Dynamic Fractioning of the Gravitational Hydrostatic Pressure: A hemodynamic model for the venous pressure control by the valvo-muscular pump

C Franceschi[1], M Cappelli[2], JM Escribano[3], E Mendoza[4]

[1]Centre Marie Thérèse Hôpital Saint Joseph 189 rue Raymond Losserand 75014 Paris

[2]Private practice, Florence

[3]Vascular/Endovascular Department, Vall d'Hebron University Hospital, Universitat Autònoma de Barcelona (UAB), Barcelona, Spain

[4]Venenpraxis Wunstorf. Speckenstr 10, 31515 Wunstorf

Abstract

Dynamic Fractioning of the Gravitational Hydrostatic Pressure (DFGHSP) is a pillar of a hemodynamic model of the venous pathophysiology. It describes how the valvo-muscular pump varies the distal venous pressure in the lower limbs. It results from an inductive reasoning based on clinical signs and instrumental data at rest and during the action of the valvo-muscular pump of the calf. It does not claim to be the final truth, but a new "as if" model that improved the diagnosis and the treatment of the venous insufficiency (CHIVA, French acronym for Cure Conservatrice et Hémodynamique de l'Insuffisance Veineuse en Ambulatoire) according to several randomized studies and meta-analyses. That approach overturns the classic diagnosis and treatment of venous insufficiency because it is conservative and opposes the widely spread destructive based view. It needs a minimal study of basic fluid mechanics which can explain venous hemodynamics, the core of venous pathophysiology. The proposed **DFGHSP** fluid mechanics model is compared with the hemodynamic clinical and instrumental data in order to assess its pathophysiologic relevance.

Keywords venous insufficiency, venous pressure, varicose veins, CHIVA, venous pathophysiology

1-Introduction

Dynamic Fractioning of the Gravitational Hydrostatic Pressure (DFGHSP) is a pillar of a hemodynamic model of the venous pathophysiology. It describes how the valvo-muscular pump varies the distal venous pressure in the lower limbs. It results from an inductive reasoning based on clinical signs and instrumental data at rest and during the action of the valvo-muscular pump of the calf. It is obvious that any new theory/model, even if it is better than the previous ones, is never the final truth, but a step to be improved/revised in the future. Therefore, it does not claim to be the final truth, but a new "as if" model that improved the diagnosis and the treatment of the venous insufficiency (CHIVA, French acronym for Cure Conservatrice et Hémodynamique de l'Insuffisance Veineuse en Ambulatoire)[1,2] according to several randomized studies and meta-analyses[3-8]. That approach overturns the classic diagnosis and treatment of venous insufficiency because it is conservative and opposes the widely spread destructive based view. It needs a minimal study of basic fluid mechanics which can explain venous hemodynamics, the core of venous pathophysiology. Other important parameters of venous hemodynamics such as the residual pressure is not discussed in this article.
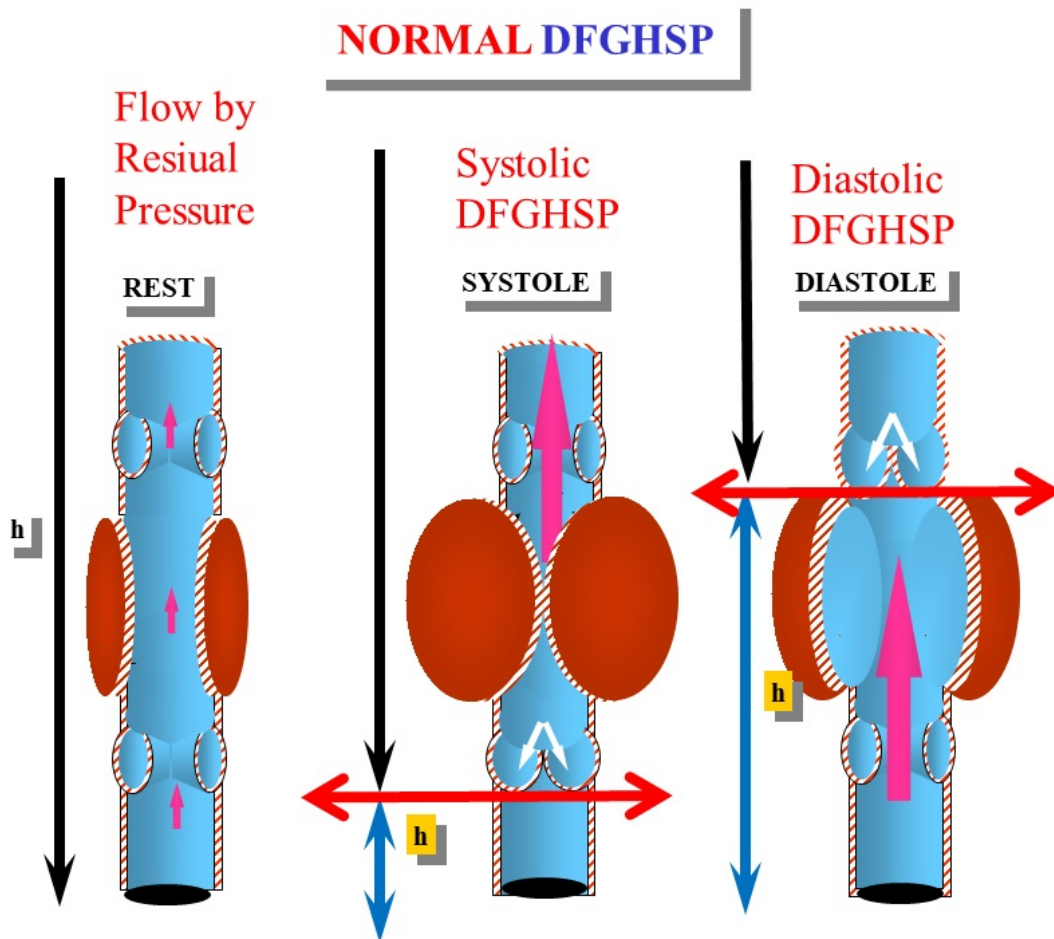
Fig. 1 - Normal DFGHSP : h : fractioned venous blood column height.

2-Basic physics, Facts and consequent model regarding the Gravitational Hydrostatic Pressure

Gravitational Hydrostatic Pressure GHSP Definition[9]: Gravitational Hydrostatic pressure GHSP is exerted by a **fluid at equilibrium** in all directions at a given point within the fluid, due to the force of gravity. It increases in proportion to height of the fluid above the point of measurement (**Blaise Pascal**, 1647)

$P = \rho gh$

ρ (rho) is the density of the fluid,
g is the acceleration of gravity
h is the height of the fluid above the object

While Pascal law regarded just the fluids at equilibrium, 91 years later **Daniel Bernoulli** extended it to flowing fluids (1738) with the mathematical formulation of Bernoulli's principle. The full version of Bernoulli's principle includes both the work (body displacement by a force) by the pressure and by the changes in potential energy from changes in height. In this form, the principle says the total of the pressure P, dynamic pressure DP, and potential pressure GHSP is a constant. It does not consider viscosity or compressibility.

$P = p + \frac{1}{2}\rho v^2 + \rho gh = $ Constant
P is Total Pressure TP
p is Pressure sometimes called Static Pressure SP
$\frac{1}{2}\rho v^2$ is dynamic pressure DP

Total Pressure P and Static pressure p variations between 2 levels h_a and h_b of the fluid according to the flow velocity v:-

$P_a - P_b = p_a + \frac{1}{2}\rho v_a^2 + \rho gh_a - p_b + \frac{1}{2}\rho v_b^2 + \rho gh_b$

If v = 0, $P_a - P_b$ = $p_a - p_b = \rho gh_a - \rho gh_b$, $P_b = p_b = \rho gh_b$

If $v_a = v_b$, $p_a - p_b = \rho gh_a - \rho gh_b$**and $P_b = p_b + \frac{1}{2}\rho v_b^2 +$**

ρgh_b

Valve incompetence hampers the
Dynamic Fractioning of the Gravitational Hydrostatic Pressure DFGHP
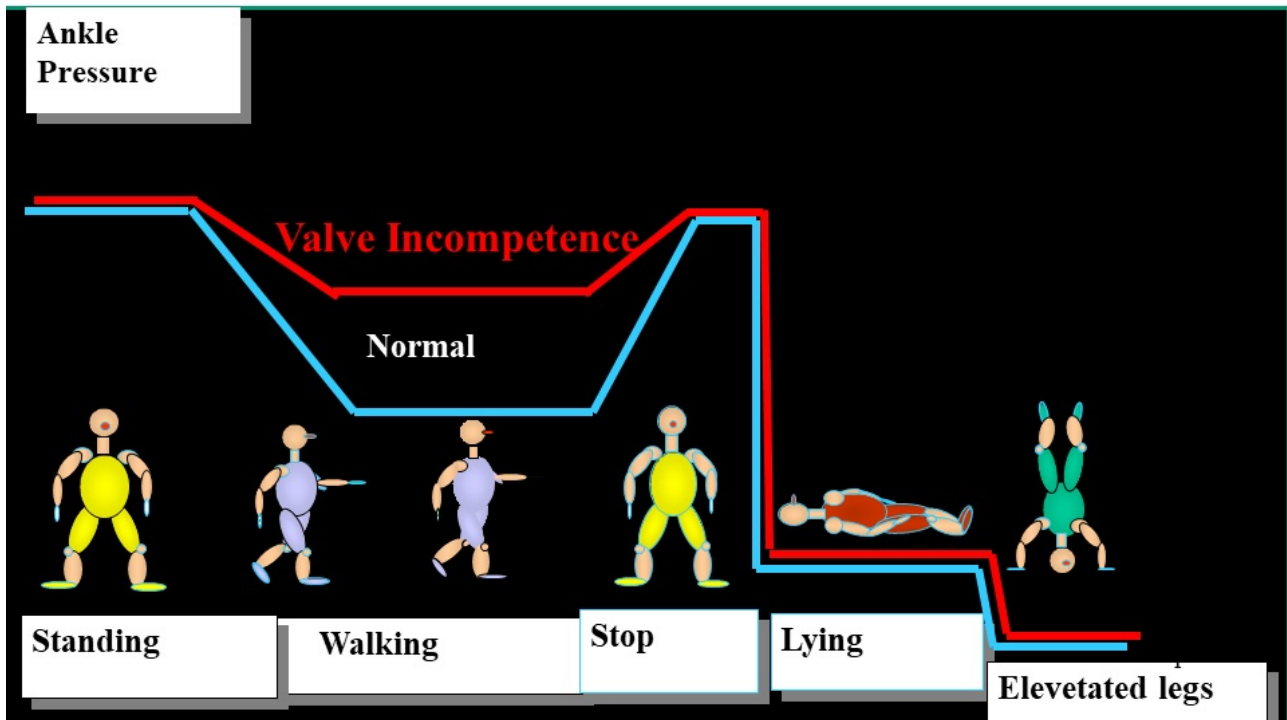## NOT AT REST BUT ONLY WHEN WALKING

Fig. 2 - DFGHSP : Ankle pressure drops dramatically when walking in healthy l but not in case of valve incompetence.

Total pressure and dynamic pressure arise from Bernouilli's equation and are significant in the study of all fluid flows. For that reason, Bernouilli's equation is usually considered eligible for the blood despite its non-perfect incompressibility and its non-Newtonian viscosity (the viscous stresses arising from its flow, at every point, are not linearly correlated to the local strain rate). So P = GHSP (ρgh) + the energy provided by its work (p + $\frac{1}{2}\rho v^2$).

The pressure that Bernoulli's principle is referring to, is the internal fluid pressure that would be exerted in all directions during the flow, including on the sides of the pipe. The Static Pressure p and GHSP ρgh are the parts of the Total Pressure exerted in all directions including the sides. Dynamic pressure $\frac{1}{2}\rho v^2$ is the part of Total Pressure exerted only in direction of the flow. So pressure measured is equal to Total pressure when the sensor faces the flow upstream, equal to p + ρgh when it is lateral and minus Dynamic pressure $\frac{1}{2}\rho v^2$ when it faces downstream (Pitot).

We call Lateral Pressure LP, the pressure exerted against the sides i.e. Static Pressure p + GHSP ρgh. If the volume flow is too little to fill the conduit, the sides won't be much strained but the Total Pressure remains, including GHSP since the stream remains continuous, i.e not fractioned.

We call **Hydrostatic Pressure HSP** also **Gravitational Hydrostatic Pressure GHSP** because **HSP** is often confused with **Contact Pressure CP**. As a matter of fact, HSP and CP are different because HSP obeys a force due to a vectorial **remote attractive forces** (gravitational field lines) between 2 distant masses, (Newton Universal Gravitational force responsible for the apple fall and the matter weight) directed constantly toward the earth center. So, it increases downwards despite a **top-down "negative Pressure Gradient"**. **Contact Pressure** is different because it results not from gravity but from **contact forces** provided for example by pumps that press the fluid in a direction that depends on their feature and position and usually provide **a positive pressure gradient**.
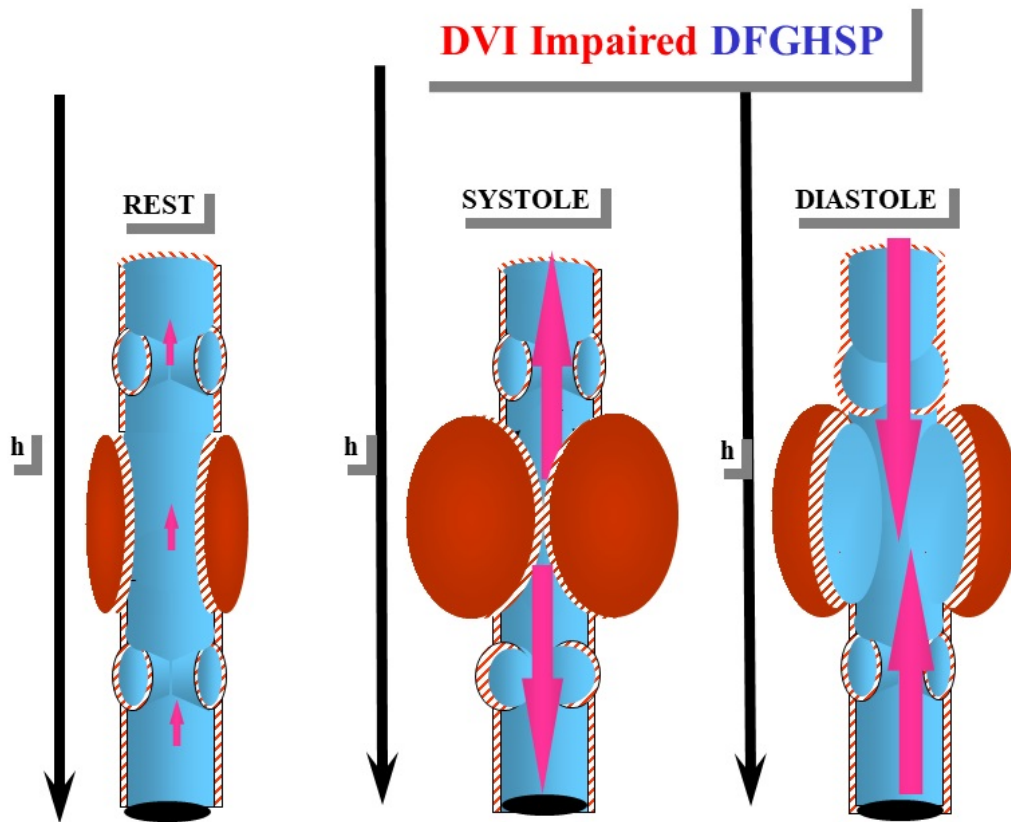
Fig. 3 - DFGHSP impairment: deep venous valves incompetence : h: No fractoning.

3-Fractioning of the Gravitational Hydrostatic Pressure FGHSP Definition

According to the formula GHSP = ρgh, shortening or segmenting h fractions and decreases P.

3.1-Static Fractioning of the Gravitational Hydrostatic Pressure FGHSP Definition

At rest the height (elevation) of the continuous column of fluid, i.e GHSP varies in 2 conditions: 1-According to the position: GSHP is null when horizontal, maximum when vertical and intermediate between these 2 extreme positions. 2- According to the level of interruptions of the fluid column, excepted in case of U tube where the non-fractioned branch still transmits the maximum pressure to the fractioned branch.

3.2-Dynamic Fractioning of the Gravitational Hydrostatic Pressure DFGHSP Definition: Fig 1

In absence of static fractioning, the fractioning can be achieved by a valve alternate pump made of a flush chamber and at least 1 valve on either side. We call it, **Dynamic Fractioning of the Gravitational Hydrostatic Pressure DFGHSP**. As a matter of fact, during the push

(systole), the resulting upstream valve closure fractions the GHSP at its level and during the aspiration (diastole), the resulting downstream valve closure fractions at its level. So, the DFGHSP lowers the GHSP below the valves in proportion to their elevation height h. Above the downstream valve diastolic pressure doesn't change and increases with the additional energy provided by the systolic push of the pump. **The number of valves inside, upstream and downstream the chamber may vary according to the feature of the pump but it results in the equivalent effect provided there is at least 1 valve on either side of the flushing chamber and they contract simultaneously. As any variable volume between at least 2 valves can constitute the flushing chamber of a pushing sucking pump, various serial and/or parallel pumps can work as a unique pump if they contract and relax in a coordinated way**.

3.3-DFGHSP impairment: Fig 2

3.3.1-Absence or incompetence of the valves of the pump Fig 3

Absence or incompetence of the downstream valve produces a diastolic reflux and impairs the diastolic fractioning at its level Absence or incompetence of the upstream valve produces a systolic reflux and impairs the systolic fractioning at its level.

3.3.2-Absence or incompetence of valves in a parallel pump

Absence or incompetence of the downstream valve impairs the diastolic fractioning at its level.

3.3.3- Absence or incompetence of valves in a collateral conduit connected to both up and downstream sides of the pump

During the pump diastole, the absence or incompetence of valves in a collateral conduit impairs the diastolic fractioning and makes the flow turn back into the pump through the upstream pump connection at each diastole. **We call this loop a Closed Shunt that in addition to impair the DFGHSP increases the diastolic total pressure due to** $p + \frac{1}{2}\rho v^2$ activated by the pump aspiration resulting from the chamber dilation that releases the resistance to the GHSP until its total dilation. Notice that the static pressure $p = $ GHSP when the fluid is still or when it flows without resistance friction (see above). Notice too that in case of incompetence of the proper valves of the pump, the diastolic reflux into the pump prevails on the collateral reflux that cannot occur. We call this case a "**competitive deep reflux**" (see below).

3.3.4- Absence or incompetence of valves in a collateral conduit connected to a competent collateral that connects to both up and downstream sides of the pump

In that case, the pump diastole triggers reflux only in the incompetent collateral which at it turn aspires some flow of the competent collateral. As this flow is not made of diastolic reflux from the pump, there is no closed shunt effect. We call it **Open Deviated Shunt ODS** (see below).

3.3.5-The conduit strain increases with the flow

According to:

If v = 0, Pb = pb = ρgh_b
and
If $v_b > 0$, Pb = pb+ $\frac{1}{2} \rho v_b^2$ + ρgh_b,

we see that Static Pressure pb increases with the Total Pressure Pb. So, extensible tubes as veins dilate furthermore because the diastolic reflux energy is added to the GHSP.

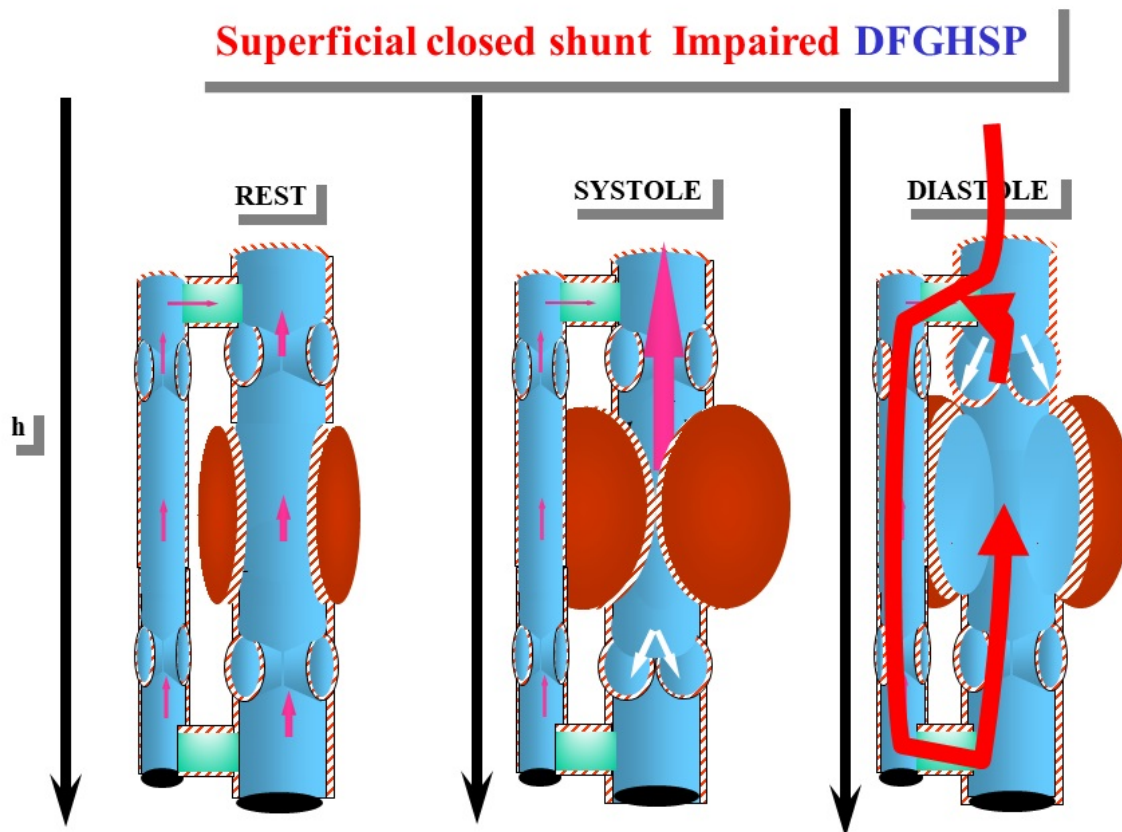*Fig. 4 - DFGHSP impairment: Competent Deep venous valves. Superficial venous valves incompetence : closed shunt + h: No fractoning.*
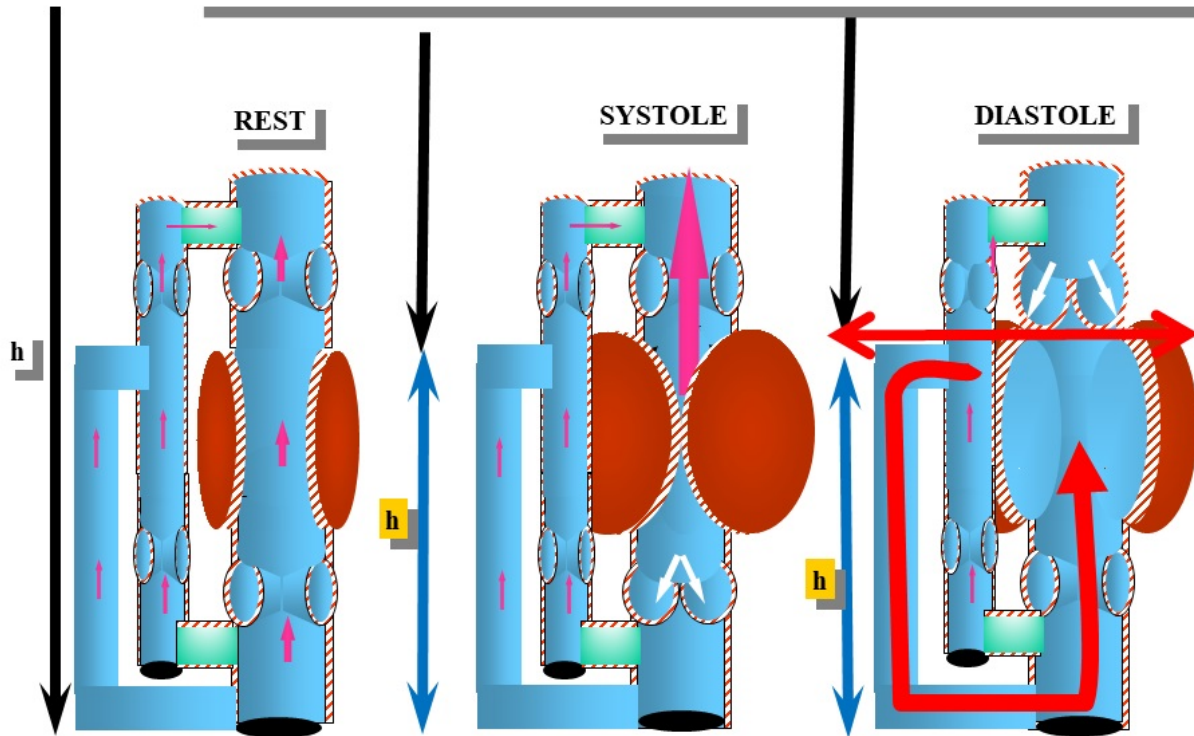
Fig. 5 - DFGHSP impairment: Competent Deep venous valves. Superficial venous valves incompetence Open deviated shunt+h: No fractoning.

Similarities between physics and hemodynamic models according to clinical and instrumental data

4-Clinical data regarding the HSP

As collapsible and compliant tubes, veins are "per se" pressure probes inside the limits of their dilation capability (Young module). So their clinical calibre appearance is a qualitative assessment of the venous pressure variation. At rest, i.e when the venous flow depends only on the cardiac and thoraco-abdominal constant pumping, the calibre variation of the veins according to the position is correlated to the Gravitational Hydrostatic Pressure GHSP, i.e. to the height of the continuous blood column according to the Pascal law.

4.1-Position

- maximum in upright position, varicose caliber collapses in proportion to the foot elevation above the heart.

- Venous hypertension (Trans Mural Pressure excess) due to GHSP is responsible for edema, skin disorders and ulcers that reduce/heal with prolonged lying stance and reoccur in prolonged upright position.

4.2-Fractioning

4.2.1-Static fractioning

Trendelenburg maneuver (1891)[10]: compression with a finger of the collapsed varicose GSV at the groin first in lying position, then asking the patient to stand up while keeping the compression, shows a delayed swelling compared to the same action without compression. The refilling delay could be due to the deep venous pressure at rest (no deep GHSP fraction due to open valves) transmitted to the GSV through their inter-connections (U tube effect).

Trendelenburg operation: Substituting the finger compression by a GSV ligation led to below varicose veins

collapse i.e pressure decrease and its consequent ulcer healing.

CHIVA: varicose veins collapse after flush disconnection of closed and open deviated shunts.

4.2.2-Dynamic fractioning

When walking, the varicose veins due to GSV incompetence doesn't collapse due to the superficial GHSP impairment. The **Perthes test**[11] consists in blocking the incompetent GSV reflux with a tourniquet at the thigh then asking the patient to walk. The varicose veins collapse when he walks because of the DFGHSP diastole of the deep veins which aspires back (reflux) the GSV flow no more overloaded neither by the GHSP column above the groin or by the Closed shunt. In case of valvo-muscular pump defect (muscular palsy and/or deep valve incompetence) the varicose veins doesn't collapse because the deep DFGHSP is impaired. This is a basic principle of the CHIVA strategy.

4.2.3-Static and Dynamic fractioning

While the Dynamic fractioning effect on the varicose collapse is immediate and constant, the Static fractioning need time to be constant because, the venous wall "remodeling" to fit the shunt overflow ablation and GHSP reduction need a "biological healing time". This is confirmed by the CHVA flow up[12, 13].

5-Instrumental data regarding the GHSP

5.1-Duplex Scan

At rest:
Veins identification and calibre assessment show not only superficial but also deep veins reduction.

Dynamic assessment:
Dynamic tests simulating (squeezing) or reproducing (Paranà test) the valvo-muscular pumping. A diastolic overflow in incompetent superficial veins assesses the closed and deviated shunts and at the same time a correct valvo-muscular pumping. The absence of superficial varicose veins diastolic reflux is usually due to an impaired valvo-muscular pumping (Deep competitive reflux). In contrast with the Open deviated shunt Valsalva test triggers a reflux only Closed shunts.
The various escape points to be disconnected as not only SFJ, SPJ, buttock thigh and legs perforators but also the pelvic escape points Escape points (Inguinal, Perineal, Clitoridean and Obturator)[14-17]

5.2-Air and Strain gauge Plethysmography

Both show an increase of calf volume when standing still respect to lying and a decrease when activating the valvo-muscular pump of the calf, i.e the DFGHSP.

When the deep venous network and/or superficial is incompetent, the volume reduction is proportional to the DFGHSP impairment. When the incompetence affects only the superficial veins, the superficial shunts disconnections restore the DFGSP and the consequent volume lowering[18].

5.3-Invasive methods

Paradoxically the usual venous pressure at the ankle when standing still is around 90 cm Hg i.e. 120 cm H_2O, which correspond only to the height foot-xyloid instead of expected foot-top-head 170 cm. This can be explained by the shield effect of skull and thorax that prevents the atmospheric pressure transmission to the intra chest and cranial veins where the positive venous absolute pressure despite < atmospheric pressure and relative pressure is negative, i.e less than the Atmospheric Pressure (risk of air embolism when inserting a needle in the jugular vein in a sitting patient)[19]. Negative pressure is referred to "vacuum pressure" and equal Absolute pressure – Atmospheric pressure . According Bernoulli, the pressure measurement varies with the sensor direction respect to the flow direction (see above Pitot tubes)

5.3.1-Venous pressure invasive measurements

Venous pressure measurements by the mean of needles and catheters at the ankle (Posterior Tibial Vein PTV and GSV) **confirm the plethysmographic data**. It is very low when lying, increases dramatically when standing still, and decreases when activating the valvo-muscular pump of the calf. It doesn't decrease in case of GSV incompetence. The decrease is restored by blocking the refluxing GSV at the groin with a tourniquet[20-22]. These data fit to the DFGHSP impairment and restore model regarding the incompetent collateral conduit here represented by the GSV. Two other data favour this model. The first one is the no diastolic reduction and systolic increase of the popliteal vein pressure above the downstream valves of the calf pump. The second one is the pressure lowering around 30 mmHg equivalent to the height ankle- knee, i.e below the downstream valves of the calf pump. The hypothesis of this reduction should not be due to the total veins emptying because the pressure measurement attests for the presence of at least a minimal blood column.

5.3.2-Venography

Venography has a limited use because it cannot assess properly the hemodynamic complexity of the venous insufficiency. As a matter of fact, it cannot be performed under the conditions that fractionate the venous blood column, as standing, walking and/or calf compression and Paraná maneuver[23].

6-Consequent Diagnosis and Treatment according to the DFGHSP model

This model regards the venous incompetence due to valve incompetence and not the ones due to venous obstructions. So, the assessment must confirm the absence of significant hemodynamic obstruction by non-invasive means. The clinical diagnosis relies on clinical signs as postural varicose caliber variation and Perthes test. The non-invasive instrumental assessments as Plethysmography are useful especially for trials and follow-up because they provide quantitative data but not mandatory in daily practice. Unfortunately, they don't provide enough anatomic and hemodynamic details. Duplex Scan by Ultrasound Echo-Doppler is non-invasive, and provides at the same time anatomic and hemodynamic data provided it is performed according to the appropriate method, as the one used to draw the venous mapping necessary to decide a proper CHIVA strategy. The CHIVA strategy consists of GHSP fractioning, Shunts disconnecting and Veins preserving. Most of the time, GHSP fractioning and Shunts disconnecting are performed at the same time and place which consists of treating simultaneously two combined causes of venous pressure excess. **In case of upper thigh disconnection/fractioning, the remaining height of blood column may be sometime not reduced enough to lower properly the pressure at the ankle. In that case a below knee fractioning is performed flush below an intermediate re-entry perforator. The treated varicose veins collapse all along the walking time but their definitive collapse when standing still needs the** **biological time that is necessary to the venous wall "remodeling" until to fit to its appropriate restored physiological flow even if retrograde**. Disconnection and fractioning are also eligible in case of deep veins as Superficial Femoral Vein incompetence and TPV closed shunts[19].

7-Discussion

CHIVA represents a disrupting method because it contrasts with the dominant destructive methods. It complies to the DFGHSP model diagnosis and therapeutic consequences, i.e. treating the veins dilation by correcting its hemodynamic cause, so restoring the normal pressure and calibre that fit to its physiologic draining flow regardless the direction (CHIVA disconnected shunts still show a retrograde flow but no more pathogenic). The trials, studies, reviews and Cochrane confirms its prevalence on surgical and endo-venous destructive methods in terms of recurrence, complications and side effects. The welcome dispute of this hemodynamic model should be replaced by another physically coherent. Anyway, it could be temporarily accepted at least as "DFGHSP-like" because it may account for venous pressure drop at the ankle from 120 to around 50 cm H_2O which equals the height of the knee, i.e. below the upper valves of the calf pump. The future progresses in valve restoring or prosthetic should also restore the DFGHSP.

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