occlusion. The presence of well-defined filling defects on at least two radiographs or nonvisualization of the femoral vein with good opacification of the proximal and distal veins was included in the definition. Follow-up VOP tracings were included also in patients with a proven DVT, irrespective of whether evidence of DVT persisted on the most recent duplex scan or phlebography test.

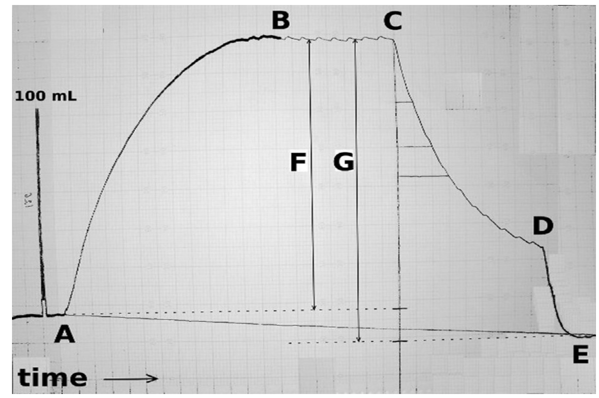


**Fig 1.** A calf volume vs time pen tracing of venous occlusion air plethysmography (APG) in a patient after deep venous thrombosis (DVT). *A,* Thigh cuff inflation to 80 mm Hg. *B,* Calf volume plateau. *C,* Sudden thigh cuff deflation. *B-D,* Increase in rate of the pen recorder to improve detail. *E,* New baseline. *F,* Inflow volume. *G,* Outflow volume. *G* minus *F,* Net decrease in calf volume.

**VOP.** All the tests were performed during the same session as the duplex ultrasound examinations by the same person (E.K.) with the APG air pump, a 5-L sensor calf cuff, a 100-mL calibration syringe, and a pressure transducer (APG, Model 1000, air pump with pressure-volume transducer; ACI Medical, San Marcos, Calif). An X-Y pen recorder (Hewlett Packard, Palo Alto, Calif) was used to trace the output onto graphic paper for analysis and archived. All examinations were performed in the supine position, with the knee slightly flexed and externally rotated and the heel resting on a 30-cm support. The sensor calf cuff was applied, calibrated by displacing 100 mL of air, and set up to record changes in calf volume. A high thigh tourniquet was inflated to 80 mm Hg until the calf volume reached a plateau. It was then deflated suddenly by disconnecting the mercury manometer. The following measurements were taken from the resulting trace (Fig 1):

1. The inflow or congestion volume, defined as the volume increase from the original baseline to the plateau.
2. The outflow or drainage volume, defined as the volume decrease from the plateau to the new baseline.
3. The net change in volume, defined by subtracting the inflow volume from the outflow volume.
4. The outflow fraction in 1 second ($OF_1$), defined as the reduction in volume during 1 second divided by the *outflow* volume, then multiplied by 100, to express the result as a percentage. The rate of the pen recorder was increased just before deflation and during the early part of the outflow curve to facilitate an accurate calculation of the $OF_1$ (Fig 1).

**Reference data.** Comparative reference values were obtained from a recent publication on the right legs of 19 healthy volunteers.[6] The median age (range) was 31