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ORIGINAL ARTICLE

CHIVA: hemodynamic concept, strategy and results

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ABSTRACT

The first part of this review article provides the physiologic background that sustained the CHIVA principles development. Then the venous networks anatomy and flow patterns are described with pertinent sonographic interpretations, leading to the shunt concept description and to the consequent CHIVA strategy application. An in depth explanation into the hemodynamic conservative cure approach follows, together with pertinent review of the relevant literature.

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CHIVA is a French acronym for "Cure conservatrice et Hemodynamique de l'Insuffisance Veineuse en Ambulatoire" (Conservative and Hemodynamic treatment of the Venous Insufficiency in an office based setting). It is a saphenous-sparing therapeutic approach for lower limb chronic venous disease (CVD) based on hemodynamic concepts proposed by Claude Franceschi in 1988.[1-6] The hemodynamic model takes into consideration the pressure overload occurring in the presence of valvular incompetence and/or a drainage obstacles. The consequent pressure and flow overload leads to vessel dilation, tissue drainage impairment, onset of CVD signs and symptoms (edema, varicosities, skin changes and ulceration, pain, heaviness, itching).

CHIVA strategy is aimed to restore a physiological drainage by an accurate hemodynamic investigation, without any venous ablation. Hemodynamic correction identifies the specific overloaded networks, subsequently suppressing the pressure overload by targeted ligations that are customized on each specific reflux pattern.

Detailed duplex ultrasound scanning (DUS) and preoperative mapping are essential to detect the exact refluxing points to treat: a therapeutic act that can be obtained by mini-invasive procedures under local anesthesia in an office-based setting.

Apart from the possible vital role as arterial bypass,[7-12] the saphenous sparing feature preserves a main conduit for the tissue drainage: a hemodynamic scenario that is considered as the basis for reducing the onset of recurrences. Several randomized trials compared CHIVA with Stripping [13-18] or compression.[19] A Cochrane review (2013) demonstrated the need for further investigations but also summarized the evidence for a long term lower recurrence rate when the saphenous-sparing rather than the ablative strategy was used.[20]

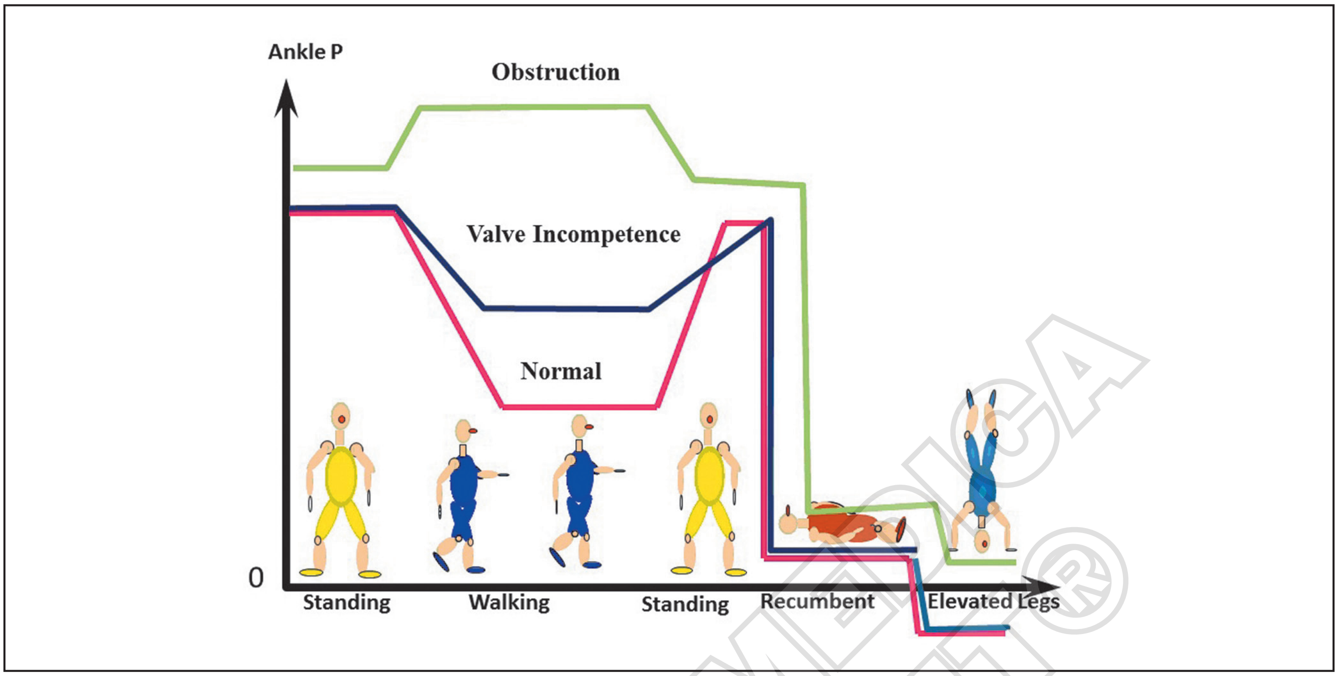

Figure 1.—Ankle venous pressure according to posture.
Ankle venous pressure shows no differences among healthy and CVD cases, whatever the posture is. The difference appears only upon VMP action. Obstruction increases the ankle pressure whatever the posture is, particularly whenever walking (venous claudication).

Hemodynamics principles

Tissue drainage, thermoregulation and heart filling are the three main functions of the venous system, made of conduits and pumps that drain the tissues from the capillaries to the heart, according to a cardiopetal venous pressure gradient (VPG) that drives the blood. VPG is represented by the pressure difference between the postcapillary residual pressure (ReP) and the right atrial pressure (RAP), (VPG=(ReP-RAP)/ankle-heart distance). The heart [21] and abdomino-thoracic [22] pumps act permanently, and the peripheral valvo-muscular pump (VMP) occasionally. [23-25]

ReP, VMP and gravitational hydrostatic pressure (GHP) constitute the intravenous and capillary pressure (IVP).

$$IVP=p+\frac{1}{2}\rho v^2+\rho gh=Cte \text{ (Bernouilli's law)}$$

p=static pressure; $\frac{1}{2}\rho v^2$=dynamic pressure; ρgh=GHP=gravitational hydrostatic pressure; ρ=density; v=flow velocity; g=gravity acceleration; h=height of the liquid. GHP varies only with the vertical height of the column h. $\rho gh1<\rho gh2$.q varies only with p ($p1+\frac{1}{2}\rho v1^2=p2+\frac{1}{2}\rho v2^2=Cte$); $p+\frac{1}{2}\rho v^2$ is the sum of Rep and VMP pressure.

Intravenous lateral pressure (IVLP) is the static and hydrostatic part of IVP=p+ρgh. This hemodynamic interpretation is accepted despite the facts that blood is not a Newtonian fluid, the vessels are not ideal conduits and the system is not steady (in particular during VMP systole).

ReP is the remnant after the arterial pressure loss through the arteriolo-capillary resistance according to the Poiseuille Law. VMP pressure derives from the plantar sole, calf and thigh muscle contraction (systole) /relaxation (diastole). GHP values varie with the height of the blood column, *i.e.* the body posture.

IVLP acts on the venous wall and capillary determining the so called transmural pressure (TMP), expressed as a difference among the IVLP and the external venous pressure (EVP) (represented by the atmospheric and tissue pressure).

TMP determines venous calibre, according to the Tension (laplace law) and wall Compliance. Tension=Stretching force=TMP/vessel radius. Compliance is the venous vessel feature of dilation according to the TMP. Venous calibre=Compliance/Tension is

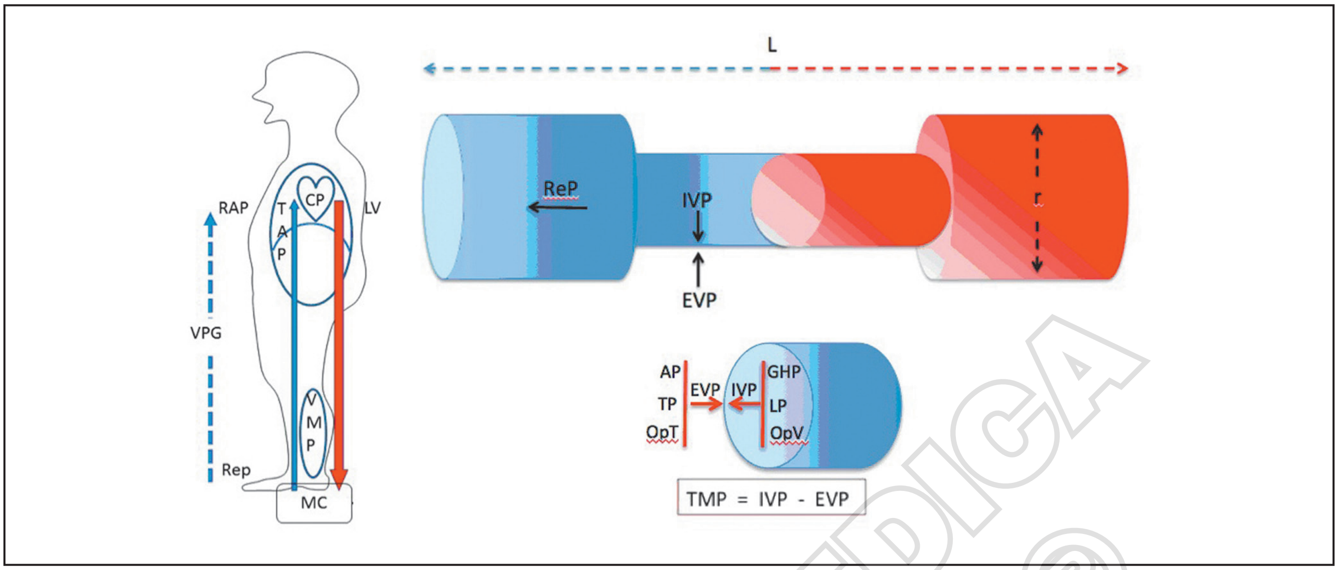

Figure 2.—Venous pressure gradient determinants.
VPG: venous pressure gradient; ReP: residual pressure; RAP: right atrial pressure; TAP: thoraco-abdominal pump; VMP: valvular-muscular pump; LV: left ventricle; CP: cardiac pump; MC: micro-circulation; r: arterioles radius; L: microvessels length; IVP: intra-venous pressure; EVP: external venous pressure; AP: atmospheric pressure; TP: tissue pressure; OpT: oncotic tissue pressure; OpV: oncotic venous pressure; LP: lateral pressure; HP: hydrostatic pressure.

usually described by a sigmoid curve, related to Hook's law of elasticity. Nevertheless, the variable compliance of the venous wall makes the caliber variations not linear.[45] Another factor represented by the turbulences can affect the venous wall. Reynolds Number describes the conditions for a change of laminar flow (parallel vectors) into turbulent (anarchic vectors) inside a conduit. When its value is attained for a specific velocity/kinematic viscosity ratio, turbulences redirect vectors against the venous wall, adding their dilating effect to the lateral pressure. With time, the consequent dilation results in disappearance of turbulence due to velocity lowering which itself stops the dilation progress.

The possibility of containing important volume values inside the venous bed, thanks to the wide compliance values, leads to a significant pressure value stabilization despite the increasing amount of blood gathering there: it is the so called reservoir effect that supplies instantly the right heart variable preload needs.

Inside the capillaries, together with the Oncotic pressure, TMP determines the tissue drainage according to Starling law. Thus, TMP can be considered as the main parameter to consider in a CHIVA strategy, being the result of the action of several factors acting both on the macro and micro-vasculature. An increase in TMP is in fact responsible for venous dilation, formation of varicosities and drainage impairment (edema, skin disorders, ulceration). CHIVA goals aim to suppress the flow and pressure overload, affecting the factors determining turbulence and reducing TMP. A consequent varicose veins caliber normalization and physiological draining restoration is expected.[46]

ReP normal value is around 20 mmHg at rest. Nevertheless, it increases as a result of micro-heat (thermoregulation), inflammation and arterio-venous shunts because of decrease in resistance to flow. ReP increases also in proportion to the resistance caused by pathological venous obstacles (thrombosis, hypoplasia, venous ablation) and right heart failure (Figure 1).

According to CHIVA interpretation this resistance increase favors the appearance of matting, spider veins and postablation recurrent varicose veins in the attempt to by-pass the drainage obstacle, justifying a saphenous-sparing approach as CHIVA.[16]

Besides the invasive method, TMP can be measured at the ankle similarly to the arterial pressure detection, by using a DUS assessment of the posterior tibial vein, evoking the flow by a cuff.[26-37]

The thoraco-abdominal pump is involved in VPG determination too (Figure 2).

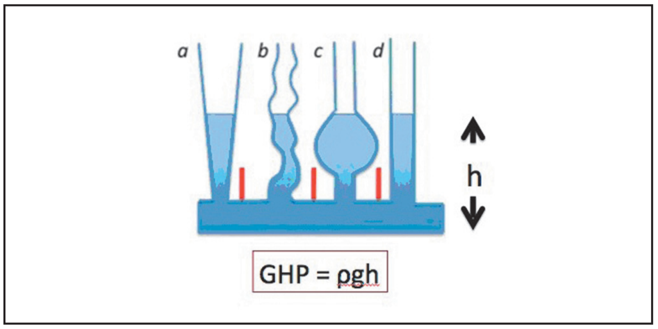

Figure 3.—Gravitational hydrostatic pressure (GHP).
GHP depends only on the vertical height of the fluid and not the length, shape or volume of the pipes.

Intrathoracic and/or intra-abdominal venous pressures vary with the breath throraco-abdominal compression (systole) and relaxation (diastole) phases, alternately increasing and decreasing the VPG. The forced systole (coughing) reverses the VPG, closes the below venous valves and stops the flow. Reflux occurs if the valves are incompetent. This is the rationale underneath the so-called Valsalva Manoeuvre (VM) obtained by activating the thoraco-abdominal musculature or, even better, by blowing into a closed straw.[38]

GHP is proportional to the gravitational acceleration g, the blood density ρ and to the blood column height h (GHP=gh). According to the Stevin's law, it creates a hydrostatic pressure (potential energy) directly related to the column height itself (communicating vessels principle) (Figure 3). GHP varies dramatically with the body posture change whenever the blood column vertical height (h) changes. At the ankle it decreases from a standing value around 90 mmHg down to null in a recumbent position, even becoming negative (lower than the atmospheric pressure) whenever the feet are raised above the heart level.

During motionless standing the GHP at the ankle is maximal because all the valves are open so that the blood column is continuous from the ankle to the heart (h).

In case of a life habit of prolonged motionless standing the high pressure prolonged regimen can lead to CVD-like symptoms appearance despite the absence of evident refluxes. Conversely from pathology, in a healthy individual, these signs and symptoms disappear

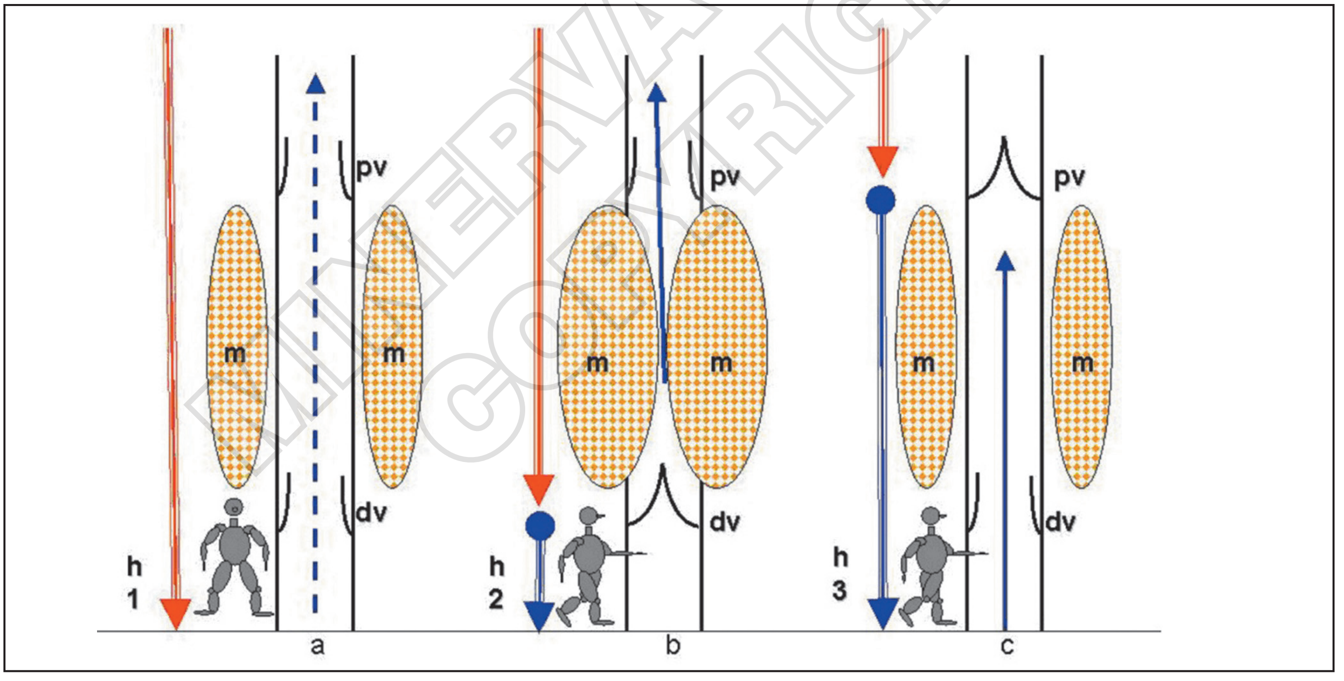

Figure 4.—Dynamic fractioning of the gravitational hydrostatic pressure following the valvulo-muscular pump activation.
M: muscles; dv: distal valves; pv: proximal valves; h: GHP column height.
Dv and Pv cyclic opening and closure reduce GHP during VMP systole (b) and diastole (c) by blood column segmentation into height h1, h2, h3.

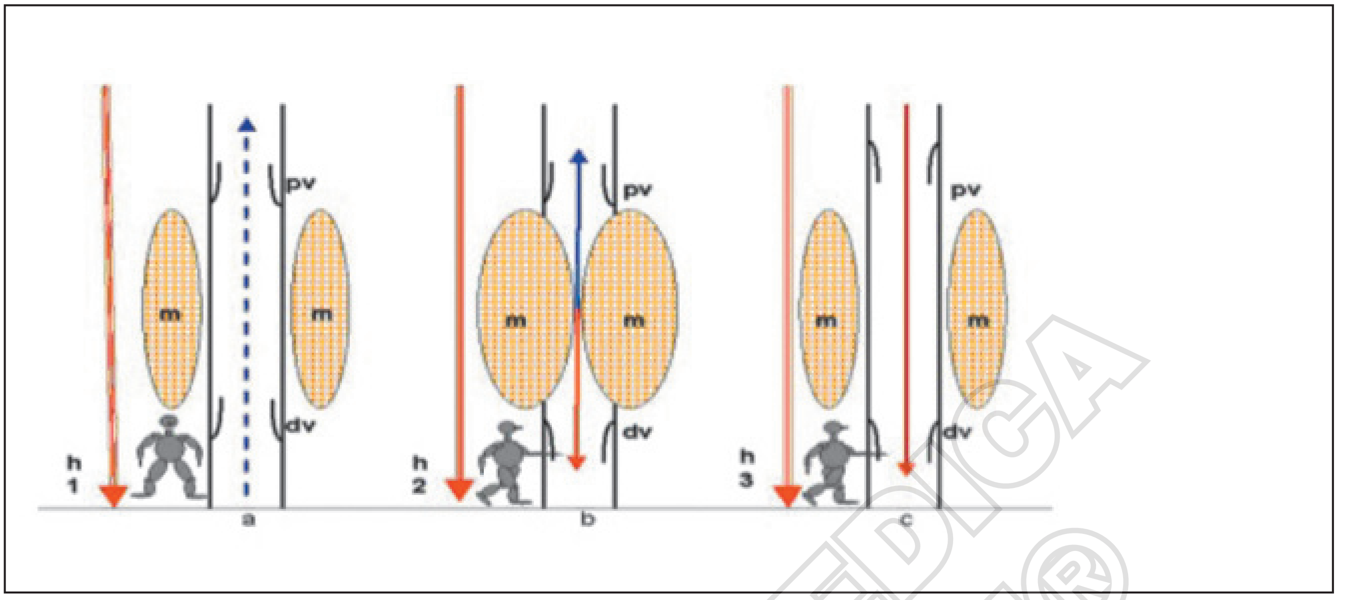

Figure 5.—Pathological dynamic fractioning of GHP.
M: muscles; dv: distal valves; pv: proximal valves; h: GHP column height.
Dv and Pv cyclic opening and closure reduce GHP during VMP systole (b) and diastole (c) with impaired blood column segmentation (h1=h2=h3), so leading to a persistent GHP overload.

as soon as the VMP creates a 35 mmHg of pressure gradient among the calf and the thigh, thus decreasing the pressure overload (Figure 3).[39, 40]

In the upright position the physiological way to reduce GHP is the alternate closure of the venous valves upstream and downstream the muscular pumps along the lower limbs. Indeed, these alternate closures dynamically compartmentalize the blood in smaller hydrostatic columns that download their pressure load at every step of valvulo-muscular systo-diastole.

In this scenario the venous valves are to be considered as a single functional unit together with the muscular pump, creating the so called valvulo-muscular pump (VMP). In order to restore the venous drainage and lowering the pathological increased TMP, CHIVA exploits the physics laws acting on this dynamic physiological mechanism, calling it dynamic fragmentation of the gravitational

hydrostatic pressure (DFGHP) (Figure 4).[1-4, 41]

In a pathological condition of venous reflux, there is a VMP failure in dynamically compartmentalizing the hydrostatic columns, with a consequent DFGHP impairment.

Extent (total or partial) and localization of VMP failure determines the severity of the drainage subversion (Figure 5).[40-44]

Despite a healthy VMP, DFGHP is impaired also when incompetent superficial veins connect to the deep competent veins below and above the VMP (Figure 6). This condition represents the large majority of cases of CVD. In these cases, beside the Shunts disconnection, the CHIVA targets is fractioning (segmenting) this too high superficial incompetent column by means of selected interruptions, restoring the DFGHP, suppressing the pressure overload, favoring a low lateral pressure inside the capillaries, leading to liquid and catabolite aspiration into the venous system.[1-4]

Clinical anatomy and drainage hierarchical order

In 1988 a lower limbs anatomical classification was proposed according to the different compartments created by the muscular fascia, with pertinent clinical correlations regarding the drainage direction.[1-4] The classification was based both on anatomical and sonographic investigations.[45-47] These three different compartments

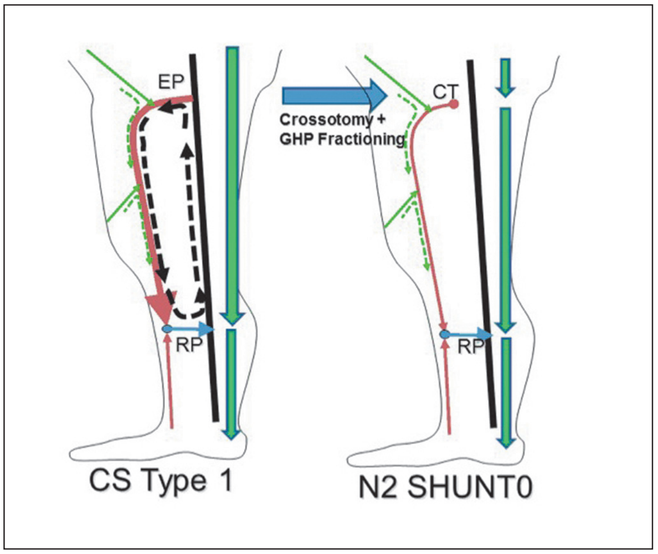

Figure 6.—Shunt Type 1 (short) Closed Shunt therapeutic strategy.
Back dotted line: CS systo-diastolic loop (closed circuit). Thick green arrows: blood column height and its segmentation. Green thin dotted lines: N3 diastolic flow direction during the VMP diastole. During the diastole, the deep blood refluxes from N1 toward N2 (SFJ is the EP), overloading the GSV that refluxes downward, then turning back into N1 by an upper leg perforator (N2>N1 RP). The consecutive systole propels the same blood up to EP where it leaks once more into the GSV. This recirculation in closed circuit defines the Closed Shunts CS.
SFJ incompetence impairs the DFHGP, so adding high GHP to the shunt overloading flow.
N2 SHUNT 0: The high tie blocks the leaking flow from N1, fractioning the GHP.

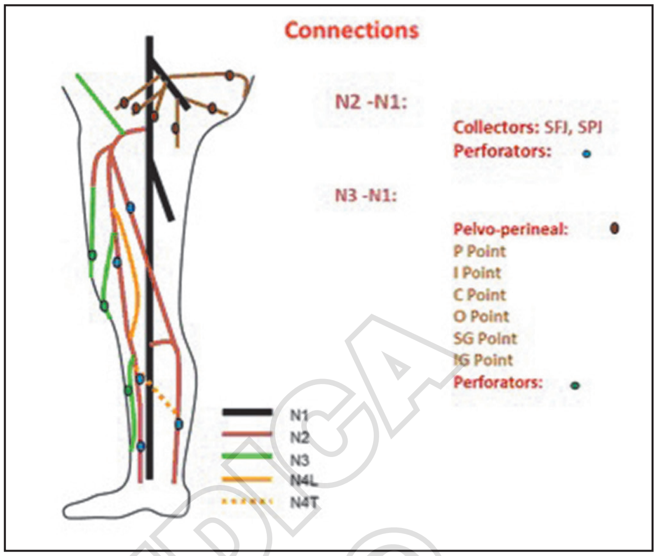

Figure 7.—Anatomical classification.
Is based on vessels localization below (N1), in between (N2) or above (N3, N4L, N4T) the muscular fascia. N1: Deep venous system below the muscular fascia. N2: Saphenous system in between the fascia splitting (GSV, SSV, Giacomini). N3: tributaries above the fascia (GSV and SSV tributaries and extrasaphenous ones). N4: tributaries interconnecting two N2 segments (N4L whenever connecting longitudinally two segments of the same N2 vessel; N4T whenever connecting transversely two segments of two different N2 veins.
Junctional points among the networks are the sapheno-femoral junction (SFJ), the sapheno-popliteal one (SPJ), the PV. Pelvic escape points: Pudendal (P), Inguinal (I), Clitoral (C), Obturator (O), Superior Gluteal (SG), Inferior Gluteal (IG).

(networks N1, N2 and N3 were recognized by the 2006 UIP consensus document on lower limb venous anatomy (Figure 7).[48, 49]

Venous network N3 is superficial to the fascia and is represented by the saphenous tributaries that are surrounded by subcutaneous fat. An N3 subdivision distinguishes as network N4 longitudinal (N4L) or transverse (N4T) those N3 tributaries that connect the same (N4L) or two different (N4T, Leonardo's vein interconnecting the great and small saphenous vein [SSV] for example) segments of the N2 saphenous system.

Venous network N2 collects blood from N3 and consists of the great saphenous vein (GSV), SSV, anterior accessory saphenous vein (AASV) and Giacomini Vein which vessels lay inside the fascia that splits in two, wrapping the N2 veins like a natural elastic stocking.[47, 50, 51]

Venous network N1 includes the deep vessels (femoral, popliteal, soleal and gastrocnemial veins) that are located deep to the fascia and surrounded by muscles.[44, 52]

A hierarchical order of physiological venous drainage occurs directly from the most superficial network N3 into N1 or indirectly through the N2 collectors (Figure 8). Consequently, a reflux could be also defined as any change of the hierarchical order of venous emptying, whatever the N3 or N3 segmental flow direction.[53] For this reason, reflux should no longer be a mere time cut-off value, rather it could be defined as any change of the hierarchical order of venous emptying. At the same time a retrograde flow is not necessarily a pathological reflux, as long as it still obeys the physiological hierarchy and is not overloaded (so called Shunt 0, see following section). In the same way a physiological direction does not always mean normal physiology: in case of an obstruction, a collateral vessel can offer a natural by pass in the physiological direction but in the pathological drainage hierarchy.

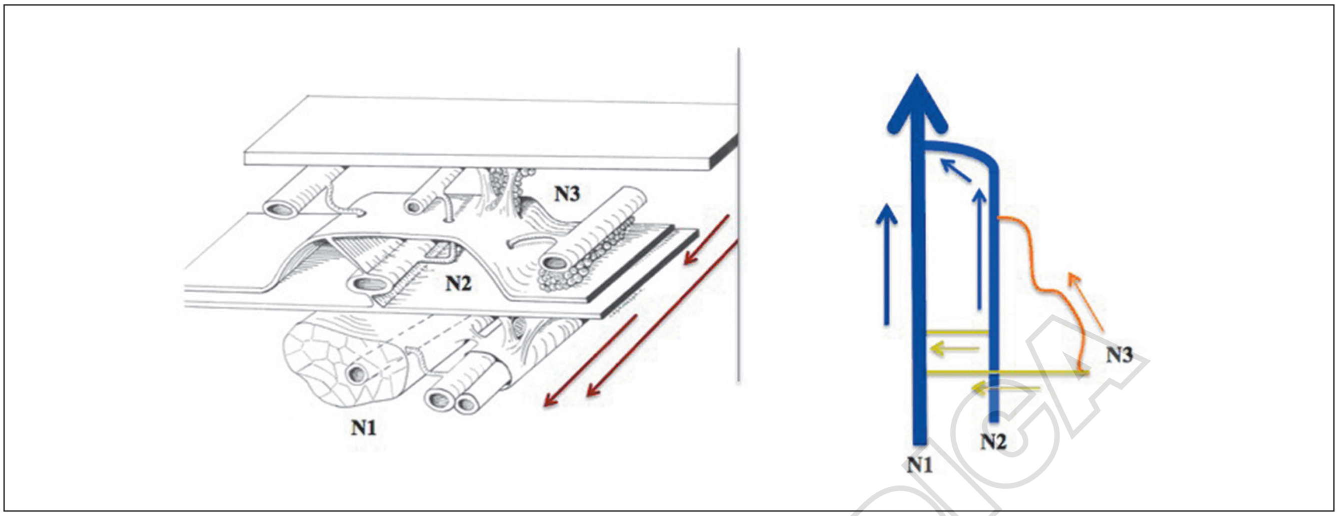

Figure 8.—Hierarchical order of venous drainage.
Deep venous system (N1) is below the fascia being wrapped by the muscular bellies, saphenous systems is in between the fascia splitting being wrapped by the same muscular fascia, tributary system is above the fascia.

Venous blood moves from the periphery towards the heart, from the surface to the deepest compartments due to a decreasing pressure (pressure gradient) from the most superficial compartments to the deepest ones (N3>N2>N1). This decreasing pressure, physically mandatory is testified by experimental investigations.[54] This gradient inversion produced by the pumps (VMP diastole, cardiac and thoraco-abdominal systole) normally prevented by valve closure, is impaired when valves are incompetent. Indeed, lower limb venous hemodynamics is the expression of the balance among the action exerted by residual pressure, by the height of the hydrostatic column and the action of the pumps.[2, 44]

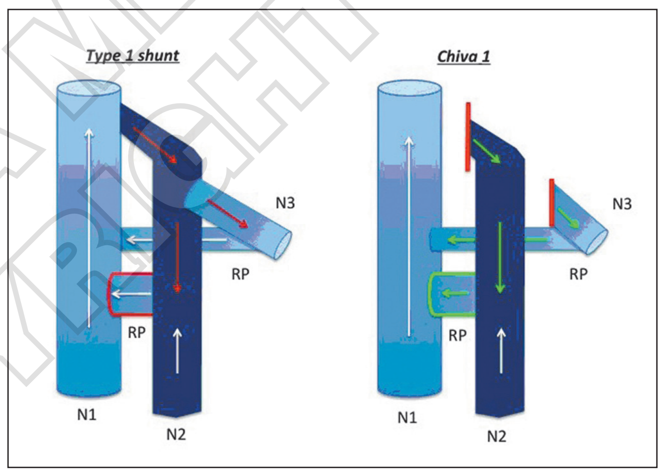

Figure 9.—Type I+ II shunt. Shunt I and Shunt II disconnection at the same time (CHIVA 1 one shot).

The shunt concept

According to fluid dynamics, a shunt is defined as a conduit that diverts flow from another conduit, *i.e.* an arterio-venous shunt diverts flow from an artery into a shunting vein. The veno-venous shunts are veins that divert flow from another vein (shunted vein) against the physiological order of the venous drainage through an incompetent veno-venous connection, called escape point (EP). Then they redirect back the shunted flow into the deepest department through another veno-venous connection called re-entry point (RP) according to the physiological hierarchy.[1-4, 6] The shunt is always overloaded by the pressure and flow of the shunted vein that leads to a TMP excess and to the related clinical consequences (Figure 9).

Incompetent venous connections representing the N1 to N2 EP can be the SFJ, the SPJ, perforating veins (PV) focused on N2, from N1 to N2. The N1 to N3 EP are focused on N3 and on the Pelvic leak points (Inguinal point, perineal point, clitoridian point, obturator point, superior and inferior gluteal points) (Figure

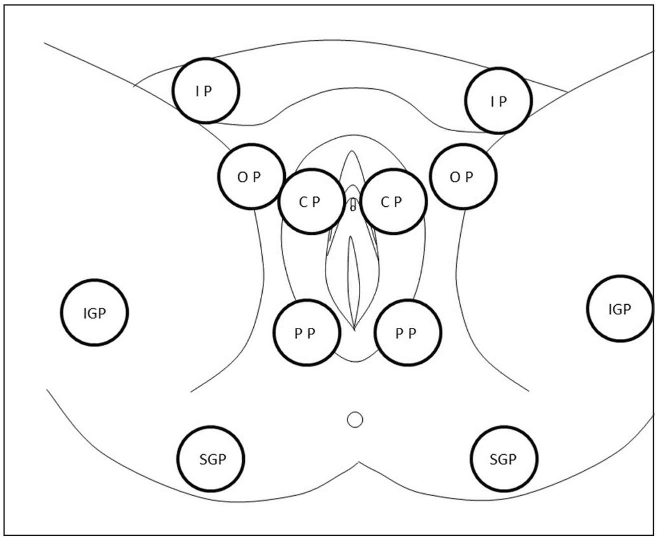

Figure 10.—Pevic leak points.
Perineal Point (PP): perineal veins drain the skin, then receive the posterior labial vein and pass through the superficial aponeurosis of the perineum (*fascia perinealis*) by an orifice called perineal point (P Point) After crossing the P Point, the veins ascends between the deep and superficial transversalis muscle of the perineum, then converges with the bulbar and cavernous veins and connects to the pudendal vein in the Alcock Canal.
Inguinal point (IP): the Inguinal point is the annulus *inguinalis superficialis* where the round ligament vein of the uterus passes through, draining the venus mount then connecting to the uterine vein.
Clitoral point (CP) is the plexus where the clitoral and anterior labial vein connects to the bulbar veins. Obturator point (OP) is the obturator foramen where the obturator vein passes through, connecting the femoral vein and/or the GSV end to the hypogastric vein.
Superior and inferior gluteal Points (SGP and IGP) are the aponeurosis holes crossed by the gluteal superficial veins and sciatic veins connecting to the hypogastric vein.

10).[1-4, 6, 55, 56] At the same time the RP that can be represented by the SFJ, the SPJ or the PV, according to the different shunt types. In addition, the conditions for overloading pressure and flow occurrence depend on the systo-diastolic phase (contraction/relaxation) of the pumps and the residual pressure, according to the different shunt types.[1-4, 57]

Shunt types: hemodynamics classification and related therapeutic strategy

Three main types of shunts are hemodynamically described, according to their patterns and their systolic or diastolic activation: closed shunts (CS), open deviated shunts (ODS) and open by-passing shunts (OBS) (formerly called open vicarious shunts OVS by European CHIVA practitioners) (Figure 11).[1-4, 57]

Closed shunt

Definition.—A CS derives its name from its creation of a "closed" circuit among the EP and RP (Trendelenburg's private circulation), so allowing blood overloading recirculation.

Hemodynamic features.—During the VMP diastole a CS is overloaded through the EP from the deeper compartment flow. The pressure gradient feeding the reflux is provided by the VMP systole and by the height of the incompetent hydrostatic column into the shunting vein (DFGHP impairment). CS are subdivided in 5 types (I, III, IV, V, VI perforating veins) according to their pathways and the location of the EP and RP.[1-4, 57]

Shunt I: anatomic example.—A typical example is an incompetent sapheno-femoral junction (EP from N1 to N2) with a refluxing GSV draining towards a RP that is represented by a perforator flowing from the GSV back to the deeper N1 compartment during muscle relaxation. According to the CHIVA therapeutic strategy it is mandatory to break this vicious circle at the EP, in order to decrease the pathological venous hypertension inside the shunt. In the example above a high tie will be effective in treating the EP and thus in suppressing the venous pressure overload.

The resulting shunt (so-called Shunt 0) keeps draining through the RP, but only the physiological draining flow, according to the hierarchical order, although this is in a retrograde direction. Shunt 0 flow is evoked by the VMP diastolic tests (see below) but, due to the suppression of N1>N2 or N1>N3 EP the Valsalva manoeuvre is negative. At the same time the pressure overload relief leads also to a calibre reduction (Figure 6).

Sometimes Shunt 0 is too long so that the below GHP column needs a complementary fractioning. It is the case of a shunt 0 made by a long incompetent saphenous trunk from the groin down to the ankle where the effective RP is localized (so-called "terminal perforator").

In this scenario the column can be fragmented below the knee, by a flush ligation below an intermediate perforator that in this way becomes the RP (Figure 12).

In case of incompetent N3 tributaries, Shunt I disconnection leaves behind an ODS Shunt II (see below). For that reason, it is disconnected at the same time flush to N1 (CHIVA 1 one shot) (Figure 9).

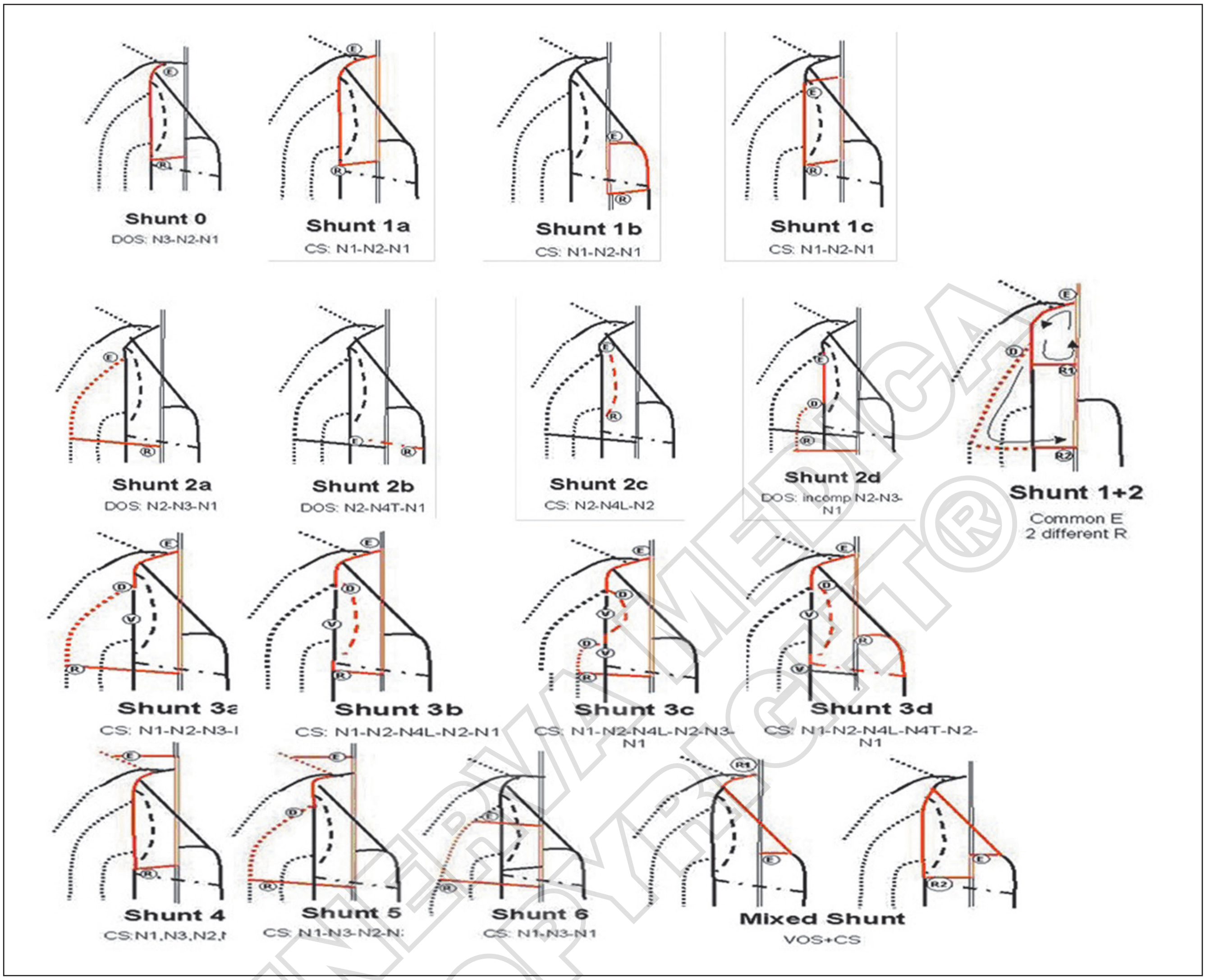

Figure 11.—TEUZPITZ Shunts Classification by CHIVA team.

Shunt III: anatomic example.—Shunts III have a peculiar configuration that does not allow the same therapeutic strategy as for Shunt I because of the lack of RP focused on N2. For example, in Shunts IIIa (N1-N2-N3-N1) N1-N2 and N2-N3 are disconnected at the same time, N2 will not drain anymore and will lead to N2 stasis, thrombosis and recurrence (Figure 13).

For this reason, two specific therapeutic strategies are proposed: one shot (CHIVA1 step) and two shots (CHIVA 2 steps).

CHIVA 1 step consists of N2-N1and N3-N2 EP disconnections combined at the same time with a N2 devalvulation below N2-N3 junction resulting in N2 and N3 shunts 0 (Figure 14).

CHIVA 2 first step, a simple flush ligation of the incompetent collaterals is performed.

CHIVA 2 steps consists of the disconnection of the CS not N2 flush to N1 but N3 flush to N2, stops the reflux in N2 because it can no longer empty in N1 through the disconnected incompetent N3. N3 is shunt 0 because the remaining diastolic reflux is no longer overloaded by N1 nor N2 and drains according to the physiological hierarchy N3>N1. N2 shows no more reflux and its calibre is reduced by the suppression of the

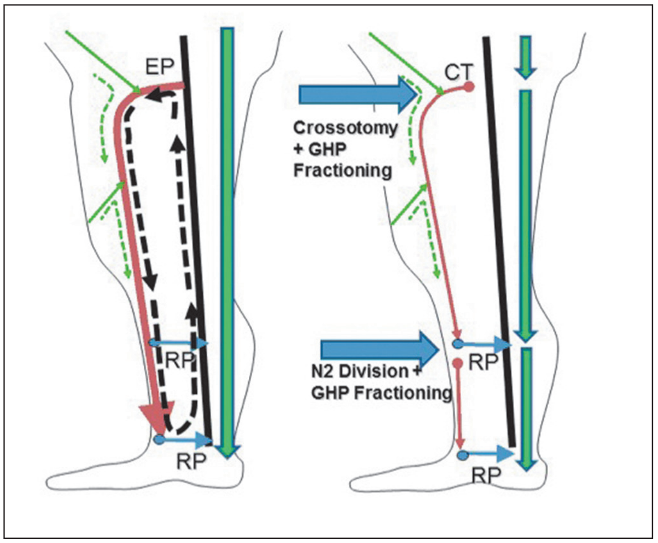

Figure 12.—Type I (long), closed shunt therapeutic strategy. Back dotted line: CS systo-diastolic loop (closed circuit). Thick green arrows: blood column height and its segmentation. Green thin dotted lines: N3 diastolic flow direction during the VMP diastole. In case of long closed shunt, the EP disconnection leaves behind a too high Shunt 0 (from the ankle up to the groin). In this case, an additional disconnection is performed below an intermediate perforator RP.

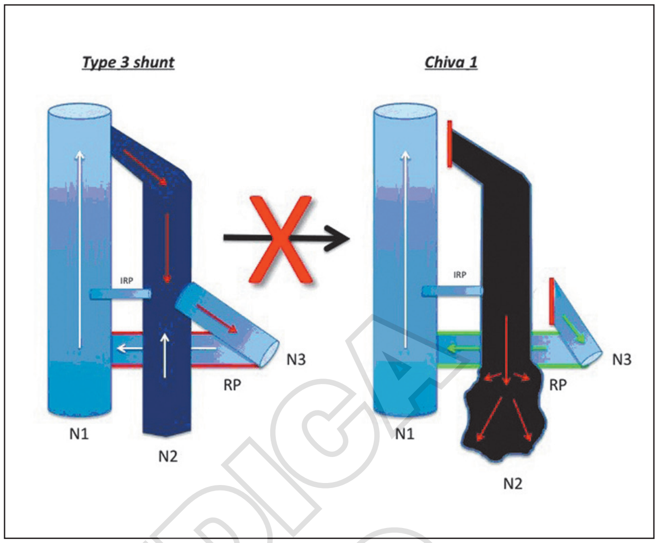

Figure 13.—Incorrect indication to CHIVA 1 in a type 3 shunt. IRP: inefficient re-entry perforator.

overload from the closed shunt energy, but because N1 valves are incompetent, it remains under a still too high unfractioned blood column. For this reason, the below N2 valves can be forced down to a perforator, creating a Shunt 1 (N1>N2>N1) which is treated in a second step by N1>N2 disconnection (Figure 15).

Restoration of valve competence occurs in almost the 50% of cases, indicating the frequent spontaneous saphenous flow restoration without treatment of the N1-N2 leaking point.[46, 58, 67]

This second step is not necessary if the reduction of the N2 caliber restores the efficient valve closure (Figure 16).

Open deviated shunts

Definition.—An ODS is not associated with recirculation. It is just a N3 refluxing overloaded by N1 then draining into N1 (N2-N3 EP).[1-4,58] There is no link to N1-N2 or N1-N3 EP, so it is a closed circuit. Its overload depends mainly on the height of the hydrostatic column above EP.

The subdivision of shunt type II in type A, B and C is not related just to the shunt pathway but also to the N2 hemodynamics. In type IIa Shunt the EP is from N2 to N3, without GSV incompetence, so characterizing a mild N3 overload.

In type IIb Shunt the EP is from N2 to N3, with GSV incompetence, without any re-entry along its length before the origin of the refluxing tributary. For this reason N2 becomes more overloaded and its disconnection leaves behind a high potentially incompetent column that could lead to more frequent recurrences.

In type IIc shunt the EP is from N2 to N3, with GSV incompetence and one or more RP along the GSV trunk. N2 is more overloaded but its disconnection leaves behind a high incompetent column that is easily drained by the GSV RP.

Shunt IIa: anatomic example.—There can be a competent sapheno-femoral junction with an incompetent GSV mid-leg tributary having a re-entry perforator along the same refluxing tributary tract and draining directly into the deepest compartment (N1). In this case the EP is represented by the compartment jump from the GSV (N2) to the incompetent tributary (N3). The blood that refluxes along the incompetent tributary during muscle relaxation gets back to the deeper compartment N1 by the RE perforator. During the subsequent muscular systole blood will flow along the N1 compartment without jumping into the above N2 compartment (GSV) thanks to the competence of the sapheno-femoral

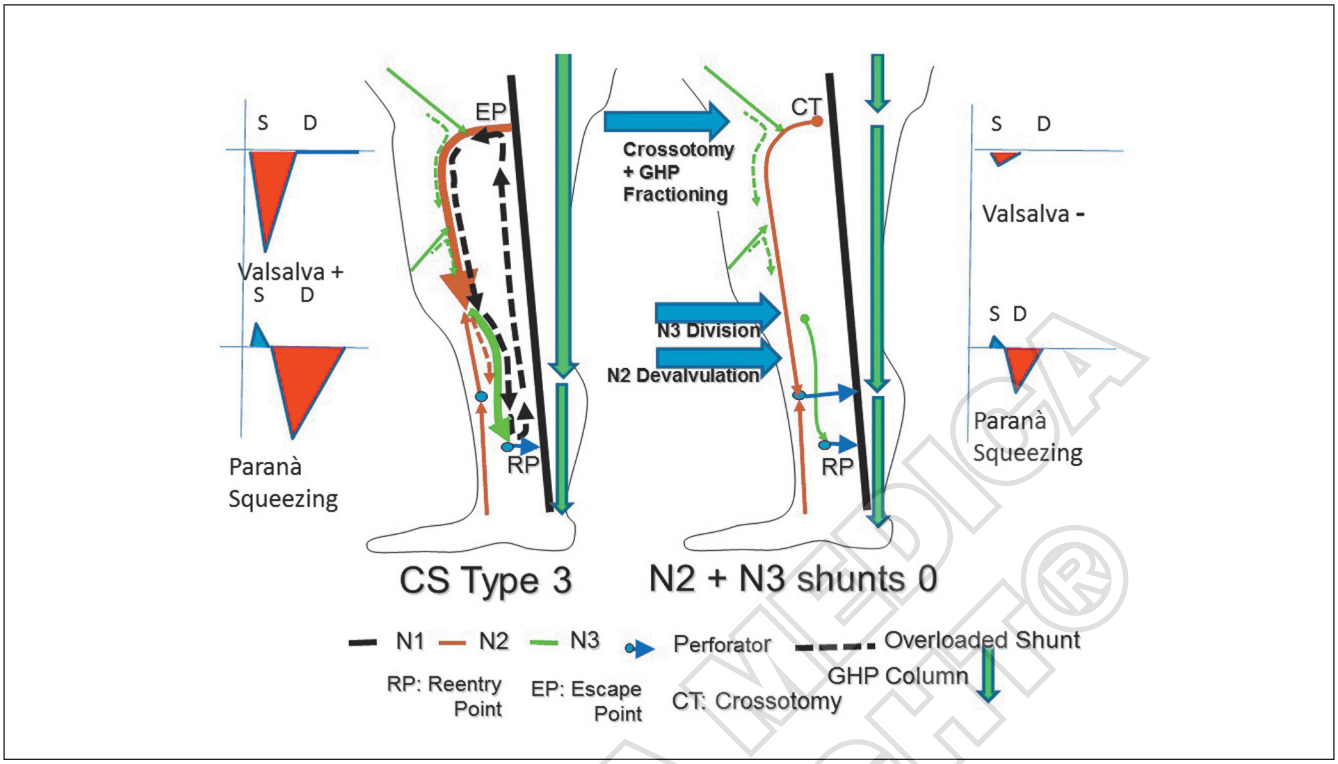

Figure 14.—Shunt IIIa: one shot strategy.
Back dotted line: CS systo-diastolic loop (closed circuit). Thick green arrows: blood column height and its segmentation. Green thin dotted lines: N3 diastolic flow direction during the VMP diastole. During the diastole, the deep blood refluxes from N1 toward N2 (SFJ is the EP), overloading the GSV that refluxes downward into N3, then turning back into N1 by a low leg perforator (N2>N1 RP). Lack of RP focused on refluxing N2. Squeezing or Paranà maneuver provoked flows. Competent N2 devalvulation down to a RP.

junction. In this case there is no recirculation, thus the shunt is defined "open". In this scenario CHIVA strategy aims to decrease the shunt venous pressure stopping the pathological compartment jump at the EP. In the example above a flush ligation of the incompetent tributary will stop the N2-N3 reflux, letting the same tributary drain through its own RE perforator directly into the N1 compartment. Once the EP has been ligated, no further aspiration occurs toward the more superficial compartments, thus no further reflux occurs in the vein that contained the same EP (Figure 17). The previously incompetent vein will not be overloaded anymore because of the ligation, draining retrogradely toward its own RP.

Open bypassing shunt

Definition.—OBS by-passes venous obstacles/obstructions. Usually the EP is below the obstruction, flowing back into the deeper compartment through a RP that is above the same obstacle.

Hemodynamic features.—An OBS is due to the resistant venous obstruction that increases the upstream residual pressure, so diverting the flow through a more superficial channel in order to by-pass the obstacle (Figure 18). The drained tissues suffer and swell and its veins dilate as long as the OBS does not reach a large enough calibre with a low resistance in order to restore the TMP. Contrary to CS and ODS, OBS is NOT activated during diastole, but only during the VMP systole and sometimes permanently by the RP when the by-passed obstacle is hemodynamically more important.

Because OBS is a "natural defence mechanism", it has to be spared. For this reason OBS have to be respected and not confused with CS and ODS (Figures 18, 19) On the other hand, the same phenomenon oc-

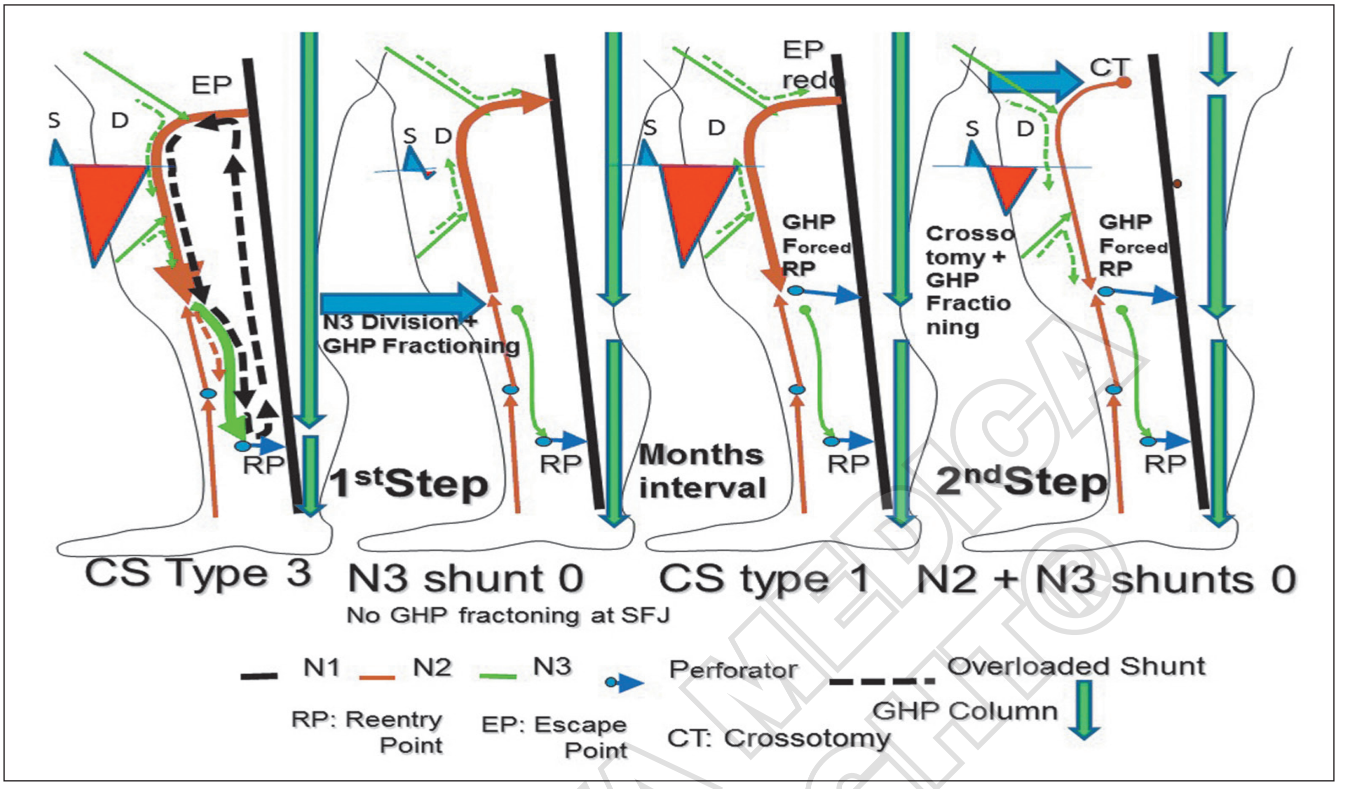

Figure 15.—Closed shunt type III a: two steps strategy.
Back dotted line: CS systo-diastolic loop (closed circuit). Thick green arrows: blood column height and its segmentation. Green thin dotted lines: N3 flows.
Squeezing or Paranà maneuver provoked flows.
First step: Curves: N3-N2 EP disconnections. Result: N2 reflux suppression and N3 shunt 0
Second step: When redo of N2 reflux resulting in Shunt1, N1-N2 EP disconnection. Result: N2 and N3 shunts 0.

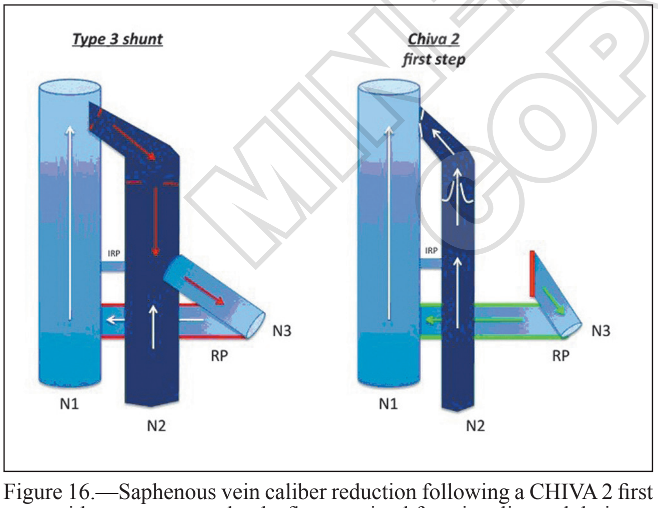

Figure 16.—Saphenous vein caliber reduction following a CHIVA 2 first step, with consequent valve leaflets regained functionality and drainage restoration.

curs after ablation of the superficial veins, explaining short term matting and other skin changes and long term varicose recurrence (Figure 11).[11] This phenomenon explains part of the varicose recurrence after ablation of superficial veins. Indeed, due to the residual pressure, these ablated veins are progressively by-passed by varicose collaterals.

OBS: anatomic example.—In the presence of a proximal thigh femoral vein occlusion by organized thrombus a perforating vein connecting the same femoral vein to the GSV can reverse its drainage direction, allowing flow from the deeper N1 toward the more superficial N2 network. This shunted blood drains through the GVS in a cardiopetal direction, so bypassing the femoral obstruction and then finding its RE point at the sapheno-femoral junction (Figure 19). Another example

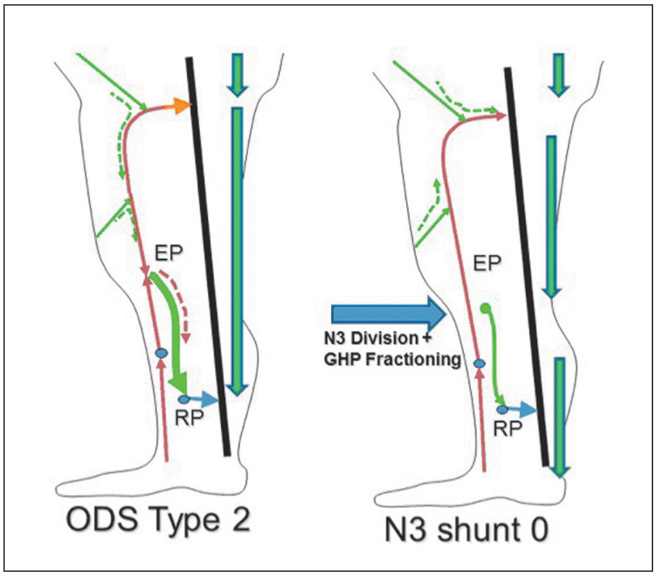

Figure 17.—Type II open deviated shunt.
Back dotted line: CS systo-diastolic loop (closed circuit). Thick green arrows: blood column height and its segmentation. Green thin dotted lines: N3 flows.
N3 is overloaded by N2. No N1>N2 reflux. A N3-N2 EP disconnection is performed, leading to N2 reflux suppression (no diastolic reflux, ascending normal systolic flow) and N3 shunt 0 (diastolic reflux toward its own RP, no more overloaded by N2, draining according to the physiological hierarchy N3>N1).

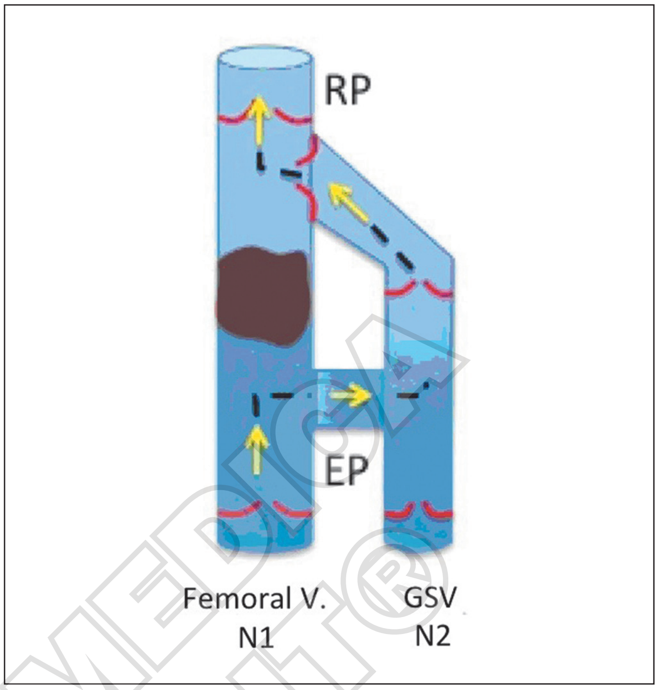

Figure 18.—Open by-passing shunt.

is a femoral vein obstacle diverting the blood from the popliteal vein into the SPJ into the Giacomini vein and thus into the GSV, in order to get back into the deep system by the SFJ.

Also in a case of left iliac venous obstacle, the femoral flow (N1) can force a reflux through the SFJ (EP) then proceeding through the GSV arch, its upper tributaries (N3) and finally the opposite femoral vein (N1) through the opposite GSV arch and its SFJ. A spontaneous so-called Palma OBS is formed.

Combined deep and superficial venous incompetence

The "competitive reflux"

Whenever deep venous insufficiency coexists with a large not refluxing or slightly refluxing superficial varicose vein such as GSV, a competitive deep reflux is suspected. Indeed, a severe deep vein incompetence impairs its proper VMP diastolic aspiration, capable of emptying the incompetent GSV. It will be easy to con-

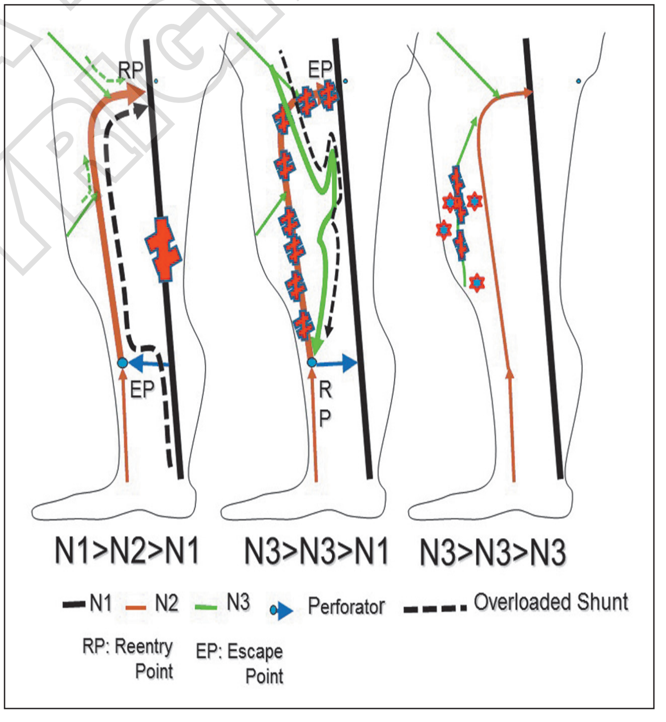

Figure 19.—From the left to the right: Closed deep vein – bypass through GSV; Obstruction after removal of GSV, bypass through tributary; obstruction after removal of tributaries: micro bypass, matting.

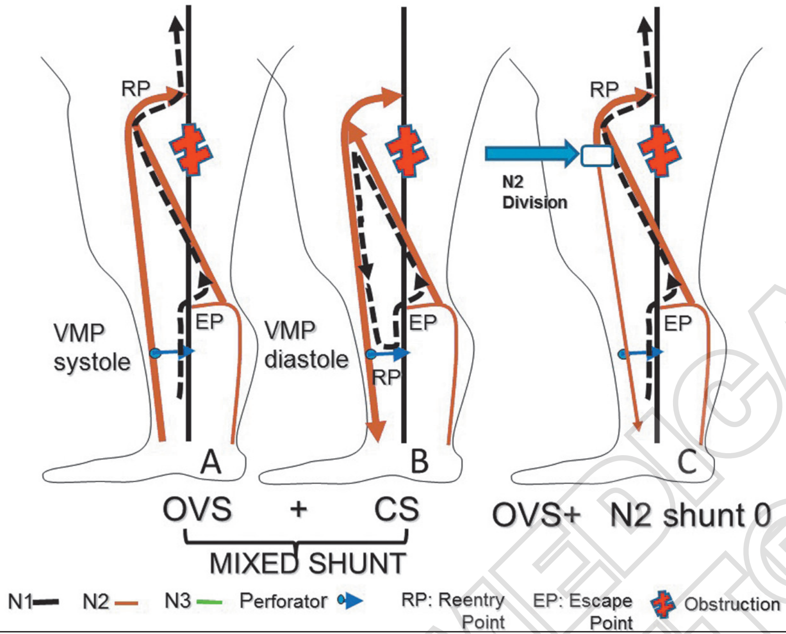

Figure 20.—Short saphenous vein mixed shunt. Femoral obstruction. A) VMP systole: ODS is activated. Popliteal reflux N1 through SPJ EP flows upward along the Giacomini, the proximal GSV then joins the femoral vein trough the SFJ RP; B) VMP diastole: CS is activated. Popliteal reflux N1 through SPJ EP flows upward along the Giacomini, but differently from ODS, turns backwards through the GSV to a leg RP. So, their EP and Giacomini path are common but their GSV paths and RP are different; C) treatment consists of the CS disconnection and OBS preservation, by ligating the GSV flush its junction with the Giacomini Vein.

firm by a simple Perthes manoeuvre: placing a tourniquet at the varicose vein root will not make the vein collapse despite the VMP activation. In this scenario CHIVA strategy does not give indication to ODS and CS disconnection, since the superficial reflux decreases proportionally to the increase of the deep incompetence.

Mixed shunts

Definition

Mixed shunts (MS) are constituted by one or more consecutive veins, competent or not, that play the role of OBS during the VMP systole and the CS role during the diastole. They are possible in all the network, assuming that the EP is common and RP are different from one another.

Hemodynamic features

In MS the EP and the initial part of the venous path are common to both OBS and CS, while the terminal paths and RP are different and divergent. The anatomic example is shown in Figures 20, 21.

Venous malformations

The basic hemodynamics of truncular/extra-truncular venous malformations does not differ from the hemodynamics of varicose vessels. Malformations are subjected to the same laws of physics thus they consist of the same shunt types.

An OBS is created for example whenever compensating thrombosis, venous absence or hypoplasia; a CS/ODS is created whenever part of an overloading reflux in an incompetent vein.

The extra-truncal malformations that do not play a consistent draining role and appear to have a very low/static flow into the muscles, articulations, neuro-vascular bundles and intra cutaneously can be eventually ablated if symptomatic and/or responsible for DVT/PE. In case of truncal malformations CHIVA strategy does not differ from non-malformed vein treatment.

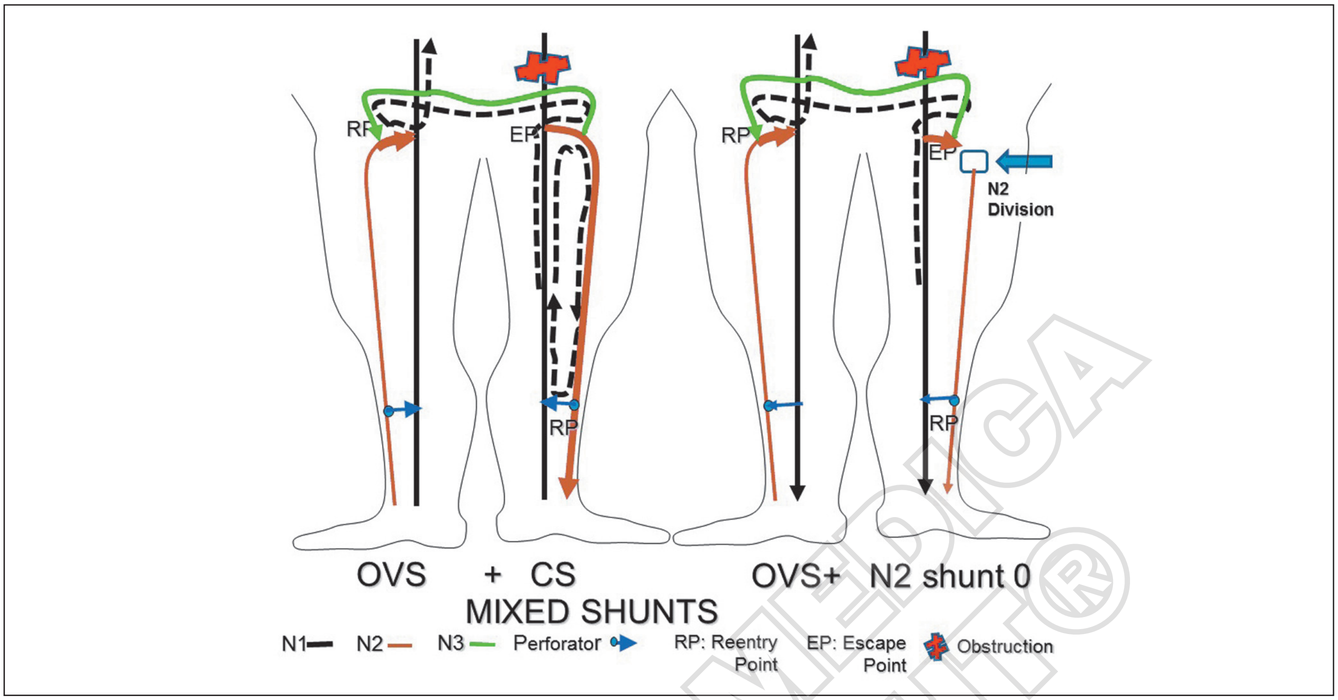

Figure 21.—PALMA Mixed Shunt.
Left ILIAC obstruction: left femoral vein N1 refluxes through the same left SFJ (EP N1>N2) then the GSV arch (N2) during the systole (OBS) and diastole (CS). OBS and CS diverge at the GSV-. OBS flows to the right femoral vein (N1) through the left and right external pudendal veins and right GSV arch (spontaneous palma). CS flows backwards into the PTV (N1) through the below GSV and the upper leg perforator (RP) N2>N1. Treatment consists of the CS disconnection and OBS preservation, by ligating the GSV flush below the right external pudendal vein.

The peculiar case of marginal vein treatment strategy relies on the necessity to preserve this vein whenever compensatory of femoro-popliteal hypoplasia (OBS) and/or draining a superficial capillary angioma (increased residual pressure).[59-65]

Technical notes

As stated in the CHIVA rationale, all signs and symptoms such as pain, edema, varices, skin changes and ulcers are related to a TMP excess. The clinic visit includes the history and the clinical examination which shows the severity of the venous insufficiency followed by an accurate DUS assessment which is fundamental. The evaluation must be performed standing, at rest and during dynamic manoeuvres. A specific DUS with hemodynamic mapping is requested, representing the real procedural moment of the CHIVA strategy. For this reason it is considered mandatory that the operative surgeon is present at the sonographic investigation.

Several manoeuvres can be adopted for this purpose, choosing among active Valsalva (Figures 19, 20), Paranà[57] (Figure 22), Wunstorf[57] and passive ones (manual or cuff compression/relaxation).[26, 66] Blowing into a closed straw represent a reliable, reproducible way to perform a Valsalva manoeuvre detecting long lasting refluxes in these veins (Figures 23, 24).

A Perthes maneuver can be performed in order to be sure of the RP quality, eliciting a possible deep competitive reflux and predicting the clinical result of the planned disconnection.

The venous pressure in the posterior tibial vein can be measured at the ankle, so predicting also the severity of venous obstruction.[37]

A fundamental diagnostic step is the evaluation of the SFJ competence. It is mandatory to assess its hemodynamics placing the DUS sample volume on the femoral side of the terminal valve. The flow must be elicited both by Valsalva and compression/relaxation manoeuvers. Only whenever both of them are found positive the SFJ has to be considered incompetent. In fact it is demonstrated how

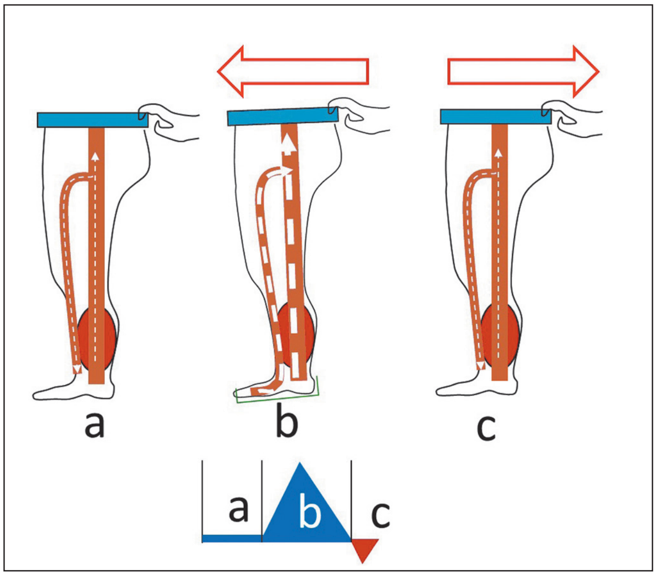

Figure 22.—Paranà maneuver. A) At rest; B) slight push at the waist triggers a proprioceptive reflex calf and sole pumps activation (systole), followed by a very short reflux (diastole).

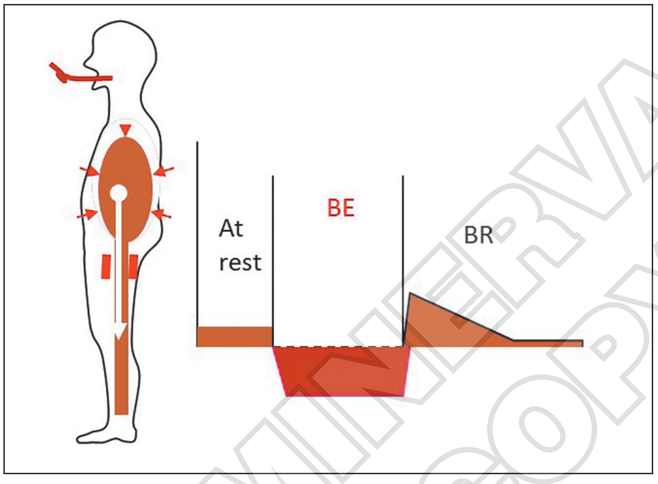

Figure 24.—Pathological Valsalva manoeuvre.
In pathology reflux occurs (Valsalva positive) when valves are incompetent. Reflux appears whenever blowing into the straw (blocked expiration phase, BE) and turns back cardiopetal at the release (BR).

other scanning protocols are increasing the risk of false positive junctional incompetence.[67, 68]

Particular attention has also to be paid to the assessment of SFJ tributaries. At the groin, superficial epigastric, pudendal and circumflex tributaries drain physiologically downward, into the GSV. This normal direction does not change whenever they drain a refluxing pelvic leak point. Compression and Paranà ma-

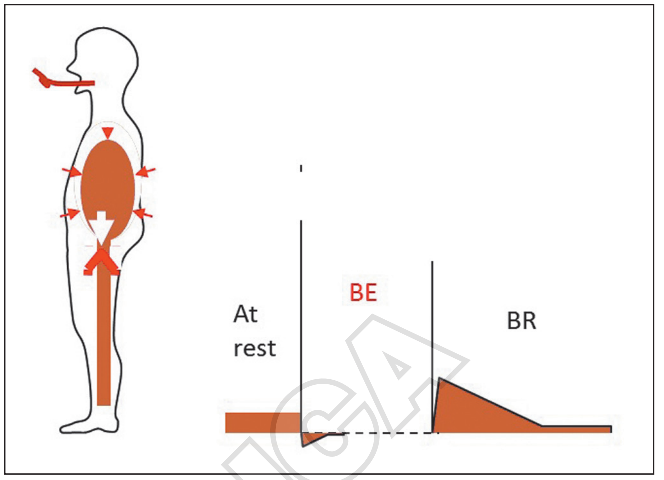

Figure 23.—Valsalva manoeuvre (performed by blowing in a blocked straw)
In physiology valvular competence (Valsalva negative) the valves are competent. The blocked expiration (BE) strongly reverses the pressure gradient, inducing only a negligible short and small reflux thanks to the correct competence of the underlying valves. At the blockage release (BR) the pressure gradient turns cardiopetal and induces an ascending flow.

noeuvres show a descending flow in both conditions, while the Valsalva manoeuvre provokes it only in case of pelvic leak (Figure 25). In addition, the presence/absence of a RE perforator focused along N2, DUS has to be assessed, due to the drastic therapeutic difference between the CS Shunts type I and Type III (see above shunt III).

A simple but really effective sonographic test is able to identify the presence of a valid RP focused on the saphenous vein: the reflux elimination test. During the digit compression of incompetent tributaries, reflux into the GSV provoked by both Parana/Compression and Valsalva manoeuver persists only when there is a RP present on the GSV trunk. Its disappearance attests for its lack, thus for a Shunt III instead of a I+II Shunt (Figure 26).

Therapeutic hemodynamic strategy

The core of the CVI is the TMP (IVP-EVP) excess. Its reduction can be obtained by hemodynamic means as increasing the EVP (compression bandaging) and/or decreasing the GHP component of IVP by the feet elevation above the heart or restoring the DHPF. CHIVA is aimed to restoring the TMP by reducing the IVP. It is based on four pillars: DFGHP restoration, CS and ODS

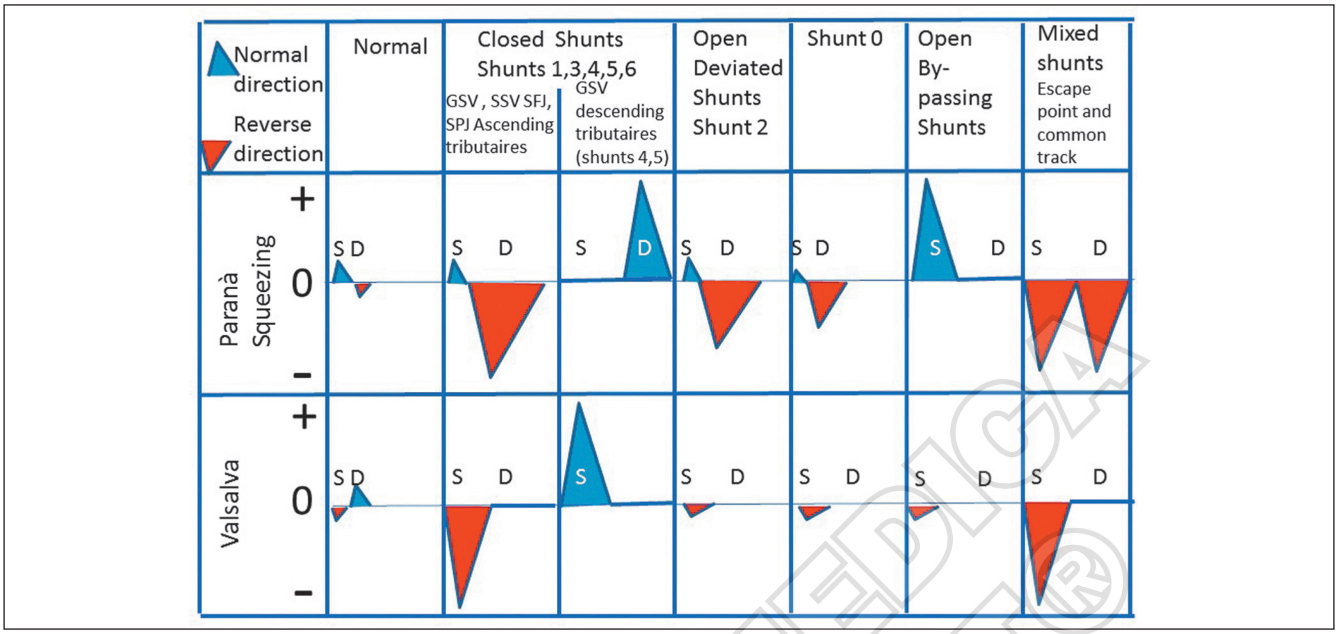

Figure 25.—DUS test at the groin.
Flow direction during the successive systolic S and diastolic D phases of the valvulo-muscular pump (Paranà test) and thoraco-abdominal pump (valsalva test) pumps according to the shunt type.

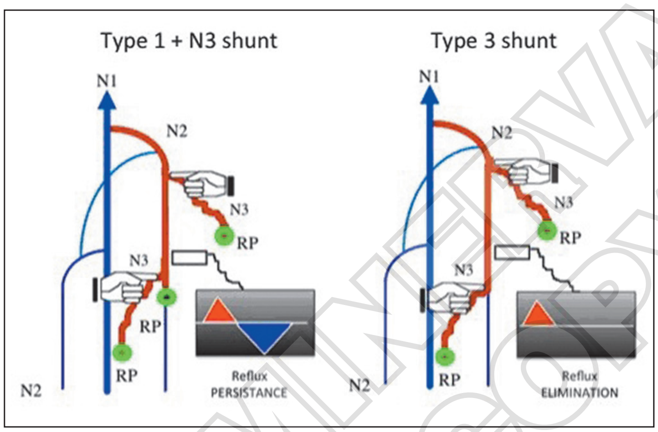

Figure 26.—Reflux elimination test.
A simple digit compression of the incompetent tributary that is endowed with its own RP will permit to discriminate among a type I + II and a type III shunt.

interruption, sparing the tissue drainage, sparing the GSV. According to the shunt type, CHIVA strategy indicates a therapeutic strategy that is customized on every kind of hemodynamic impairment. In order to restore the DHPF two therapeutic acts are possible: repairing the valves (directly and/or through prosthetic implants, rarely feasible) or CHIVA at the same time disconnecting the CS and ODS and fragmenting the hydrostatic columns of the incompetent veins into shorter segments. Usually, a segmentation of the refluxing column at the groin and at the upper leg level is sufficient (Figure 24). In this last option a perforating vein must be present for each segment in order to drain it into the deeper compartment ensuring a proper drainage of the same column. A flow diversion will remain, but not overloaded by pathological flow, thus re-establishing a physiological order of venous emptying. This restored venous pathway is called type 0 shunt.[1, 4, 67]

Therapeutic tactics

The ligations are performed under local anesthesia, locating them precisely under DUS guidance, in a mini-invasive, fast, cost-effective, and office-based procedure. The SFJ is divided between the femoral vein and the first tributary junction, so preserving the descending tributaries. This technique is called crossotomy and not crossectomy because the latter ablates these tributaries. A titanium clip is preferably placed flush on the femoral vein during a high tie in order to totally ablate the residual saphenous stump. A study comparing triple SFJ ligation versus high tie by a very thick not absorbable N°2 (not 2/0) suture has shown equivalent results, suggesting a less invasive procedure, so probably reducing the risk of neo-angiogenesis.[69, 70] A tributary segment of no more than 2 cm is excised in between the two ligations needed to disconnect the vessel, while the stumps are ligated with non-absorbable sutures. Perforator and pelvic leaks are ligated the same way.

In cases of small saphenous vein and SPJ incompetence it is usually preferable to ligate below the Giacomini confluence, in order to leave a washing drainage into the SPJ, transforming the below SSV system in a type 0 shunt.[70-75]

Elastic stocking compression (20-30 mmHg) for 2 weeks and prophylactic anticoagulation for 10 days are suggested.

Recently, a strategical and technical CHIVA approach modification has been proposed by means of endovenous devices.[71-73] Strategically there is not a flush disconnection of the N1-N2 EP as in traditional CHIVA. Technically several devices have been proposed but never reported in the literature in detail,[71-73] with the exception of a feasibility study involving a 1470 nm endovenous laser at 1 year follow-up.[74]

Results

Clinical and DUS assessment is recommended at 1 month follow-up. Great care should be taken not to confuse saphenous reflux (pathological turbulent flow, end diastolic velocity (EDV) inversion compared with the peak systolic velocity) with a post-CHIVA 1 (high tie) saphenous retrograde flow (laminar, EDV oriented on the same vectorial direction of the peak systolic velocity) which drains into the re-entry perforator. While reflux is a pathological sign, the retrograde draining flow is the natural evolution of a restored hierarchical order of emptying with a prolonged low velocity flow emptying into an efficient RP.

The positive effect of a restored drainage is also evident at the clinical investigation, where a progressive caliber reduction in standing still position is expected along the following weeks, while a sudden previously incompetent tributary collapsing is appreciated during the VMP activation, together with the symptoms and trophic lesions disappearance.[19, 46]

According to CHIVA strategy the main failure is the lack of drainage in the newly created venous network.

A typical case could be the selection of a not valid RP, as in performing a CHIVA 1 strategy to treat a type III shunt. This mistake would lead to venous stasis and thus to an increased risk of thrombosis.

Transitory failures are considered into the strategy, referring to a delayed disappearance (some months) of clinical varicosities despite the correct pressure gradient restoration. In 2013 a Cochrane review pointed out the long term efficacy of CHIVA.[20] A fundamental paper points out the need of an adequate learning curve before practicing this strategy. Not considering this fact is demonstrated to lead to a CHIVA performance worse than the ablative strategy.[18]

The need of adequate training in order to get competitive results by CHIVA strategy was stressed in the same year by Gloviczki *et al*.[76]

Instrumental objective evaluations

As indicated above CHIVA is aimed to spare the GSV, but maintaining a flow once reflux points are suppressed. Flow direction in the GSV is down-ward in CHIVA 1 procedure, flowing from the disconnected GSV junction to a re-entry perforator with outlet located on the trunk.[5, 17, 19]

To the contrary, flow direction is up-ward in the so called CHIVA 2 procedure.[58, 77-79]

While reports and controlled studies on the clinical results of CHIVA reached a good level of evidence[80] reports on CHIVA rarely assessed the hemodynamic changes induced by the procedure. However, some data is available and constitute extremely interesting models of either venous haemodynamics or patho-physiology. The following section summarizes the available haemodynamic results after CHIVA 1 and CHIVA 2 procedures.

Ambulatory venous pressure

Ambulatory venous pressure (AVP) after CHIVA 1 procedure

There is only one study assessing AVP following CHIVA 1 procedure, and no studies following CHIVA 2.

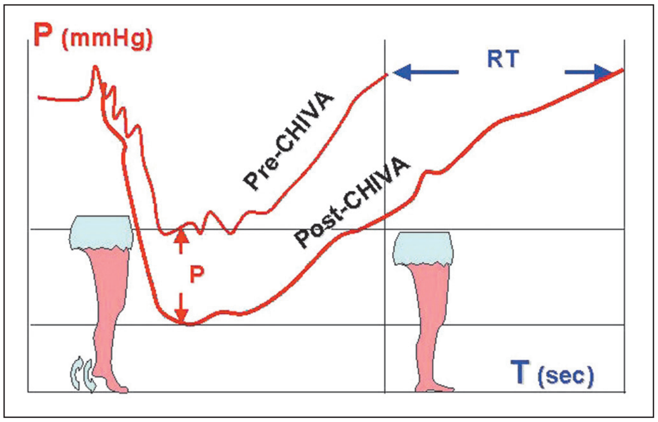

Figure 27.—Example of AVP after 10 tiptoe movements before and 6 months after CHIVA 1 operation.

In this study, 73 patients underwent AVP measurements before and 6 months after CHIVA 1. CHIVA 1 consisted of SF disconnection plus flush ligation of the tributaries at the saphenous trunk sometimes complemented by multiple stab avulsions. The preoperative mean AVP of 50.13+6.56 mmHg was reduced to 28.82+7.14 mmHg six months after the operation (P<0.001) (Figure 27).[5]

Light reflection reography (LRR) after CHIVA 1 procedure

The same group of 73 patients underwent LRR evaluation before and 6 months after CHIVA 1. Mean preoperative refilling time increased from 10.12+2.6 seconds to 19.80+4.91 seconds (p<0.001) 6 months after operation.[5]

Air plethysmography (APG) after CHIVA 1 procedure

In a RCT, 47 patients with venous leg ulcers due to primary varicose veins were randomized to either CHIVA 1 or compression.[19] Healing was 100% (31 days) in the Chiva group and 96% (63 days) in the compression group. At 3 years the recurrence was 9% in the CHIVA group and 38% in the compression group. In the surgical group APG parameters were assessed at the time of randomization and repeated six months and three years later (Table I). All four parameters, except ejection fraction, significantly improved 6 months after the operation. However, after three years, only residual volume fraction (RVF) was found to be consistently corrected and significantly improved. However, this is the more important parameter since it correlates with AVP and represents the net-volume of blood which remains stowed in the hold of the leg veins after exercise.[80] Interestingly, RVF was found in pathological values only if SF reflux recurred.

In a subsequent study APG has been used to evaluate venous function in patients in CEAP clinical class C6 at baseline and six months after surgery. In this study in about 80% of patients the procedure was CHIVA 1 with the rest of the patients having the first step of CHIVA 2 procedure. The APG parameters are shown in Table II where the highly significant improvement is well apparent.[81]

APG after CHIVA 2 procedure

A study involved 40 limbs in 40 patients with incompetence of the saphenofemoral junction and the main GSV trunk with one or more re-entry perforators lo-

TABLE I.—*Pre and postoperative APG parameters assessed in the surgical group. Grey cells describes postoperative parameters significantly different as compared with preoperative assessment (P<0.001).*

APG assessment	TV	VFI	EF	RVF
Preoperative	170±54.6	6.7±3.4	48±12.5	40±15.7
6 months after surgery	134±44.1 (-25%)	3.0±51 (-44%)	57.0±18.1	29±15.1 (-31%)
3 years after surgery	141±42.5 (-16%)	5.35±2.03 (-5.92%)	54.0±14.3 (+12%)	22.5±14.7 (-35%)

TABLE II.—*Preoperitive and 6 months postoperative APG parameters expressed as mean±SD. In parenthesis are reported the rate of postoperative volume reduction.*

APG assessment	VV mL/air	VFI mL/s	EF% of VV
Preoperation	170.0± 54.6	6.7±3.4	48±12.5
6 months postoperation	134.0±44.1* (-25%)	3.0±51.0* (-44%)	57.0±18.1

APG: Air-plethysmography; VV: total venous volume; VFI: venous filling index; EF: ejection fraction; RVF: residual volume fraction.
*Postoperative parameters significantly different compared with preoperative assessment (P<0.001).

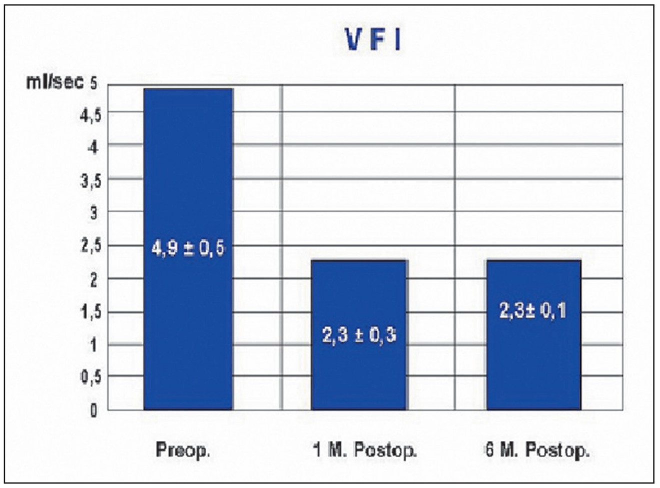

Figure 28.—VFI changes after 1st step CHIVA 2 procedure.

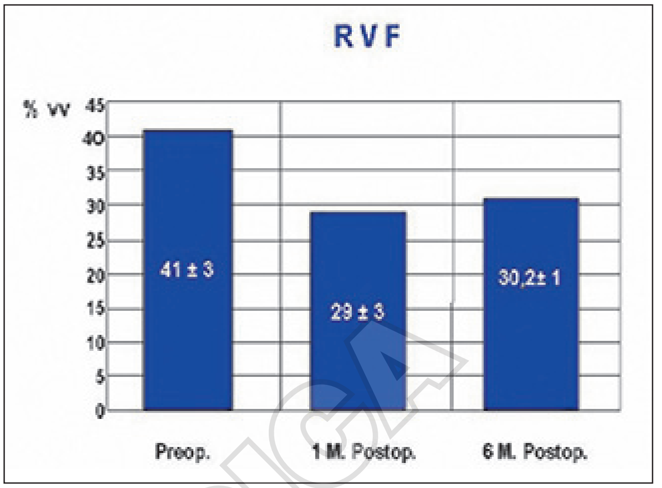

Figure 29.—RVF changes after 1st step CHIVA 2 procedure.

cated on tributary veins. Deep veins and small saphenous vein were competent. The clinical class of patients ranged from C2 to C6 (25 with C2, 7 with C3, 4 with C4, 2 with C5 and 2 with C6). APG was used for assessment of changes in venous function in a randomized study comparing CHIVA (CHIVA 1 and CHIVA 1 +2) to compression in course of active primary ulcers.[19] With the exception of ejection fraction (EF) all APG hemodynamic parameters improved significantly at 6 months. Venous volume (VV) decreased from 150 mL (95% CI 133 to 167) to 119 mL (95% CI 107 to 133). Venous filling index (VFI) decreased from 5.0 mL/sec (95% CI 5.0 to 5.9) to 2.0 mL/sec (95% CI 2.0 to 2.7). RVF changed from 42% (95% CI 36 to 47) to 30% (95% CI 26 to 34).[77]

The improvement of VFI (Figure 28) and RVF (Figure 29) is well apparent, so demonstrating that reflux in the GSV is completely suppressed by the disconnection of the tributary vein containing the re-entry perforator by just eliminating the gradient between the reflux point (*i.e.* the SFJ) and the RP in the deep veins.

Reflux in the GSV did recur at 6 months in 15% of the patients in whom a re-entry perforating vein newly developed on the main GSV trunk. The figure shows the little and not significant worsening of APG parameters by comparing 1 with 6 months results. Of course, with time a higher rate of reflux recurrence is expected with consequent worsening of APG parameters in some patients. However, when this happens high ligation is performed (CHIVA 1+2 procedure).[5, 17, 19]

Duplex scanning

Duplex scanning after CHIVA 1 procedure

One of the most debated points of the so called CHIVA 1 procedure is the persistence of downward flow with re-entry at the perforator after high ligation. Several investigators considered it a pathological reflux.[82] However, postoperative duplex investigation in CHIVA 1 procedure demonstrates significantly different hemodynamic parameters of this reverse flow (12). The cross-sectional area of the GSV decreased from 49.0±36.22 to 14.1±10.1 mm^2, indicating reduction of the volume load. Peak systolic velocity (PSV) changed in direction pre- 20.31±18.21 to post- 18.46±6.03 cm/sec, which is the natural consequence of high tie CHIVA 1. EDV changed from pre- 30.7±32.0 to post- 10.6±5.1. Finally the resistance index (RI), as an impedance parameter derived from the formula RI=PSV/PSV-EDV, was significantly different: pre- 3.50±2.22, post- 0.44±0.15 (P=0.0001). The draining significance of the reverse flow is testified by the relationship between it and the improvement of functional parameters like AVP and APG described in the previous paragraphs.

Duplex scanning after CHIVA 2 procedure

Several studies report the recovery of upward flow in the GSV after the first step of CHIVA 2 procedure.[77-79] One of the major problems is the durability of such a hemodynamic change.[79] Quite recently it has been demonstrated that this depends on the preoperative competence of the terminal valve of the saphenofemoral junction. A preoperative duplex test may predict the durability of reflux suppression following CHIVA 2 procedure.[58] At 3 years follow-up of legs with a competent terminal valve, 100% were rated as cured (Hobbs' class A or B) and 14% developed recurrent varices. Patients with an incompetent terminal valve had significantly worse results: 29% had Hobbs' class A or B, and 82% developed recurrence (P<0·001). This finding demonstrates how preoperative duplex may provide a reliable indication to minimally invasive sparing of saphenous vein surgery.

Clinical and sonographic evaluations

For several years scientific clinical and sonographic data have been collected concerning the possible saphenous flow restoration without any ablation and according with the CHIVA strategy. Moreover, in 2013 a Cochrane review highlighted the smaller recurrence risk following a CHIVA strategy rather than saphenous stripping. Three RCTs compared the CHIVA method with vein stripping, while one RCT compared CHIVA strategy with compression in venous ulcer healing.[1-5, 13, 19, 15-18, 20, 46, 58, 77-79, 83-89]

Considering the clinical recurrences and the effectiveness in ulcer healing as primary endpoints, the revision showed favorable results for the CHIVA method group compared with stripping in a follow-up reaching the ten years period.

Only one study reported quality of life data, which were in favor of CHIVA method.

An interesting paper by Chan CY retrospectively compared CHIVA strategy with endovenous laser ablation, demonstrating less postoperative pain and sclerotherapy need in saphenous sparing procedures.[90]

Side effects were reported to be more frequent in the ablative group, in particular for bruising and nerve damage. No statistically significant differences were reported concerning limb infection incidence and thrombosis.

Conclusions

CHIVA is a safe, effective, minimally-invasive, rapid and office based strategy, treating CVD by means of a venous drainage restoration rather than ablation.

Clinical and instrumental trials demonstrated a lower recurrence rate in the long term, moreover offering the chance of sparing the saphenous trunk for eventual further grafting and/or arterial "redo" procedures.

CHIVA requires no particular devices, so representing also a highly cost-effective option. The required surgical skills are minimal, as demonstrated by its successful use also by non-surgical physicians. However, the required hemodynamic expertise and sonographic skills are advanced, putting the procedure outcome in jeopardy if performed without adequate training.

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