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The Vasculab manoeuvre: simulating walking in venous investigations

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ABSTRACT

The Vasculab manoeuvre (VA) is a dynamic manoeuvre, specifically designed to study the physio-pathology of the venous calf muscle pump (CMP). It could be defined a simulated "*in situ*" step and adopts a simplified scheme of the walking step. The patient rolls forward on the leading foot, standing on the toes of both feet (systole, S) and can remain in this position to perform a sustained systole (SS) or can relax, shifting the weight on the other side (diastole, D). VA observations require a training period, while the patient must be provided a set of simple instructions, in order to get the knee extension and the spontaneous rolling on the foot plant. BMode ultrasound shows that in all examined cases MGVs are compressible in systole. A set of CMP specific measurements can be performed, like the refilling time and the stroke volume. VA is the only manoeuver to perform an ultrasound venous investigation in movement. In diastole the refill occurs by capillary inflow (vis a tergo) while reflux comes from incompetent veins. MGVs are taken as a model for the CMP, while the endo-venous compartment of the calf is used as a volumetric model of the leg. VA is a simply executable manoeuvre, which however hides a complex physiopathology, providing the estimation of the CMP parameters. In addition, VA can be used also in several types of plethysmography.

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1. Introduction

Several manoeuvres apply an external solicitation to evaluate venous patency and reflux in veins. They can be subdivided into static manoeuvres, like Valsalva, and dynamic ones, like Paraná [1–3].

Essentially, two are the time phases. The evocation phase or systole is followed by the rest phase or diastole. A sustained systole can be interposed between the two.

For instance:

- in the Valsalva manoeuvre the hyper-pressure phase is the systole, while the diastole is the spontaneous breath relaxation. The optional sustained systole occurs if the patient is requested to maintain the hyper-pressure for some time.
- the Paraná manoeuvre can be effected from rear or from forward. The systole occurs pushing from rear or pulling from forward, while the diastole is the spontaneous return to the equilibrium position. Sustained systole, which is optional, occurs if the patient is requested to maintain the forwards unbalanced position [1,2].

Generally, dynamic manoeuvres are more effective than static ones. The Paraná manoeuvre has shown to be quantitatively more effective of the calf squeezing test in moving blood in the saphenous-femoral and saphenous-popliteal junctions [3].

2. Analysis of a walking step

A physiological walking step is subdivided into stance and swing phases. Starting with the foot on the ground, stance continues with a rolling forward movement, reaching finally the highest position when standing on toes [4,5].

During the swing, the foot dorsiflexes, matching the rising and the forward relocation of the limb and reducing the height, so that the fore extremity of the foot does not touch the ground, thereby saving energy. The loss of dorxiflexion is observed in a special pathological gait, where the foot falls and the leg must be raised to a higher position, in order to insure an effective walking, requiring a greater energy loss.

In physiological walking, limbs are generally in opposed phases: the one is in the stance, the latter in the swing. Sometimes both limbs are on the ground, but in different functional positions. The complete roll of the leading foot occurs only when the rear one is swinging. Limbs can be both swinging for a limited time, only during running and jumping.

3. The Vasculab manoeuvre

Vasculab is a mailing list on Internet, which since 1990 guests discussions about vascular diseases. Many discussions on Vasculab focused on the physio-pathology of the venous calf muscle pump (CMP). The Vasculab manoeuvre [6–8] (VA) tries to answer to the many questions raised on the list about venous physio-pathology.

VA is defined as a ***simulated 'in situ' step*** [7], though the definition cannot describe all the technical details of the manoeuvre. The adopted eponym instead reminds its original relationship to the Vasculab list.

VA adopts a simplified step scheme, which simulates the venous behaviour of CMP.

There are several variants, according to the leading limb, right (RT) and left (LT), and to the site where measurements are taken: saphenous femoral junction (SFJ), saphenous popliteal junction (SPJ), greater saphenous vein (GSV), shorter saphenous vein (SSV), medial and lateral gastrocnemius veins (MGVs and LGVs).

Another variants depends on the position of the examiner, who can stay in front or behind the patient, according to the measurement site.

In the current study the majority of measurements were taken from rear and on the medial gastrocnemius veins (MGVs), which are located in an important part of the CMP, their greater diastolic refill generally occurring in an anatomical loop, constituted by two parallel MGVs [7–15], (Fig. 1-A) The MGVs loop is connected upwards with the popliteal vein and downwards with the SSV at the gastrocnemius point. These anatomical features are present in almost the totality of the individuals. A lot of small tributary input veins go into the MGVs loop, transferring blood from muscles to the CMP.

As for all the other manoeuvres, VA consists of three phases: systole (S), sustained systole (SS) and diastole (D).

For instance, in RT VA the right leg is put forward, the right foot is in front, the left one is behind. Legs are slightly apart and feet are parallel. At the beginning the weight is on the left limb and the right toes are slightly dorsiflexed. The patient rolls forward on the leading foot, standing on the toes of both feet (S). He/she can remain in this position to perform a SS or can relax, shifting the weight on the other leg (D).

VA can be performed only once or in a sequence of systolic-diastolic cycles (nVA), which simulates walking. In nVA dorsiflexion is effective, while in the single manoeuvre it is less important. However dorsiflexion, in VA or nVA, is not placed in the same sequence as in the physiologic walking step, but in the leading foot at the end of each diastole, excepted the last one.

Another variation of VA is the VA_{step}, which can be executed only once. At the end of the last systole of a single VA or a nVA sequence, the patient performs a step forward with the rear foot, which becomes now the leading one. VA_{step} can be used successfully to study the real dorsiflexion, which occurs physiologically as the swing phase starts in the rear foot.

These procedures require a training period. The hand must follow the moving limb with the probe and the images and the Doppler measurements must be stable, reliable and repeatable. Otherwise technical artefacts will overlap completely the measurements (Fig. 2).

An additional training is required to study swing dorsiflexion in VA_{step}, following the leg during the flight. Though the study is only preliminary, this is nowadays the only method to study swing dorsiflexion by ultrasound.

Sometimes the Vasculab manoeuvre cannot be performed, for instance when ambulation is impeded by objective obstacles, such as palsy, arthrodesis or a debilitating status which prevents the standing position, or in the elderly when the manoeuvre could be dangerous.

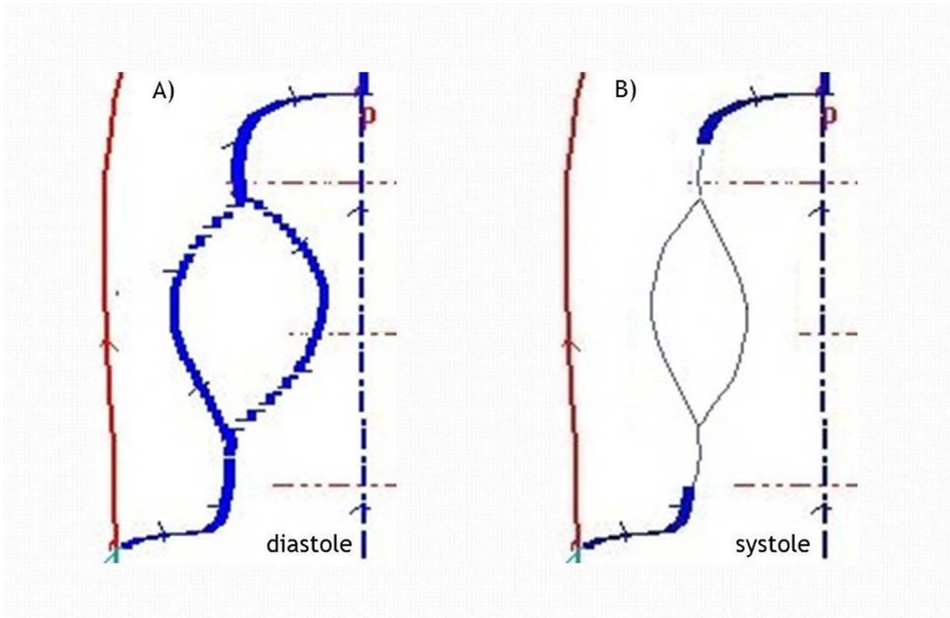

Fig. 1. The systole in the calf muscle pump. (A) The MGVs loop at rest (B) During CMP contraction, MGVs are compressed for a limited length. The contraction length (CL) is the vertical difference between MGVs upper and lower compression limits. CMP- calf muscle pump, MGVs – medial gastrocnemius veins, CL – contraction length.

Fig. 2. Ultrasound in movement. Ultrasound probe and lower limb joint movement. Following with the probe the moving leading limb, the patient and the operator move together as a single block.

4. Methods

4.1. Subjects and materials

Almost 100 consecutive patients, who asked for a consultation for problems of venous origin, were examined and data were gathered in order to set up the procedure. Only a few of them underwent a measuring procedure, following an experimental design, and subsequently signed for an informed consent.

Ultrasound investigations were performed using a General Electric (GE) Logiq E device with a multi-frequency probe, ranging 7.5–13 MHz. Other simple measurements were taken with a tape meter and a chronometer.

4.2. Technical details

Only the practical details are here reported, which were adopted since May 2012, in a daily experience of almost 4 years, and resulted to be useful in the ultrasound observations of MGVs during VA:

- The rear foot must sustain all the body weight at the start of S and at the end of D. The centre of pressure [4] (COP) is the point of application of the ground reaction force. It must be on the rear foot at the start of the manoeuvre, returning to it at the end.
- In S body is shifted slowly forwards and at the end of S (toe standing) it is completely on the leading limb (Fig. 3).

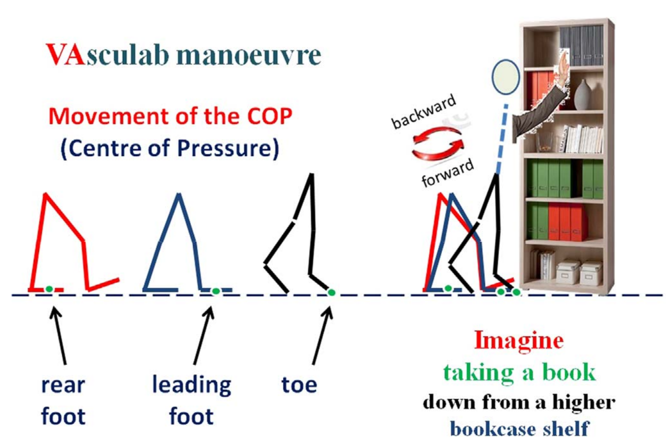

Fig. 3. The movement of the COP. The systolic-diastolic sequence in the Vasculab manoeuvre. Forward rolling in systole and backward rolling in diastole. As a simple instruction, tell the patient to imagine taking a book down from a higher bookcase shelf. COP – centre of pressure.

- The weight must not be distributed on both limbs in diastole, so producing undetectable contractions of the calf (or other) muscles of the leading limb. These contractions prevent a complete relaxation and the venous expansion, producing instead a variable refill, according to the muscle activity. On the contrary, shifting back the weight on the rear limb, a complete relaxation occurs and the diastolic refill becomes repeatable.
- During the movement the leading knee must not be bent. The foot must roll as if the sole were a circumference arch. If the knee is extended, the movement occurs correctly around the COP, placed at the sole of the foot. The COP too moves forwards as in a ship under movement from the waves. The rotation occurs around the moving COP, which behaves as an instantaneous centre of rotation called metacenter (Fig. 3).

4.3. Ultrasound in movement

The probe is placed horizontally or slightly oblique upwards and in contact with the skin. It is strongly held between the palm of both hands below and both the thumbs above. Both the index fingers are positioned with a light pressure on the medial and lateral calf margins (Fig. 2). The probe must be placed in the point of maximal diastolic refill of MGVs (MaxRefill), previously detected statically and marked with precision, e.g. with a marker pen. The index fingers and the probe touch the skin, while leg movements carry the fingers and the probe together, thus allowing the observation of moving segments. During VA the leading limb, the probe and the examiner behave like a moving block, which follows the movements of the leading limb.

4.4. Notation and VA variants

A synthetic symbolic notation can be used to report the procedure details and the results of a venous manoeuvre.

$$[\text{side}][\text{site}][n_{[m]}]M^{S[,SS]}{}_{D}[-q]$$

M is the manoeuvre term. S is the systole, SS the sustained systole, D the diastole. n is the total number of repetitions of the M manoeuvre, while m refers to the mth repetition, when the measurements are performed. The last term q allows the introduction of synthetic notes or qualifiers. Terms in square brackets are non-mandatory.

For instance, nVA and n_mVA are general notations for a VA sequence. n is the number of performed cycles, while the observations refer to the mth manoeuvre. These values can also remain unassigned, being non-mandatory. For instance 5 VA is a sequence of 5 VA, while 5_3 VA refers to the 3rd VA in a sequence of 5 VA and n_3VA refers to the 3rd VA in a sequence of n VA, where n is unassigned but clearly greater than or equal to 3. However, by default nVA means only a repeated sequence of VA manoeuvres.

Finally, regarding VA results on flow, RT GSV $3_3VA^{-,0}_{+}$ means that in the last manoeuvre of a sequence of 3, performed on the right greater saphenous vein, flow is ante-grade in systole, null in sustained systole and retrograde in diastole. The simplest minimal notation is M^S_D, describing what happens during systole and diastole of the M manoeuvre.

4.5. The refilling time

When the patient finally stops at the starting time of diastole (t_0), the weight is now on the rear foot. The time t_0 can be successfully marked, introducing only for a while the tip of one of the index fingers between the probe and the skin (for instance in an angle), producing an instantaneous shadow in the ultrasound field.

It is possible to follow the venous refill in diastole until a stable

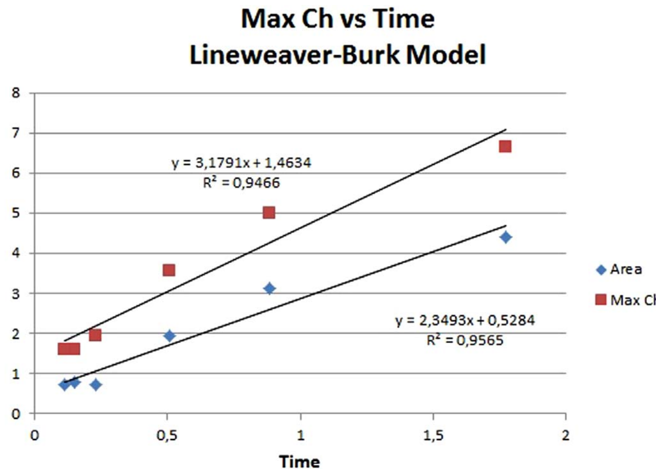

Fig. 4. Refilling can be represented in a graph reporting in abscissa and in ordinate respectively the reciprocal of time and of the area or the calibre, according to the Lineweaver-Burk model. In such a way, the curve is transformed into a linear plot and the refilling parameters are computed easily [16]. The computation is very quick, but data collection is time consuming.

point of maximal calibre is reached, while images are video recorded or stored and then reviewed in cineloop. As ultrasound devices report the time and the frame number of the observation, t_0 is assigned the time of the first frame, which contains the shadow entering the ultrasound field.

In addition, if using the cineloop, it must be sufficiently long to capture completely the diastolic phase. Depending on the used device, a too short time can start the registration again from an intermediate moment of the diastole, being lost then the t_0 time.

It is easy to measure the maximal tele-diastolic calibre ϕ_{max} and the starting calibre ϕ_0 (generally null, if the vein is patent).

The 90% volume $\phi_{90\%}$ is computed as follows:

$$\boldsymbol{\phi}_{90\%} = \boldsymbol{\phi}_{\mathbf{0}} + 90\%(\boldsymbol{\phi}_{\mathbf{max}} - \boldsymbol{\phi}_{\mathbf{0}}) = 90\%\boldsymbol{\phi}_{\mathbf{max}} + 10\%\boldsymbol{\phi}_{\mathbf{0}}$$

When $\phi_0 = 0$, the formula simplifies to.

$$\boldsymbol{\phi}_{90\%} = 90\%\boldsymbol{\phi}_{\mathbf{max}}.$$

Knowing t_0 and the frame number of each image and searching for a $\phi_{90\%}$ calibre in the previous frames, the corresponding time is measured. Subtracting t_0, the result is the 90% refilling time ($RT_{90\%}$), analogous to the one used in air plethysmography (APG) to estimate the severity of reflux. When many points of the time course of the MGVs calibres are known, a more precise but also more time consuming method can be applied, using a statistical estimate of $RT_{90\%}$ [12–14]. More complex methods adopt computations, which are used daily in laboratory estimation of enzyme kinetics [7,12–16] (Fig. 4). However, for practical uses the above described simplified method is more quick and easy applicable to clinical environments, requiring only a few seconds, if performed by a trained operator. The sequence of the required operations in this simplified method can be reported in an easy graphical algorithm (Fig. 5).

RT Measurements are not-exclusive to VA, but they can be performed with other manoeuvres, provided they are able to activate the CMP.

4.6. Tourniquets

VA can be performed using a tourniquet, placed for instance at the lower third of the thigh, to exclude reflux from the SFJ or from a Dodd's perforating vein. The tourniquet can also be placed below

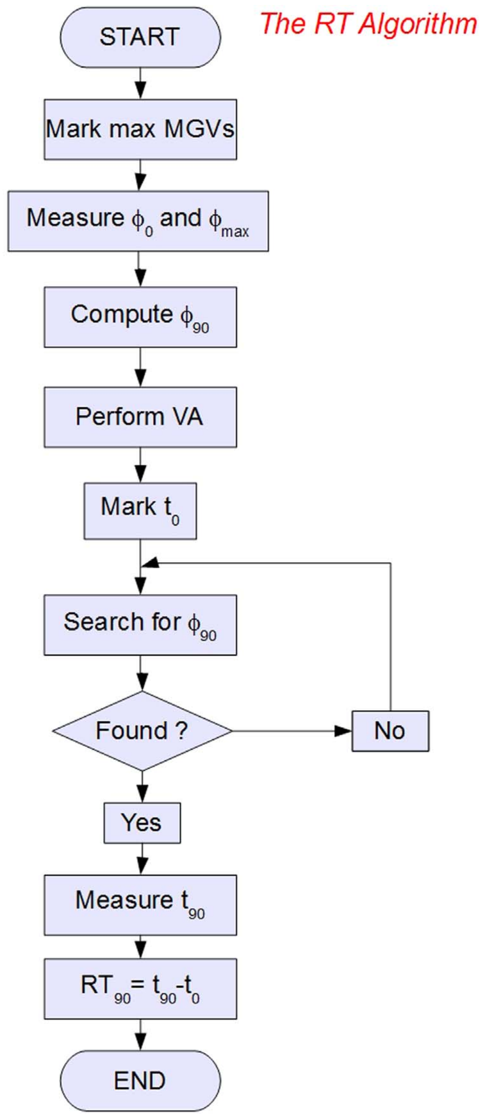

Fig. 5. The refilling time can be measured by a quick ultrasound procedure, outlined in a simple flow-chart, which describes clearly the sequence of the required steps. Only the "Search for ϕ_{90}" step is more complex, requiring an iterative procedure with trials and errors. For explanation of symbols see the text.

the calf, to exclude the reflux from calf perforating veins and the caudal ejection towards the superficial veins of the leg, or with two tourniquets at both the described sites. In addition, a tourniquet can be placed in a position which is just above the calf and below the knee, in order to exclude the escape points at the lower third of the thigh and from the SPJ.

These are the most common places, but tourniquets may also be placed in other positions. Among them, the first position described, at the thigh, is the most useful one.

Taking into account these positions, a simple notation can be used for the refilling time, as outlined in the following lines:

- $\mathbf{RT_{[\%]}}$ - Refilling time, choosing an arbitrary % refilling value, omitted if deduced from the context
- $\mathbf{RT^{L}}$ - A tourniquet is applied above the knee
- $\mathbf{RT_{L}}$ - A tourniquet is applied below the knee
- $\mathbf{RT^{L}_{L}}$ - A tourniquet is applied to both previous sites

where square brackets point to a non-mandatory notation. For instance, $RT_{90\%}$ is generally used, thus the 90% value is often omitted. Using other % values, the difference can be underlined in the notation or deduced instead from the context.

Placing tourniquets is not-exclusive to VA, as they can be used also with other manoeuvres. In addition, VA observations are not necessarily limited to ultrasound investigations.

As regards the patient, He/She must be given a set of much simpler instructions, like "place the weight on the one or on the other limb". Taking the patient's belt to avoid falls, gently push forward and pull backward the patient to test the movement from rear and then ask to "repeat the movement in a forward-backward sequence". Then in order to get the knee extension and the spontaneous rolling on the sole of the foot, more simply tell the patient to imagine taking a book down from a higher bookcase shelf (Fig. 3).

An analogous from forward procedure pulls forward and pushes backward. The choice depends on the site of the investigated vein and consequently on the position of the examiner.

4.7. Color and pulsed wave Doppler

Color and pulsed wave (PW) Doppler can detect ante-grade, retrograde flow and reflux, their duration and in which time phase (S, SS or D) they occur. During the limb movement the PW sample volume can be dislocated considerably, non-focusing rightly the

Table 1
Effect of several manoeuvres on the venous stroke volume.

#ref	*2337*		**Date** 16/02/2016				**Patient**		*U.D.*	
M [ ]	*F [X]*		**Age**	*40*				*RT [X]*	*LT [ ]*	
Site	*GSV trunk at midthigh*									
Shunts	*ShI + II GSV*			**Strategy**		*Ob Chiva SFJ + tributary phlebectomy*				
Calibres (cm)		**max**	*0,68*		**min**	*0,61*		**Area (cm²)**		*1,30*
	Manoeuvres	**Systole**			**Sustained systole**			**Diastole**		
		vmax (cm/s)	**time** ms	**SV** ml	**vmax** (cm/s)	**time** ms	**SV** ml	**vmax** (cm/s)	**time** ms	**SV** ml
P	Paraná	– 6,92	1590,00	5,50	0,00	545,76	0,00	15,41	2861,00	22,04
TT	Tip-toe	– 7,24	292,85	1,06	0,00	818,64	0,00	4,56	492,52	1,12
DF	Dorxiflexion	– 11,22	752,08	4,22	0,00	186,36	0,00	12,90	3094,00	19,96
VA	Vasculab	– 12,80	1377,00	8,81	0,00	1730,00	0,00	18,09	3993,00	36,12

Device: GE Logiq E. Settings: sample volume 0,8 cm, screen speed 1, steering 0, centred baseline. SV – Stroke Volume (ml), GSV – greater saphenous vein, Ob Chiva – Office based Chiva, SFJ – Safenous femoral junction, Sh I+II – one term of the shunts classification. Other terms in the table are self-explanatory.

examined vein. The Doppler signal could then be false, owing to artefacts by movements. The same applies to the Color, but the effect is less important, because the Color region of interest (ROI) has generally a wider window than the PW sample volume. The width of the PW sample volume should be then increased, in such a way its movement to be less important than in the structures under investigation, so reducing the effects of artefacts by movement.

4.8. Measurements

Though the aim of the paper is only to introduce the VA manoeuvre without extensive measurements and computations, in a few cases a preliminary comparison was effected on dynamic manoeuvres. They were executed only once in a fixed time sequence: Paraná (P), Tip-toe (TT), Dorsiflexion (DF), Vasculab (VA) (Table 1), each one followed by an adequate rest period, much longer than the time required to let the diastolic effect vanish in the examined vein.

The sequence was always performed in the standing position. This simplifying choice could however result unusual for TT and DF, because they are generally performed in the sitting position with a hanging leg, for instance in air plethysmography.

The Color was on and the PW sample volume size was enlarged to 8 mm in order to minimize the artefacts due to limb movement. The PW velocity sweep was reduced to let the screen contain a complete systolic-diastolic manoeuvre.

After a first attempt, the velocity range was enlarged to allow velocities greater than the adopted scale to appear in a single window, instead of being erroneously reported on the other vertical side of the measuring area.

A time threshold of 500 ms was adopted to define the reflux.

4.9. The stroke volume

The comparison was performed using the venous stroke volume (SV), defined as the mean velocity (v_m) multiplied by the time length of flow (T) and the venous cross section area (A).

$$\mathbf{SV = v_m * T * A}$$

T is simply the elapsed time when flow stops before the end of the observation time, otherwise it is the time required for velocity to reach the 5% of v_{max}, while v_m was estimated during the time T by a device automatic computation. The velocity time integral (VTI), when the device provides this value automatically, can correctly and efficiently substitute the product v_m*T.

$$\mathbf{SV = VTI * A}$$

In the hypothesis of a circular section, which is highly probable in the standing position, the area is computed from the diameter ($A = \pi d^2/4$) and.

$$\mathbf{SV = \pi\, VTI * d^2 / 4}$$

NB! velocity in cm s^{-1}, diameter and VTI in cm, A in cm^2, SV in cm^3, T in s.

5. General results

A great deal of mainly qualitative results will be presented, while only a few quantitative data will be shown.

In all the observed patients the MGVs anatomical loop was present, together with the already described upwards and downwards connections. Variations occurred in the size of the MGVs and in their response to CMP activity.

During VA systole, MGVs collapse into a null virtual calibre. On the contrary, when thrombosis involves the lumen, the tele-systolic volume ϕ_0 is not null. When the thrombus is recent, VA is discouraged, due to the risk that it may fragment, mobilize and embolize.

5.1. The contraction length and the ejection fraction

MGVs collapse in systole, but compression affects the veins from a position above the MaxRefill point to another position below it.

I.e., the length of the veins involved in the systole has a local superior and inferior limit and the compressed compartment is anatomically delimitated (at least in vertical direction). The upper and lower limits can be estimated qualitatively and quantitatively in BMode.

The contraction length (CL) and the ejection fraction (EF) can be computed [9–15] as parameters of the CMP (Fig. 1-B).

CL is the vertical height difference between the superior and the inferior contraction limits. EF instead is given by a ratio, CL divided by the total length of the MGVs pump, extending between the connections of the MGVs, upwards with the popliteal vein and downwards with the shorter saphenous vein, at the gastrocnemius point. A more accurate value is given by the respective ratio of volumes, though the computation is more time consuming, as it requires the knowledge of the calibres of each segment of the MGVs.

The superior and inferior contraction limits were always the same in the successive cycles of a nVA sequence. Thus CL did not change at all, while the changes in nVA affected only the value of the maximal diastolic calibre, owing to the reduced available time in each cycle.

5.2. Refilling time

The area section (A) and the maximal changing axis (generally the minor axis) (MaxCh) can be both reported graphically vs time, resulting in curves which have almost the same shape [12–15] (Fig. 6-A). In a sample of 6 refilling curves, gathered in 2 legs, each leg with 3 different tourniquet positions, MaxCh and A are related, according to the following relationship (Fig. 6-B):

$$\mathbf{Max\ Ch = k_1 * A;}$$

where MaxCh is in cm, A in cm^2 and $k_1 = 0{,}55 \pm 0{,}09\ cm^{-1}$ is the mean of 6 regression coefficients, computed over all the 6 refilling graphs.

The refilling time computed from the area (RT_A) or from the calibre (RT_C) graphs has a strict relationship:

$$\mathbf{RT_A = k_2 * RT_C;}$$

where RT_A and RT_C are measured in s and $k_2 = 1{,}48 \pm 0{,}16$ is the non-dimensional regression coefficient of 4 data couples of related area and calibre refilling.

Approximately, in this limited size sample, it is possible to say that A is twice MaxCh, while RT_A is 3/2 of RT_C.

As regards the refilling time measured with different tourniquet positions, a general theoretical relationship can be set, confirmed also by several preliminary results.

$$\mathbf{RT_L \le RT \le RT^L}$$

i.e., the shorter refilling time occurs placing the tourniquet at the ankle (RT_L), an intermediate value is got without tourniquets (RT), the longest one is measured placing the tourniquet just above

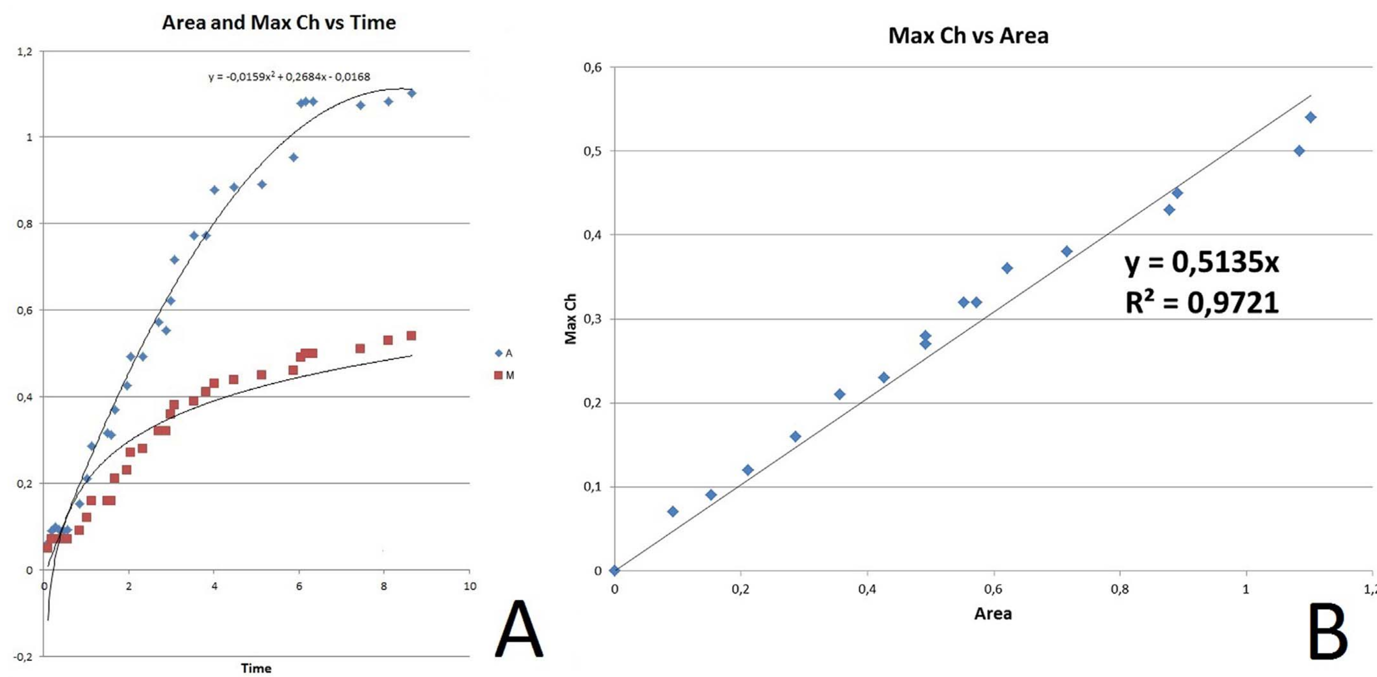

Fig. 6. Area and MaxCh (A) can be plotted against the time in the refilling graph. Curves are non-linear and have almost the same shape. (B) MaxCh and Area are in a linear relationship. Only one of the refilling curves is reported, together with its statistical parameters. R^2 is the determination coefficient (the squared correlation coefficient), which measures the fraction of the dependent variable which is explained by the statistical regression. Note that R^2 is very high, i.e. the relationship is almost exact. MaxCh – Maximal changing axis (generally the minor one).

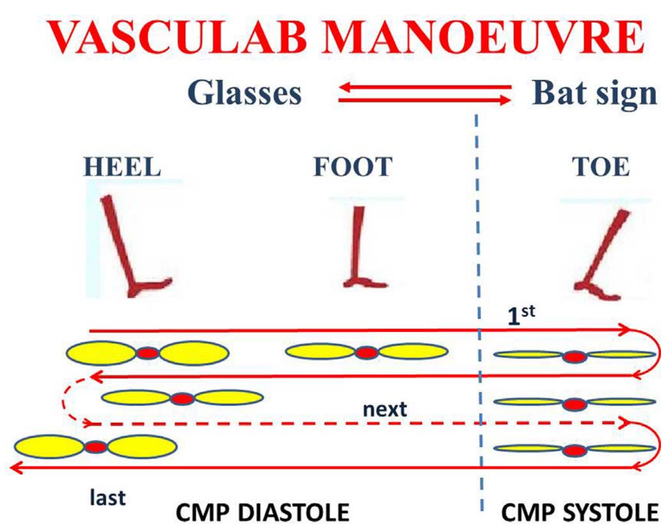

Fig. 7. In cross section the MGVs loop has in systole a linear shape similar to bat swings (the bat sign), while in diastole the image resembles the glasses on the nose. During nVA oscillations, the transverse shape of the MGVs loop changes continuously from the “glasses” to the “bat”. CMP – calf muscle pump, MGVs - medial gastrocnemius veins, nVA - sequence of n Vasculab manoeuvres.

the knee (RT^L), while no relationship can be previewed when the tourniquets are placed at both sites (RT^L_L), because the value depends on the comparison of the refluxing volumes originating from above and below the CMP. In healthy people the above refilling values are almost the same, in the uncertainty range, due to the absence of reflux.

5.3. Venous shape

In the diastolic phase, the refilling occurs changing the shape of veins, from a tele-systolic slight linear shape to an end-diastolic circular one, taking generally an elliptical contour during the refilling time. In the MGVs loop, the linear shape is similar to bat swings (the bat sign), while at the end of the refilling the image resembles the glasses on the nose (a small artery in the middle). During nVA oscillations, the transverse shape of the loop changes continuously from the “glasses” to the “bat” [14] (Fig. 7), with a great anatomical variation in the size of the glasses.

In daily observations the well-known dumbbell shape reported as typical for empty veins was never observed in tele-systole. The vein resembled instead an undulated line, constituted of 2 foils converging into 2 angles, as it generally occurs in a folded paper sheet. Thus all the interpretations and models involving the dumbbell shape of empty veins should be revised, when taking into account these observational data [18,21].

During refilling, the linear undulated shape becomes gradually the max axis of the ellipsis, which is also the less variable axis, the greatest increments involving instead the minor axis. In addition, there is a starting phase, where the volume is almost fixed, then a linear increase, until a final asymptotic volume is reached. This sigmoidal behaviour was firstly studied in the 70's [18–22] and then completely forgot and rarely reported in papers about venous compliance.

5.4. Rotation

Still qualitative observations show that the ellipsis changes continuously, the major and minor axes starting a rotation as if the vein could roll. The rotation slowly continues and then finally vanishes, when the vein approaches the circular shape and the definition of major and minor axes lose any meaning. Shape change and rotation depend each other and on transmural pressure (TMP) as well as on structural points which fix the vein to the connective tissue.

Partial thrombosis and inflammation can provide fixing points, which can influence the shape evolution.

In venous insufficiency, a great increase in TMP during refilling can mask the rotation, the vein reaching the final circular shape very quickly. Applying a tourniquet on the thigh instead reduces

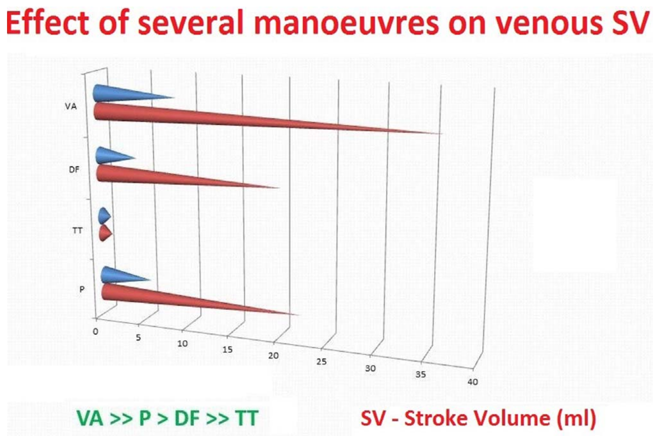

Fig. 8. Comparing the GSV stroke volume in systole and diastole during several manoeuvres. For each manoeuvre, the upper cone is the systole, the lower one the diastole. GSV – greater saphenous vein, VA – Vasculab manoeuvre, DF - dorxiflexion, TT – tip-toe, P - Paraná.

the time rate of TMP, revealing a previously undetectable rotation.

These are ready-made information, available also to quick observations, though they have nowadays no practical application. However, if confirmed, observing a rotation without tourniquets could allow to conclude very simply that venous insufficiency is not severe.

5.5. Veins activation

MGVs observation allows the comparison with the different behaviour of other veins. For instance, in almost all people, the MGVs collapse at the start of the toe-standing phase of VA. Soleus veins instead collapse only in the extreme systolic phase, when toe standing provides the maximal vertical excursion.

Superficial veins like GSV and SSV, confined within the fascia duplication or saphenous eye [23–25], and the tributaries and communicating veins, located superficial to the superficial fascia, are totally uninfluenced by VA systole.

The time sequence of VA systolic changes is therefore.

$$\mathbf{MGVs} \rightarrow \mathbf{soleus\ veins} \rightarrow (\mathbf{GSV},\ \mathbf{SSV},\ \mathbf{veins\ in\ the\ septa})$$

where the step in parenthesis could also never occur.

5.6. Ecodoppler results

Table 1 reports an example of a PW Doppler comparison, where measurements are gathered in a female patient, 40 yo, affected by chronic venous insufficiency, terminal valve reflux at the right SFJ, with a GSV shunt I+II [2,26]. The site chosen for the measurement is the GSV trunk at the mid-thigh.

In all the tested manoeuvres systolic velocities are negative (ante-grade flow), while diastolic ones are positive (diastolic reflux). In the sustained systole instead no velocity is detected and the elapsed time clearly has no use.

All the manoeuvres show a diastolic reflux ($\mathbf{P}^{-;0}_{+}$, $\mathbf{TT}^{-;0}_{0}$, $\mathbf{DF}^{-;0}_{+}$, $\mathbf{VA}^{-;0}_{+}$), except TT which has a positive diastolic velocity with a duration less than 500 ms.

Comparing the SV values, the manoeuvres can be ordered, going from the maximal to the minimal effect:

$$\mathbf{VA} >> \mathbf{P} > \mathbf{DF} >> \mathbf{TT}$$

where "$>$" means "greater than" and "$>>$" means "much greater than". (Fig. 8).

The same pattern applies as to the systolic as well to the diastolic values.

Though its limited value, this single case experiment showed clearly that, limited to the GSV trunk, VA is the most effective manoeuvre, while TT is the most ineffective one in moving blood. P effect is slightly greater than in DF and in both P and DF it is much greater than in TT, while VA has an almost double effect than P and DF.

According to the experimental design described in this paper, a validation study of VA with ultrasound and APG is still in progress, to compare the hemodynamic effect of VA to other commonly used dynamic manoeuvres.

Interestingly, preliminary results show that in APG the amount of mobilised blood with VA is much greater than with the other manoeuvres [17].

6. Discussion

Quantitative measurements are still in an anecdotal phase, thus only useful suggestions can be derived. A detailed validation procedure is actually programmed, using a much wider sample.

Measuring MaxCh and deriving then the A value, if needed, using the approximated formula, is more simple and quick. The quick RT_C measuring method is based on calibre measurements and RT_A can be easily derived as 3/2 of RT_C.

The reason of this RT difference using the calibre or the area could be due to the time course of venous refilling. During all the refilling interval it is mainly the MaxCh calibre to increase, while the other calibre remains essentially the same. Only at the end of the refilling, when the MaxCh has reached its maximal value, the other calibre adds its increments. Thus the MaxCh calibre refilling could result naturally shorter than the area refilling. Additional observations are needed to clarify this issue.

Though only in a limited sample, Doppler measurements show that VA is much more efficient than the other manoeuvres in mobilising GSV blood volume.

However, some remarks are useful to understand better the right role of VA, compared to other tests, especially P, which competes more in efficiency.

Both VA and P are still non-validated by a reliable quantitative study, while they are currently used in a clinical environment. While VA is tested since 4 years in a single centre study, P is practiced almost since 20 years in many vascular labs. In addition, its use is increasing day by day, also thanks to the continuous educational campaign provided by Vasculab in the vascular world, especially among outstanding vascular experts in diagnostic imaging.

VA is the only manoeuvre available to study the CMP in movement, while P is the preferred test to study the reflux.

However, VA and P can be both equally applied to every type of study. Some qualitative observations show that also during P the MGVs can collapse. On the other side, VA can very efficiently study the reflux, in all its phases (S, SS and D).

As to the training period, VA_{step} is difficult, VA requires a short training, while P is very simple and is subjected to artefacts in a minor extent.

VA can be applied to several anatomical sites. The great majority of observations in the current paper were taken in the MGVs, chosen as a venous CMP model.

Thus an additional experimental validation could investigate the role of:

1. The MGVs as a reliable venous model for the CMP;
2. The endo-venous compartment of the calf as a volumetric model of the leg.

In a single VA systole a great quantity of blood is ejected upwards. In diastole, instead, blood refills the veins from the arterioles and capillaries or refluxing from incompetent veins.

A similar behaviour is seen in the first systole in nVA, while in all diastolic phases except the last one a new movement intervenes, pushing blood centripetally.

The time of diastole, interposed between the two systoles in the sequence, shortens depending on the step rate. Capillary input and venous reflux, as well the diastolic refill and the subsequent systolic ejection are smaller. A complete relaxation does not occur in the diastolic phase and a greater resistance opposes to capillary input. Muscles work in anaerobiosis (like in apnoea) and the greater resistance also prevents the reflux.

In the first nVA diastolic phases MGVs have not a sufficient time to expand completely, being soon squeezed in the subsequent systole. Only the final diastole allows the complete expansion of CMP veins, being followed by the rest period, when weight returns on the rear leg.

In APG the CMP venous compartment gets empty almost completely in the first nVA manoeuvre, while the subsequent ones allow a further small entity emptying, depending on the severity of reflux [17].

The ultrasound examination estimates the endo-venous refill of the deep compartment. Other tests like APG measure the global refill of the veins included in the air chamber. In other types of plethysmography, instead, refill is related to the limb section corresponding to the position of the sensor.

A comprehensive web page [6] was set up to report the theoretical issues and the practical examples in the daily use of the VA manoeuvre. The web page will be continuously updated to report the future advances in the ultrasound study of the calf muscle pump.

7. Conclusion

VA hides a complex physiopathology, but its execution is extremely simple. It shows the endo-venous dynamics reliably and quantifies flow and calibres during a simulated step. In addition, VA can be used also in methods other than ultrasound investigations, like several types of plethysmography.

Conflict of interest

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