LOWER LIMB DOPPLER ULTRASOUND FOR THE STUDY OF VENOUS INSUFFICIENCY

Dr. Paola Paolinelli G.

Diagnostic Imaging Service, Clinica Las Condes, Santiago, Chile.

Abstract

Venous insufficiency is defined as an impaired venous return, which affects the superficial or the deep system, or both. This condition may be caused either by an alteration in the muscle pump, a venous obstruction, a valvular incompetente, or right-sided heart failure. It translates into a dynamic venous hypertension manifested through the development of varicose veins or trophic skin changes.

The surface failure is due to the presence of veno-venous shunts, which provoke a flow loss from the deep system through a vanishing point and then returns through another entry point. The study is performed with the patient in standing position, by stimulation of muscle pump through various exercises or increasing central pressure with Valsalva maneuver. The mapping is a graphic expression of the study and must show the type of shunt, location, and pattern of varicose veins.

Keywords: Venous Doppler exam, Venous insufficiency, Venous mapping, Veno-venous shunts, Ultrasound.


Corresponding author: Dr. Paola Paolinelli G.
ppaolinelli@clinicalascondes.cl

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Introduction

Venous insufficiency is a highly prevalent condition clinically manifested by the presence of varicose veins, telangiectasias, skin trophic changes, and ulcers. Color Doppler exam has proven to be a useful tool for the study of venous insufficiency and its consequences, by determining the source of reflux, the relationship between different venous systems, and the detection of anatomical variants. A properly conducted study is very useful for surgeons in treatment planning. Therefore, knowing in detail the anatomy and its variants, the physiopathology and presentation patterns of disease, is of vital importance.

I. Normal anatomy and variants

The venous system is divided into three sections: deep, superficial, and communicating systems (1).

(a) Deep system

Also called primary network (2), is located in the deep compartment under the muscular fascia or deep fascia and follows a path parallel to the arteries.

(b) Surface System (1)

It comprises interconnected venous structures that drain into two major veins: the internal saphenous vein or great saphenous, and the small saphenous or external saphenous vein.

The subcutaneous space, where superficial veins are to be found, is separated by a membrane termed superficial or venous fascia, in a deeper subcutaneous site located between superficial fascia and muscle fascia (called interfascial or saphenous compartment), and a truly subcutaneous compartment between the fascia and the skin (Figure 1).

Figure 1. Anatomic distribution of venous system. Planes: (1) Skin. (2) Superficial or saphenous fascia. (3) Aponeurotic or muscle fascia. Compartments: (4) Deep compartment, location of deep venous system. (5) Saphenous or interfascial compartment. (6) Truly subcutaneous compartment, where collateral or tributaries veins are to be found.
Saphenous compartment contains the secondary network (2), which comprises the internal and external saphenous veins, the anterior accessory saphenous vein, the thigh extension of the external saphenous vein (also known as vein of Giacomini, femoropopliteal vein or anastomotic magna), the medial and lateral marginal veins of the foot, and the dorsal venous arch of the foot. Through ultrasound (US) exam it is easily recognized by its biconvex appearance limited by the fascias, the so-called "saphenous eye sign" (Figure 2a) given that its configuration resembles this organ.

**Figure 2.** Superficial compartment. (a, b) Saphenous or interfascial compartment. Transverse cross-section (a) and longitudinal section (b) of internal saphenous vein (arrowhead), located between the muscle fascia (thick arrow) and superficial or saphenous fascia (thin arrow). (c) Truly subcutaneous space. Internal saphenous vein in saphenous compartment (arrowhead) and tributary vein in subcutaneous space (long arrow). Superficial fascia (short arrows).

Tertiary network is located in the truly subcutaneous space (2), which comprises tributaries or collateral veins (Figure 2c). Any venous structure located in this compartment should be considered as collateral or tributary veins. Location has a physiological importance since as a result of being in an open compartment they are more likely to suffer strain, unlike the saphenous veins.

**(c) Communicating or perforating system**

Formed by veins running through the muscle fascia, draining venous flow from the surface into the deep system (Figure 3).

Anatomy of the superficial and perforating systems, as well as superficial tributaries, will be thoroughly reviewed.

**Figure 3.** Communicating or perforating vein that perforates the muscle fascia (arrows), with normal flow from the superficial to the deep system.
SUPERFICIAL VEINS

1. Internal saphenous system (GSV)

It extends from the anterior aspect of the medial malleolus as a continuation of the medial marginal vein of foot, ascends through the medial aspect of the leg and thigh to reach the saphenous-femoral junction (SFJ) at groin. It is located in the saphenous or interfascial compartment, with its typical appearance in the thigh (sign of the eye) (Figure 4a), and in the leg it lies in the gastrocnemius-tibial angle (Figure 4b), covered by the superficial fascia. This fascia may be difficult to identify in exceedingly thin patients or in knee and ankle.

Deep system drainage

It occurs at the saphenofemoral junction or arch of the internal saphenous vein, which is located in the inguinal region. Adjacent to the ostium, it presents a terminal valve, that is usually easily visualized, and a preterminal valve, a further 2 cm distal which marks the distal area of the SFJ. Tributaries or collateral veins open between these two valves (1) (Figure 5).

Figure 4. (a) Internal saphenous vein in saphenous space in the thigh. "Eye sign". (b) Internal saphenous vein in gastrocnemius-tibial angle (arrow) in leg.

Figure 5. Saphenous-femoral junction. (a, b) Arch of internal saphenous vein. Terminal valve (white arrow), preterminal valve (arrowhead). (a, b, c) Proximal collateral veins: superficial iliac vein (green), superficial epigastric vein (yellow), superficial pudendal vein (purple).

Tributary or collateral veins

Internal saphenous vein is often accompanied by parallel veins of different sizes which might be confused with the very same saphenous vein or regarded as a double saphenous vein, but they are easily distinguishable due to their location above the superficial fascia. There are relatively constant tributary veins: (a) Tributaries draining directly into the arch of the internal saphenous vein: Tributaries are classified into proximal and distal veins (1). Proximal veins drain the abdominal wall and pudendal areas, being divided into the superficial iliac,
the superficial epigastric, and superficial pudendal veins. (Figure 5). They are formed either by a single vein or by several venous channels. These veins are clinically relevant because they can cause reflux towards the internal saphenous vein, compromising the arc valve.

Distal collateral veins are typically two: one lateral and one medial (Figure 6). The lateral is termed accessory saphenous vein and it is present in 40% of patients. It travels along the anterior aspect of the thigh and drains into the internal saphenous vein, adjacent to the sapheno-femoral junction, where a fairly constant lymph node can be found. It is easily recognizable and distinguishable from internal saphenous vein because it is aligned with the femoral vessels, in contrast to the internal saphenous vein, that lies medial to them (Figure 6c). It is very important to recognize and describe it, especially in varices with normal internal saphenous vein or in postoperative relapses.

**Figure 6.** Distal collaterals: (a and b) Accessory saphenous vein (red arrow) and anastomotic magna (green arrow). Internal saphenous vein in blue. (c) Cross-section. Accessory saphenous vein (red arrow) aligned with the femoral vessels (white arrows). Internal saphenous vein (blue arrow).

The medial collateral vein, which usually binds distal to the preterminal valve, continues in the external saphenous vein along the posterior aspect of the thigh; it is called anastomotic magna or vein of Giacomini (Figure 8). There is another tributary vein, the central vein of the lymph node, which lies adjacent to the accessory saphenous vein. Occasionally, it may be incompetent and generate reflux towards the internal saphenous vein.

(b) **Tributaries draining into the internal saphenous vein**

One of the most consistent collateral veins corresponds to the so-called posterior arch, with wide variability in its drainage into the internal saphenous vein; it is often responsible for developing varicose veins in venous insufficiency.

**Patterns of presentation of the internal saphenous system**

Various different patterns of presentation of the internal saphenous system and its tributaries are recognized; they are grouped as follows (Figure 7):
(a) Unique saphenous vein running transversally in the interfascial compartment at thigh and leg level, with no tributaries identified (Figure 7a).

(b) Presence of double internal saphenous vein in interfascial compartment, with variable extension into thigh and leg, with no collateral veins (Figure 7b).

(c) Presence of normal internal saphenous vein in interfascial compartment, both in thigh and leg. The origin of the posterior tributary arc is variable at thigh, knee or leg level (Figure 7c).

(d) Presentation similar to above, with hypoplasia or atrophy of the internal saphenous vein distal to tributary vein. Origin of the tributary may also be at thigh, knee or leg level (Figure 7d).

The presence of accessory saphenous vein can be associated with any of these patterns.

**Figure 7. Patterns of presentation of the internal saphenous system.**
Saphenous space (arrows). (a) Unique saphenous vein in saphenous space. (b) Double internal saphenous vein in saphenous space. (c) Normal internal saphenous vein plus posterior arch that can arise at different levels (in purple). (d) Developed posterior arch with origin at variable level, internal saphenous vein distal to hypoplastic or atrophic vein.

### 2. External saphenous system (SSV)

The external saphenous or small saphenous vein originates behind the lateral malleolus as a continuation of the lateral marginal vein of the foot (Figure 8) and ascends through the posterior aspect of the calf, between the two fascias, in the interfascial compartment (Figure 8b). It may appear doubled or tripled.

**Deep system drainage**

Drainage into the deep system is variable; it may present the following patterns: drainage into the popliteal vein through saphenous-popliteal junction in popliteal fossa or distal thigh (being the most common); drainage into the deep veins of the leg (gemelar veins) or continuation to the thigh through anastomotic magna, which opens into the proximal internal saphenous vein (most often), in veins of the gluteal area, in posterior perforating veins, posterolateral thigh perforating veins, or in several subcutaneous branches (Figure 8). In 2/3 of people who have the anastomotic magna, a saphenous-popliteal junction is not found (4).
Figure 8. External saphenous system. (a) Distribution scheme and variants. External saphenous vein (in blue), vein of Giacomini (in yellow), saphenous popliteal junction to popliteal vein or gemelar vein (blue dotted line). Possible drains of Giacomini vein into deep system (yellow dotted line). Popliteal area vein: tributary (in red). (b) Cross-section of external saphenous vein in saphenous space.

**Variants and Collaterals**

The vein of the popliteal area is an important superficial collateral that runs subcutaneously through the posterior aspect of the popliteal area, calf and leg, sometimes parallel to the external saphenous vein and drains into the popliteal vein, lateral to the saphenous popliteal junction.

Veins can also be seen accompanying the sciatic nerve in the posterior aspect of the leg and thigh, which may be confused with the external saphenous vein (Figure 14d).

3. Veins of the foot

The superficial system is also divided in two components: the dorsal venous arch and the medial and lateral marginal veins that give origin to the saphenous vein; they are located under the surperficial fascia, whereas collateral veins of the dorsum of the foot are located subcutaneously and continue onto the collateral veins of the leg.

4. Communicating or perforating veins

The largest veins correspond to the archs of the internal saphenous and the external saphenous veins. Most of them drain the blood flow into the deep system (entrance communicating veins). It is important to identify insufficient communicating veins with reverse flow.

II. PHYSIOLOGY AND PHYSIOPATHOLOGY

1. Physiology

The venous system acts as an important blood reservoir and conductor. It receives blood from the capillaries and takes it to the heart, against both gravity and a fluctuating thoracic-abdominal pressure; it lacks a pump of its own. To have an adequate drainage to the heart, a permeable venous system,
undamaged valvular and muscular system (valve-muscle pump), and a preserved cardiac function are required (Figure 9).

In standing position, the hydrostatic pressure of the dorsal veins of the foot would be that of the continuous column of blood running down from the right atrium to the foot if there were no valves interrupting and fractionating this migrating flow. When the muscles of lower extremities contract (muscular systole), pressure increases, thus pumping blood to the heart (Figure 9 a). By relaxing the muscles (muscular diastole), pressure falls producing reflux, which is hindered by the valves (Figure 9b); this is the phenomenon searched for when the study is performed in standing position. In this article the terms systole and diastole will not be used, as they might lead to confusion.

The superficial system drains into the deep system through the arches and perforating and/or communicating veins to subsequently ascend through the deep system.

**Figure 9.** Valvular muscular pump. (a) Contraction of muscles (in red) pumps blood to the heart, passing through the valves (arrowheads). (b) By relaxing the muscles, pressure in the veins is diminished, thus creating a sucking effect. A short retrograde flow occurs, process that continues until the valves close (circle).

**2. Physiopathology**

Venous dysfunction is defined as an impaired venous return, which compromises the superficial system, the deep system, or both, whose cause may be alteration in the muscle pump, venous occlusion, valvular incompetence, or right heart failure.

When the seal of a venous valve fails, hydrostatic pressure is transmitted in its entirety from the right atrium to the foot and blood reflux occurs, which determines the clinical manifestations of venous insufficiency, such as vascular dilation and dystrophic phenomena of the skin.

Conceptually, the anterograde flow is defined as the one having physiological direction (towards the heart), whereas retrograde flow runs in opposite direction. The vanishing point is the site where blood flows from deep to superficial compartment and the entry point is the place where blood flows from the superficial to the deep compartment (1).
The phenomenon of superficial insufficiency can be described as a venovenous shunt or retrograde loop, which comprises the vanishing point (e.g., the saphenous-femoral junction, or an insufficient perforating vein), an usually retrograde pathway, being varicose veins its visible part, and finally, a re-entry point to the deep venous system (via perforating veins) (2) (Figure 10a). This shunt may be activated during the contraction and/or muscle relaxation and has to be differentiated from other pathologies that may manifest similarly. A clear example of this is the vicarious flow that occurs in response to a venous occlusion, where the superficial system acts as a bridge or collateral pathway for allowing the blood flow to ascend (Figure 10b).

**Figure 10.** (a) Veno-venous shunt. Deep system (white arrows), vanishing point (arch of the insufficient internal saphenous vein (short arrow)), varicose superficial system (asterisks), point of entry (double arrow). Yellow arrows indicate direction of flows. Antegrade flow in deep system and communicating veins; retrograde flow in superficial system and in the arch of internal saphenous vein. (b) Vicarious shunt. Retrograde flow in the arch of internal saphenous vein, to propel flow to the superficial system, by iliac vein occlusion (in black).

Traditionally, reflux has been defined as the presence of retrograde flow with a duration > 0.5 sec (Van Bemmelen et al.) In fact, considering a fixed period of time can lead to error because characteristics of the reflux will depend on the state of the damaged valve. If damage is not so important and the closure defect is small, a long-duration and low-velocity reflux will occur (Figure 11a). On the contrary, if the damage is very severe, a short-duration and high-velocity reflux will take place (Figure 11b). Therefore, criteria for reflux include retrograde flow during muscle relaxation longer than 0.5 sec, or shorter if the velocity is greater than the anterograde velocity during muscle contraction (Figure 12).

**Figure 11.** Retrograde flow due to valve insufficiency. (a) Slightly damaged valve, with a small defect at closure point which determines a sustained and low-velocity reflux (arrow). (b) Valve badly damaged, with large defect at closure point, which determines a high-velocity and short-duration reflux (arrow)
As explained above, perforating veins (or communicating veins) transmit the surface blood flow to the deep system (ante grade flow). These veins may be insufficient, thus acting as vanishing points, and/or act as entry communicating veins, which are responsible for taking back to the deep system the flow that has escaped from it. When studied with Doppler US (3), they may have a continuous antegrade flow (Figure 12 a) or a slight retrograde flow during muscle contraction, whereas during relaxation it shows an antegrade flow greater than retrograde flow (Figure 12 b). When retrograde flow occurs during muscle relaxation (Figure 12d) or when retrograde flow during muscle contraction is greater than the antegrade flow during muscle relaxation (3) (Figure 12c), insufficient communicating vein is diagnosed.

**Figure 12. Study of communicating veins.** (a, b) Sufficient communicating veins. (a) Antegrade flow in muscle contraction and relaxation. (b) Small reflux with contraction, greater antegrade flow during relaxation. (c, d) Insufficient vessels: (c) Reflux with contraction, greater than antegrade flow during relaxation. (d) Retrograde flow with relaxation and antegrade flow with contraction.

### III. PATTERNS OF SUPERFICIAL VENOUS INSUFFICIENCY

To ensure a successful surgical treatment it is highly important to determine the anatomy and hemodynamic behavior of the venous system in order to identify which are the vanishing points that determine varices, re-entry points, and so forth.

Generally, the disease presents repeated patterns among patients, alone or in combination, which can be grouped as follows (2,3):

1. **Internal saphenous vein insufficiency**
   
   **(a) With insufficient arch (Figure 13a and b)**
   
   - to the foot: rare to find
   - to the knee: most frequent; generally, the insufficiency continues through the posterior tributary vein to the lower leg

   **(b) With sufficient arch: Reflux can be fed by (Figure 13c):**
   
   - Collateral veins of the arch
- Thigh perforating veins
- Anastomotic magna
- Tributary vein coming from the external saphenous system. Extension towards the leg is variable and insufficiency of the accessory saphenous vein, with or without involvement of the internal saphenous vein, must be included.

2. Insufficiency of the external saphenous vein (Figure 13d)
(a) From the insufficient arch (saphenous-popliteal junction), usually limited to the upper half of leg
(b) With sufficient or absent arch; insufficiency coming from the anastomotic magna

**Figure 13. Patterns of internal saphenous system insufficiency.** Internal Saphenous vein in blue, tributary veins in yellow. Red circles, vanishing points. Insufficient vessels, dotted lines. Entry communicating veins in green. (a) Insufficient internal saphenous vein from arch to the foot. (b) Insufficiency from the arch to tributary vein, which continues insufficient. Distally, the internal saphenous vein is normal. This is the commonest pattern. (c) Sufficient arch. Vanishing point from tributary veins: arch collateral veins (1), Giacomini vein (2), vulvoperineal veins (3), of external saphenous (4). Variable to distal. (d) External saphenous vein. Insufficiency due to arch or vein of Giacomini (less frequently seen).

3. Non-saphenous reflux (Figure 14)
Is the one that primarily does not compromise the saphenous system, but may be connected to it.
It is rare in men, predominantly found in women due to their own etiologic mechanisms (5) such as pregnancy and hormone load.
They are varicose veins that originate from vulvo-perineal, gluteal, and intrapelviana regions, (due to insufficient ovarian veins), and also because of perforating and sciatic veins. They are located in lateral and posterior thigh, popliteal fossa, and lateral knee.

IV. ULTRASONOGRAPHY

The objective of vascular Doppler study is to confirm venous permeability, identify the type of venous insufficiency (deep, superficial, and/or of
communicating veins), determine the points of reflux/entry, and perform the vein mapping (graphic expression of the study) as follows:

1. **Discard thrombosis**

   The study begins with patient in semisitting or standing position, with graduated compression of venous structures, recording variability of the curve in common femoral vein to discard iliac axis occlusion. Through this procedure we discard that a retrograde flow pattern actually may correspond to a vicarious flow (Figure 10b).

2. **Detection of insufficiency (for deep, superficial, and communicating systems)**

   It is performed in a standing position; the patient is placed on a protected platform with a system for measuring the height of insufficient communicating veins (Figure 15).

   **Figure 14. Non-saphenous reflux. Insufficient non-saphenous veins and their tributaries. Vanishing point in red circle. (a) Glutes. (b) Posterolateral thigh perforating veins, with varices on the lateral aspect of the thigh and leg. (c) Vulvoperineal veins. (d) Sciatic vein. (e) Insufficient perforating veins: posterior thigh, popliteal fossa, knee.**

   To force a retrograde flow in order to check indemnity of valves, thoracoabdominal pressure can be increased or contraction and relaxation of lower limb muscles can be induced:
   - Increase of thoracoabdominal pressure: Valsalva maneuver is employed. It is useful in veins above the knee.
   - Contraction (systole) followed by muscle relaxation (diastole): muscles act as a sponge, forcing blood to fall in diastole to test the valves (Figure 16).

   It can be obtained through different techniques:
   - Parana Maneuver, technique where a standing patient is slightly pushed off-balance (forward or backward) to cause muscle contraction for maintaining balance, followed by muscle relaxation.
   - Alternating weight-bearing in extremities: patient bears his/her weight on the extremity under study, and then on the other limb.
- Voluntary muscle contraction
- Dorsiflexion of the toes: the most comfortable technique for both patient and operator.
- Distal compression applied with the hand

To obtain more reliable information, one maneuver or a combination of them may be carried out.

At Doppler examination, the first stage of contraction or muscle compression manifests as an upward flow jet, and in the second phase (relaxation) reflux becomes evident (Figure 12).

Assessment of incompetent communicating veins is performed similarly, recording their location in centimeters in relation to the ground (more objective than related to the malleolus) by using a measuring tape attached to the board, or by marking directly on the skin.

**Figure 15.** Board to place the patient, with tape measure attached to it.

### 3. Vein mapping

A diagram showing vanishing points, venous flow direction, varicose packages, communicating at entry, and insufficient veins, has to be drawn. It is recommended to register vein diameters and to mark which vessels are insufficient (registering height), besides drawing arrows to show blood flow direction (Figure 17).

**Figure 16.** Muscle contraction and relaxation maneuvers. The first photo of each series shows muscle contraction and the second one shows muscle relaxation. (a) Parana Maneuver. (b) Distal compression of muscles. (c) alternating weight-bearing.

**Figure 17.** Example of right leg vein mapping. Shown: (a) Arch of normal internal sphenous vein. (b) Insufficient internal sphenous vein. (c) Insufficient and dilated superficial tributaries. (d) Normal external sphenous vein. (e) Insufficient external saphenous vein arch. (f) Anastomotic magna. (h) Sufficient internal saphenous vein. Numbers indicate the vascular diameter; arrows indicate blood flow direction; in orange, insufficient vessels; circles show vanishing points. Diagnosis: Internal saphenous vein insufficiency with sufficient arc caused by Giacomini vein that is overloaded due to insufficiency of the external saphenous vein arch.
PATIENTS WITH RELAPSED VARICES

Common clinical patterns of venous insufficiency change when the patient has undergone surgery; nevertheless, these patterns have to be taken into account whenever new sites of vanishing points and tributary veins need to be detected.

Concerning the internal saphenous system, awareness of accessory saphenous veins and tributaries coming from the gluteal or pudendal-perineal regions (from the pelvis) as well as development of neovascularization in the arch area, whether linked or not to a long remnant, is of vital importance. In the external saphenous system, the presence of perforating veins must be searched for.

Conclusions

In the cases of venous insufficiency it is crucial to carry out a complete study of the venous system both anatomically and hemodynamically, thus enabling surgeons to properly implement the surgery.

Knowledge of normal venous anatomy, its variations, and patterns of saphenous and non-saphenous reflux is of great help for conducting image-directed studies.

References

Figura 2. Compartimento superficial. a, b) Compartimento safeno o interfascial. Corte transversal a) y longitudinal b) de vena safena interna (cabeza de flecha), ubicada entre la fascia muscular (flecha gruesa) y la fascia superficial o safena (flecha fina). c) Espacio subcutáneo verdadero. Si en compartimento safeno (cabeza de flecha) y vena tributaria en espacio subcutáneo (flecha larga). Fascia superficial (flechas cortas).
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Figura 15. Tarima para colocar al paciente, con cinta de medir adherida.
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**Figura 17.** Ejemplo de mapeo venoso de pierna derecha. Se muestran: a) Cayado de SI normal. b) SI insuficiente. c) Tributarias superficiales insuficientes y dilatadas. d) SE normal. e) Cayado de SE insuficiente. f) Anastomotica magna. g) Comunicantes de entrada. h) SI suficiente. Los números indican el diámetro vascular, las flechas el sentido del flujo, en naranja los vasos insuficientes y los círculos los puntos de fuga. Diagnóstico: insuficiencia de safena interna con cayado suficiente, causada por vena de Giacomini sobrecargada de flujo por insuficiencia del cayado de la safena externa.