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The postural system as a functional venous pump

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ABSTRACT
Background: In the 90s, Inamura et al. have drawn our attention to the role played by the postural system in the return venous circulation, thanks to plethysmographic recordings which gave free rein to the imagination of the authors to suppose the functioning mechanisms of this venous pump. In 2010, two anatomists, Uhl & Gillot, transformed our representation of the venous network and made assumptions about the functioning of the venous pump. **Objective/ Methods:** The aim of this work is to verify these hypotheses by scanning the venous blood flow at the level of the sinus soleus and the popliteal vein during various posture-kinetic situations. **Conclusion:** These studies fully confirm the hypotheses. It is therefore likely that the postural system intervenes not only in the phenomena of stabilisation of the body, but also in the back venous circulation.

Keywords: Posturology; Phlebology; Venous Return Circulation.

BACKGROUND

From the first publications of Inamura et al.[1-3] it was clear that there was a very strong correlation between the venous return and stabilization of orthostatic posture leading to a particular organization of the postural oscillations. But this organization did not seem to modify structurally the phenomena related to stabilization, as if stabilization and venous return co-existed in a certain independence. The publications of Inamura and his colleagues, have had no echo among posturologists until the long-term stabilometric recordings made by Belayev and Usachev[4] showing instead that the postural oscillations of one minute could be accompanied at each oscillation, by a migration of the center of pressure. This questioned the conventional concepts, in the analysis of the stabilometric signal, of the mean position of the center of pressure and consequently the measures of deviation from the average position of the center of pressure which were used to evaluate the stability of the subject[5]. These migrations of the center of pressure then suggested the hypothesis that they participated in the ejection of the blood contained in the venous sole of Lejars[5,6]. Clumsy hypothesis because since 2010 an anatomical work[7] had shown that this venous sole of Lejars was an artifact. From the arrangement of the veins of the foot that their work had systematized, the authors speculated that the venous pump should be initiated at the level of the lateral support band of the foot, in the corresponding deep lateral vein, located between the muscle layers. The venous reflux could be due to muscular contractions as well as to migration of the pressure zones of the body weight. The venous blood expelled by this plantar pump would be directed to the superficial circulation back by the saphenous vein and to the deep circulation by the posterior tibial vein. The authors postulated that the venous pump was then relayed by the contraction of the soleus muscle and of the internal and external twins' muscles. These hypotheses emanating from anatomists were worth a control by new physiological studies, made after this anatomical publication[8-10]. The aim of this work is to verify these hypotheses by scanning the venous blood flow at the level of the sinus soleus and the popliteal vein during various posture-kinetic situations.

MATERIAL AND METHODS

Protocol

In the leg veins — popliteal vein and soleus venous sinus — we measured the speed and flow rate of the blood flow and the diameter of these veins, in 11 dynamically different situations, according to the gravitational vector direction and muscle activity:

1) Lying supine.
2) Sitting, legs dangling, feet not touching the ground.
3) Toes flexion maintained, in this sitting position.
4) Progressive plantar flexion of the foot, in 3 seconds, in this sitting position.
5) Standing, eyes closed.
6) Standing and, leaning forward, to the limits of stability.

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7) Standing, leaning gradually on his left side, in 3 seconds.
8) Standing, imitating the stepping on the spot by a transfer of the support, heel /toes, alternated between the right and left foot (when the right foot leans on the toes, the left foot is based on the heel), at a rapid pace around one second.
9) Sitting, plantar and dorsal flexion of the foot.
10) Standing, swinging rapidly back and forth.
11) Standing, swaying slowly back and forth.

Equipment

The duplex scanning of legs veins was carried out on the "SIEMENS ACUSON X700".

Population

Two volunteers were selected to participate in these measures, according to the criteria of the institution's ethics committee. Situations 9 to 11 have only been studied on one subject.

RESULTS ANALYSIS

The mean of the blood flow, measured at the level of the popliteal vein and at the level of the sinus soleus were compared between the first 8 situations and between the two veins. Mean blood flow in both the popliteal and sinus soleus veins, in each of the first 7 situations were compared, as a percentage, to mean blood flow in both veins during the eighth situation: imitation of stepping on the spot.

RESULTS

A) Representative recordings

1) Automatic activity, standing subject, eyes closed
The two velocity peaks separated by about five seconds represent the body's automatic activity to control its stability (figure 1).

2) Voluntary activity *a) Slow tilt of the subject forward*
The speed of venous flow varies because the regularity of the movement is poorly controlled by the subject (Figure 2), but on average it is similar to the linear speed of the venous flow observed in automatic control (Figure1).

b) Dorsal and plantar flexion of the foot
With the dorsal folding of the foot, the linear velocity of the blood flow is 120 cm/s, and 80 cm/s with the plantar flexion (Figure 3).

c) Slow, voluntary, forward / backward oscillations of the body
The linear speed of the blood flow in the popliteal vein with the backward movement is only 10 cm/s, whereas it is 50 cm/s in the course of forward movements. All these movements are slow (figure 4).

d) Fast, voluntary, forward / backward oscillations of the body
When the body moves quickly backward, the velocity of the blood flow in the popliteal vein is half the one when it moves forward (figure 5).

B) Comparison of the venous flows observed in various situations

Figure 1. Blood flow of the popliteal vein in a standing subject, eyes closed. Top inset: popliteal vein. Bottom: Graph showing the linear speed of blood flow in the popliteal vein during approximately 20 seconds of recording. Note: On the abscissa: time in seconds; on the ordinates speed in centimeters per second.

a) Between the popliteal vein and the soleal sinus

To facilitate the comparisons between the different experimental situations and between the two veins, the venous flow rates observed in the popliteal vein and in the soleal sinus during the different experimental situations are presented on the same graph for each vein (Figure 6 and Figure 7).

Venous flow varies a lot from one situation to another, but in the same situations it is comparable between the different subjects.

Figure 2. Blood flow in V. poplitea with a slow deviation of the body forward by 150 mm in 20 seconds (half the 'one-minute wave' of Inamura). Top inset: popliteal vein. Below is a graph of the linear speed of blood flow. Note: On the right of the graph is a scale of linear blood flow velocity in cm/s, at the bottom of the graph the time scale in seconds.

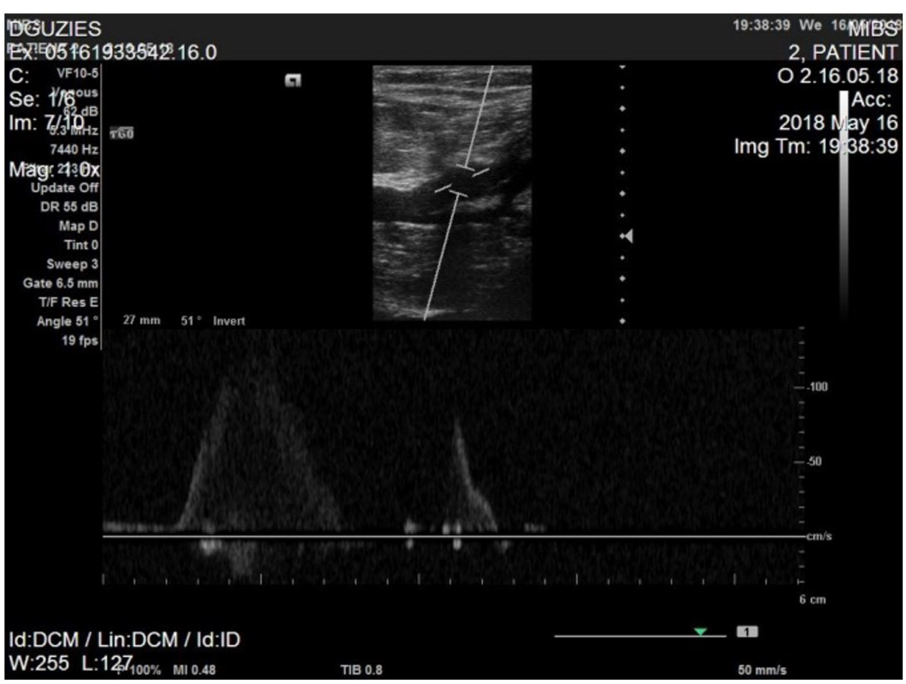

Figure 3. Dynamics of the linear velocity of blood flow in the popliteal vein during a dorsal then a plantar flexion of the foot. Top inset: popliteal vein. Bottom is a graph of the linear speed of the blood flow. Note: On the right of the graph is a scale of linear blood flow velocity in cm/s, at the bottom of the graph the time scale in seconds.

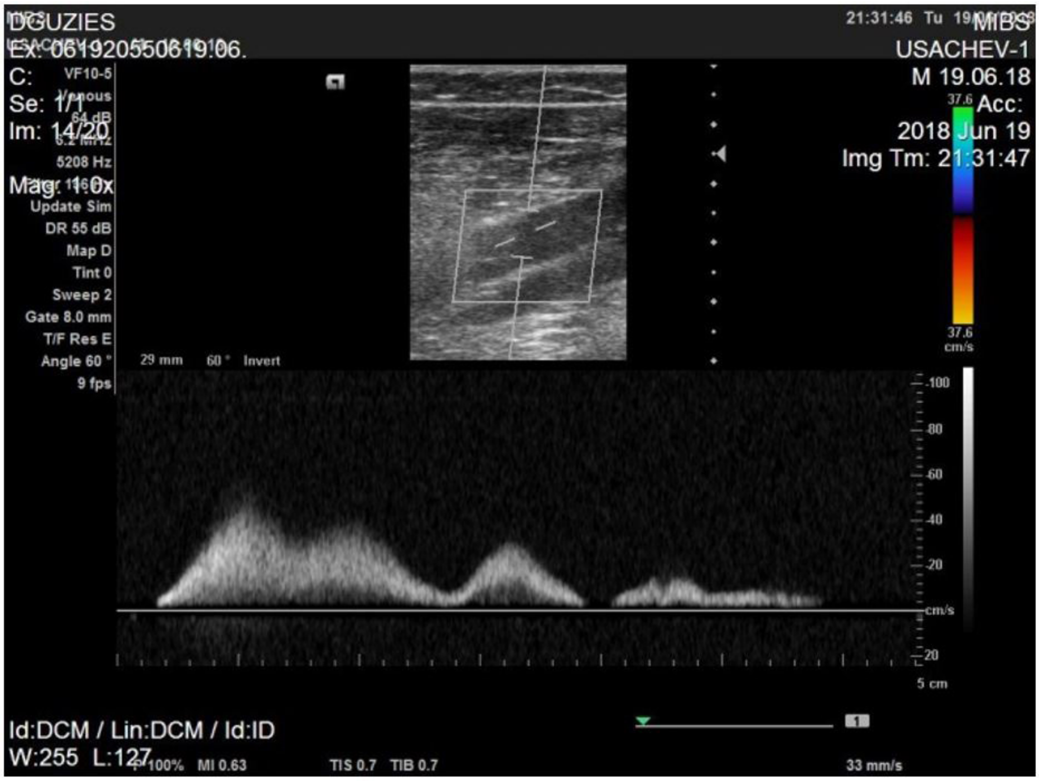

Figure 4. Dynamics of the linear speed of the blood flow in the popliteal vein with a slow back and forth movement of the body. Top inset: popliteal vein. bottom graph of the linear velocity of the blood flow. Note: On the right of the graph is a scale of the linear blood flow speed in cm/s, at the bottom of the graph the time scale in seconds.

Figure 5. Dynamics of the linear speed of the blood flow in the popliteal vein during rapid back and forth movements of the body. Note: Top inset: popliteal vein. Below: graph of the linear velocity of blood flow. To the right of the graph is a scale of linear blood flow velocity in cm/s, at the bottom of the graph the time scale in seconds.

b) Between the "mimicked walk" and the other situations
The venous flow rates observed in both veins and in both subjects were grouped together to make a percentage comparison of the "mimicked walk" situation to all other situations (Figure 8 and Figure 9).

Then it is observed that in the standing position with closed eyes, the volume speed of the blood flow, and hence the venous pump, is four times less efficient than that of the mimicked walk and 2.7 times more than lying down. In the sitting position on the table, the feet not touching the floor, the volumetric flow velocity decreases a little due to the action of gravity on the body and the leg in the longitudinal direction.

It can be assumed that, with natural walking, the difference with other samples would have been even more important, but in natural walking it is practically impossible to register the blood flow with the apparatus for technical reasons.

Hence, the venous pump in the standing position functions, but much less than when walking. Its activation is probably associated with a constant switch of the muscles to ensure dynamic stabilization of the body. A pronounced activation of the venous pump occurs with a rapid contraction of the muscles, as can be seen from the tests: sitting foot, sitting toes, standing left, standing forward. The graph of bulk blood flow in all the samples relative to the sample with mimicked walk confirms this (Figure 9).

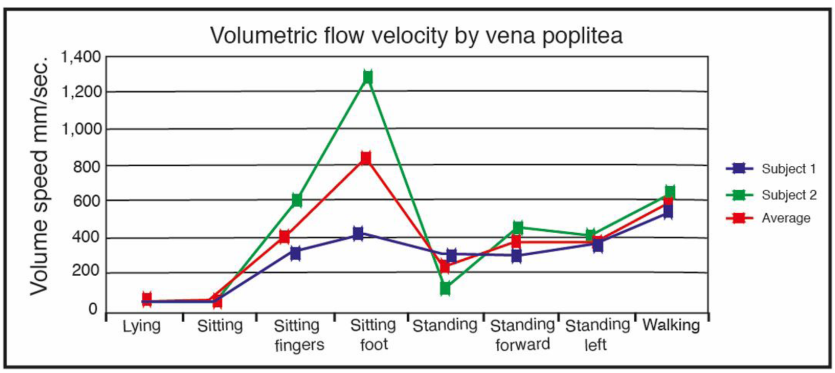

Figure 6. Volumetric flow velocity in the vena poplitea.

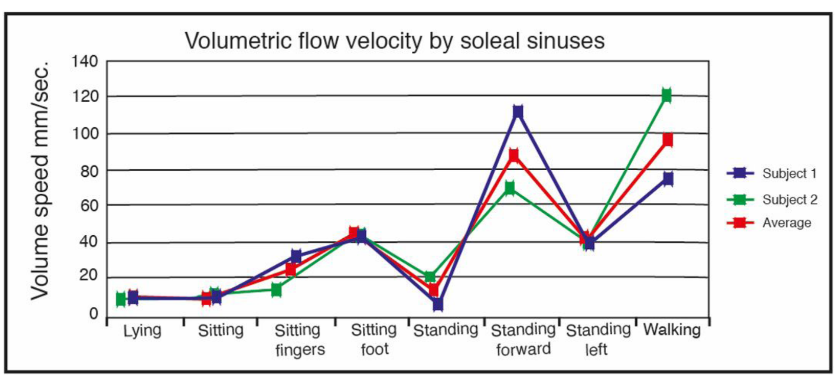

Figure 7. Volumetric flow velocity in the soleal sinus.

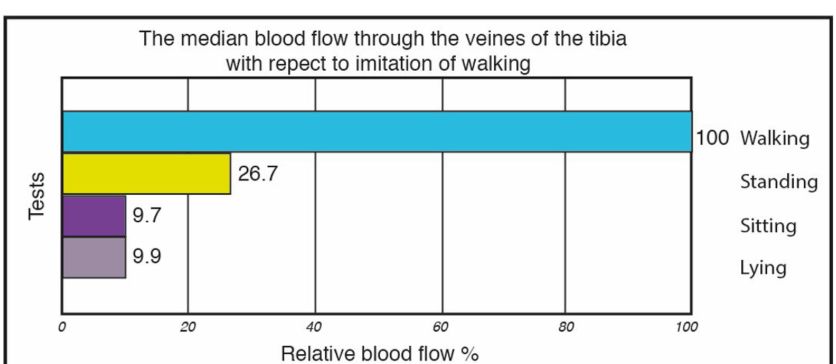

Figure 8. Mean values of the volumetric blood flow in the vena poplitea and soleal sinuses in the tests standing, sitting and lying in relation to the mimicked walk.

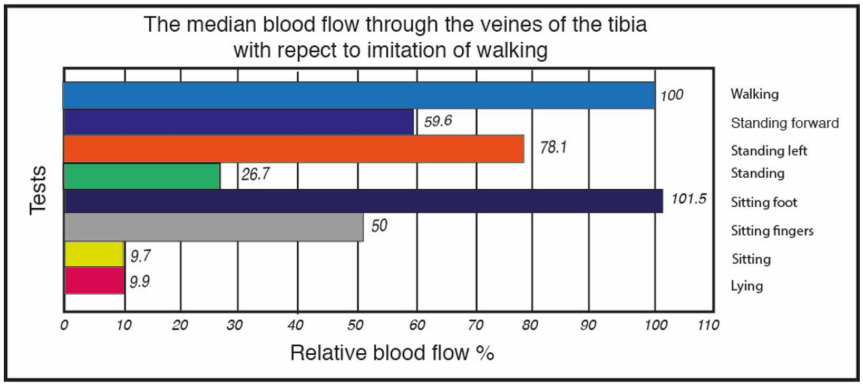

Figure 9. Mean values of the volumetric blood flow in the vena poplitea and soleal sinuses in all the tests and for the test with mimicked walk.

An only plantar flexion of the toes brings about 50% of the activity of the venous pump in relation to the mimicked walk. Plantar flexion of the entire foot gives the same result as mimicked walk. A quick tilt of the body forward brings about 78% of the activity of the venous pump in relation to the mimicked walk, and an inclination to the left: 60%.

DISCUSSION

The hypothesis of the anatomists Uhl & Gillot[7] that the venous pump must be initiated at the level of the lateral support band of the foot and relayed by the contraction of the soleus and internal and external twins' muscles is far from being contradicted by this physiology work. The situation of imitating walking, which, alone among the other situations, compresses, dynamically and alternately rapidly, the deep lateral vein of the foot under the external band is the situation which, in our experience, causes the most important venous flow, apart from the situation of progressive plantar flexion of the foot, in 3 seconds, in a sitting posture (Figure 9). The high flow observed in this last situation is astonishing, all the more surprising since it only appears in the popliteal vein and, in this sitting posture which does not relax the soleus muscle, unlike the twins, one would expect to observe a more marked efficiency of its contraction on the stagnant blood in the sinus during this posture. As for the efficiency of the contractions of the leg muscles, supposed by the anatomists, it is so obvious during this physiological experiment that it is not necessary to insist on it.

CONCLUSIONS

The venous pump begins with the compression / decompression of the deep lateral vein of the foot, during the course of the step. It continues with the effect of the contraction of the leg muscles, all the more efficient as the rhythm of these contractions increases. The stretching of the tissues of the posterior compartment of the leg also causes an increase of the venous flow, which suggests an effectiveness of the anterior tibialis, with no available guarantee from these experiments The inaugural work of Inamura et al.[1-3] is thus largely confirmed: the postural system plays an important role in the venous return circulation and the repercussion of this function on the stabilometric observations must be at last studied[5].

AUTHOR'S CONTRIBUTION

The authors VU and PMG also contributed to the design, data analysis and writing of the final version of this manuscript.

CONFLICTS OF INTEREST

Nothing to declare.

AUTHORS DETAILS

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