

Title:

“Method and apparatus for non-invasive detection of images of venous blood vessels”

DESCRIPTION

5 The present invention relates to a method for detecting, in a non-invasive manner, a patient’s hydration condition by processing ultrasound images of a venous blood vessel, in particular, but not limited to, the inferior vena cava or the major abdominal venous vessel.

Before proceeding any further, in order to better clarify the scope of the invention it is
10 worth pointing out that, in this description and in the appended claims, the evaluation of the hydration condition of the organism (of a person) involves indicating the static properties (e.g. mean size) and the dynamics (e.g. diameter variations) of the vessel (e.g. the inferior vena cava), which reflect a person’s volemic state, i.e. his/her hydration level. Furthermore, non-invasive detection of (or detecting in a non-invasive manner) the
15 hydration condition or images involves herein the extraction of data and/or information from ultrasound images, i.e. surveys that are not diagnostic and certainly not therapeutic or the like.

A main target of the evaluation is the inferior vena cava (also referred to as IVC), the dimensional variations, in particular diameter variations, or the so-called “pulsatility” of
20 which are observed in patients in the clinical practice in order to establish their hydration condition.

It is in fact known, in the clinical field, to evaluate alterations of the volemic state of patients, e.g. hospitalized in emergency room or subjected to dialysis treatments, by executing an IVC ultrasound.

25 This procedure has the advantage of not being invasive, since it is carried out outside the

patient's body and uses ultrasound, which is non-ionizing radiation; therefore, no damage is caused to the tissues hit by the ultrasonic waves.

Alterations of the volemic state may be due to overload or depletion of the volume circulating in the cardiovascular system; the causes of such alterations may be manifold, e.g. cardiac decompensation, pulmonary edema, renal insufficiency, etc.

For volemic alterations to be recognized, it is necessary to evaluate both the arterial pressure resulting from cardiac activity and from peripheral resistances, which can be measured directly (e.g. by means of a sphygmomanometer), and the central venous pressure as expression of the venous return to the heart; the latter cannot be measured directly from the outside by means of an instrument, and must therefore be estimated on the basis of other parameters.

In fact, excluding all invasive methods (which, in addition to being costly, are unfeasible in many situations) or those based on inaccurate clinical criteria, the non-invasive approach that is most commonly employed in hospital departments (emergency rooms, recovery wards, clinics, etc.) for evaluating the volemic state is ultrasound monitoring of the diameter and pulsatility of the IVC.

The latter drains the refluent blood coming from the subdiaphragmatic regions of the body to convey it into the right atrium of the heart; the IVC has a flexible and adaptable structure that is affected by the respiratory dynamics and by the heartbeat.

In patients with spontaneous breathing, cyclic changes in intrathoracic pressure produce variations in the venous return, thereby inducing a decrease or an increase in the diameter of the IVC during the inhalation and exhalation phases, respectively.

In addition to such variations of respiratory nature, variations of cardiac nature due to blood pressure waves are generated by the heartbeat, which are retrogradely transmitted inside the vena cava and cause corresponding oscillations in the diameter of the latter.

IVC diameter oscillations are broad in conditions of normal or low volemic state (hypovolemia, e.g. in case of dehydration or bleeding), or narrow when the vessel expands following a state of hypervolemia and/or atrial hypertension.

The clinical usefulness of ultrasound IVC monitoring is currently limited by a non-
5 standardized, and hence not very repeatable, method of measurement.

In particular, the IVC section is usually examined in the so-called M-mode, which, without lingering too much on the principles of operation of ultrasonography, is an operating mode of the ultrasonograph that allows observing how tissues change their arrangement over time (and hence, for example, the pulsating deformation of the vena
10 cava) when they are intersected by a single ultrasound beam. The ultrasound beam in question is positioned by the operator at the desired point on the basis of the classic ultrasound image (B-mode).

When this detection is executed in a sequential manner (at high frequency) over time, the variability of the IVC lumen is displayed on the screen in real time. Note that the detection
15 is made along a section that is fixed in space (and not integral with the vein), associated with the position of the probe and corresponding to a specific ray emitted by the ultrasound probe.

This possibility is shown in the annexed Figure 1, wherein part A) (B-mode) illustrates the selection of the ultrasonographic beam and part B) (M-mode) illustrates how the
20 minimum and maximum diameters of the vein are manually detected in relation to the respiratory cycle and the heartbeat.

Based on these manual detections, the caval index is then determined with the formula:

$$25 \quad \text{CI - IVC (\%)} = \frac{D_{\text{exp.}} - D_{\text{insp.}}}{D_{\text{exp.}}} \times 100$$

where $D_{\text{exp.}}$ is the maximum diameter (during exhalation), whereas $D_{\text{insp.}}$ is the minimum

diameter (during inhalation); the caval index has been proposed as an indicator reflecting a patient's volemic state, wherein high values close to 100 % indicate collapse conditions and low values close to 0 % indicate overload conditions.

Therefore, the caval index is an estimate of the pulsatility of the vena cava that is clinically
5 measured on the basis of detections made manually by the operator (generally a physician) who is carrying out the ultrasound. However, a number of factors may adversely affect the reliability of this measurement.

Since the vein is anchored to the diaphragm, it moves while breathing, and therefore the section displayed by the ultrasonographer changes during the measurement; this causes
10 diameter variations related to the geometry of the vein, which is not a perfect cylinder, but has an irregular shape that may vary greatly among different patients.

Moreover, since the ultrasonic probe is controlled manually by the operator, its orientation (and therefore also the ultrasound orientation) changes over time relative to the vein. It follows that the detected section will have a direction that may be more or less close to
15 the section orthogonal to the vessel, thus introducing errors in the diameter estimate.

In conclusion, it can be stated that ultrasound detections of the inferior vena cava, carried out in accordance with the currently known state of the art, are affected by indeterminations due to movements of the vein (in turn affected by respiration depth and by the respiration mode, e.g. thoracic or abdominal), in addition to vessel geometry and
20 to the actual pulsatility of the vein. Finally, it must be reminded that the caval index, calculated with the above formula, is *de facto* an estimate based on subjective measurements taken by an operator; in other words, although ultrasound technicians are specialized physicians, the measurements obtained may vary among them, or even among tests carried out on different days by the same physician.

25 In the general medical and hospital field, a need is therefore felt for the possibility of

carrying out ultrasound tests for detecting images of blood vessels in a uniform or standardized manner, i.e. overcoming or anyway reducing the dependence on the human factor, thereby increasing the accuracy and reliability of the information acquired.

One example of a device that is meant to meet this requirement is described in
5 international patent application published under number WO 2013/163605 by DBmedix Inc.

In brief, this publication describes a portable monitoring device, which is applied onto a person's abdomen at the ribcage and secured by means of an adhesive band or the like. The device has a front surface that includes a display showing the index of the inferior
10 vena cava and a graphic representation thereof, while the back houses, inside a protrusion, an ultrasound scanner.

The latter should provide, due to its position and to the shape of the protrusion, which may be convex or slightly pointed with oblique sides along which the scanner is arranged, a three-dimensional (3D) representation of the blood vessel.

15 However, some doubts arise as to the actual functionality and effectiveness of this device. In the first place, in fact, it must be pointed out that it cannot provide useful indications to an operator having to position the device on a patient. As a matter of fact, since the device lacks a display suitable for showing ultrasound images of the inferior vena cava, a medical operator will not be able to evaluate whether the position is correct or not, nor
20 if the detections made are reliable and whether they concern the vessel of interest or other nearby vessels.

If the vein is not visible to an operator, it cannot be understood how the device of WO 2013/163605 can be applied and work correctly: this document provides no explanation in this respect and, on the other hand, no solutions are known in the scientific field which
25 could overcome these drawbacks.

In this regard, it must be pointed out that this result is difficult to attain, since anatomy changes among patients and, therefore, it cannot be assumed that the vena cava has the same depth or distance from the device in different persons.

Furthermore, there are several blood vessels near the inferior vena cava, so that even a
5 very skilled ultrasound technician will not be able to point the probe correctly without the aid of a traditional anatomical view.

In light of the above, it can therefore be stated that a technical problem at the basis of the present invention is to provide a method for non-invasive detection of images of blood vessels, the operative features of which overcome the above-mentioned drawbacks and/or
10 contraindications of the prior art.

In this frame, it is therefore one object of the invention to minimize the influence of the human factor during the execution of ultrasound detections, so as to obtain reliable and repeatable results among different patients or on the same patient at different times.

It is a further object of the invention to propose a method which can be realized by using
15 ultrasound techniques that can be executed or implemented even with existing ultrasound equipment. In particular, B-mode detection is required, which is available in standard ultrasound equipment.

The idea that solves the aforesaid technical problem is essentially to make a dynamic ultrasound scan in B-mode of a section of the blood vessel to be analyzed, in particular,
20 but not limited to, the inferior vena cava. It is thus possible to identify, in the various successive images, the section of the tract of interest of the vein; the scan may be either transversal or longitudinal relative to the blood vessel and, advantageously, more information can be obtained by using both a transversal scan and a longitudinal scan.

In accordance with a preferred embodiment, the method includes a step of compensating
25 for the longitudinal and/or transversal movements of the blood vessel: accurate values of

the dimensions of the blood vessel can thus be obtained, even in the presence of pulsations or breathing of the patient, which cause movements of the vessel.

The features of the method according to the invention are more specifically set out in the claims appended to this description; the invention also comprises an apparatus for
5 implementing the method, the features of which are also more specifically set out in the appended claims.

The invention as a whole, as well as the features thereof and the effects deriving therefrom, will become more apparent from the following description of a non-limiting preferred embodiment with reference to the annexed drawings, wherein:

- 10 Fig. 1 shows an image of a ultrasound detection according to the prior art;
Figs. 2 and 3 schematically show the application of a ultrasound probe according to the invention on a patient, for making a transversal scan and a longitudinal scan, respectively, of an inferior vena cava;
Fig. 4 shows a sectional view of the abdomen during the application of the above probe
15 in the longitudinal direction relative to the inferior vena cava;
Fig. 5 shows a ultrasound image of a longitudinal section of an inferior vena cava, obtained by using the method of the invention;
Fig. 6 shows another ultrasound image of a transversal section of an inferior vena cava, obtained by using the method of the invention;
20 Figs. 7 and 8 are diagrams that show the trend of the diameter of the vena cava as a function of time, detected in accordance with the invention;
Fig. 9 shows a ultrasound apparatus in accordance with the invention;
Figs. 10 and 11 are respective block diagrams that illustrate the apparatus of the invention and the operation thereof.
25 With reference to the annexed drawings, numeral 1 designates as a whole an apparatus

for implementing the method for non-invasive detection of blood vessels according to the invention.

In this case, it is a portable ultrasound apparatus suitable for executing ultrasound tests with a probe 5 emitting and receiving ultrasound at the frequencies normally employed
5 for these applications (i.e. of the order of the MHz).

Of course, the apparatus 1 may also differ from the one shown in Figure 9; for example, it may be of the stationary type or anyway non-portable due to bigger dimensions or a different configuration.

Regardless of this, the apparatus 1 comprises a screen 3 that displays the images processed
10 by a processor and by the other electronic means 4 (e.g. ROM and RAM memories, graphic cards, bus connections, etc.) arranged inside of it.

For this purpose, the apparatus comprises an external shell structure 6 made up of two compartments 6a, 6b configured as tablets and hinged to each other, so that they can be positioned in an open condition, as shown in Figure 9, and in a closed condition, in which
15 the two compartments 6a, 6b are juxtaposed and locked together by means of locks or coupling systems (not shown in the drawings because *per se* known).

To make it easily portable, the structure 6 of the apparatus is provided with a handle 8 that can be seized like that of a suitcase, a bag or the like.

The apparatus 1 further comprises a set of controls 10 in the form of a keyboard and/or
20 push-buttons or touchpads or touchscreens, and, more in general, user interface means intended for, among other things, acquiring ultrasound data and processing them as necessary.

The ultrasound probe 5 can be applied onto the body part of interest either in the transversal direction or in the longitudinal direction with respect to a blood vessel V, the
25 pulsatility of which needs to be detected; these conditions are better illustrated in Figures

2 and 3, which highlight the non-invasiveness of the method of the invention, whereas the next one (Figure 4) highlights the ultrasound emitted by the probe 5 towards a tract of the inferior vena cava V.

5 The apparatus 1 further comprises an algorithm that allows implementing the method of the invention.

The latter comprises ultrasound scanning in B-mode of a section of the inferior vena cava or another blood vessel to be analyzed.

The ultrasound probe 5 preferably emits pulsed and uniform ultrasound, according to modes that can be set or selected by the user via the control means 10 of the apparatus 1.

10 The ultrasonic waves reflected by the blood vessel V thus produce two-dimensional ultrasound images, which are acquired by the apparatus 1 in a dynamic manner, i.e. sequentially at predefined time intervals; the length of such intervals, i.e. the image acquisition frequency, is of the order of a few frames per second: typically it will be possible to acquire a number of images per second ranging from 10 to a few hundreds.

15 This will depend on the specifications of the ultrasound apparatus in use and its data processing power, i.e. its processor and the other electronic components, the management program, and so on.

In general, it can be said that also the precision of the blood vessel detections processed by the ultrasound apparatus depends on the number of frames acquired per time unit; 20 however, it should be taken into account that a large number of images inevitably implies a large amount of data to be processed and hence requires powerful processing means (processor, memories, etc.).

This will therefore be dependent on the performance provided by the various ultrasound apparatuses; for example, portable ones are generally less powerful than stationary ones.

25 The method of the invention provides for processing the two-dimensional images

acquired on the screen 3 of the apparatus; as mentioned above, the scanning of the blood vessel V (i.e. the section thereof, the images of which are acquired) can be either transversal or longitudinal.

The method of the invention thus identifies, instant by instant, the trend of the transversal or longitudinal section of a tract of the vena cava or of the blood vessel being examined. Preferably, the method of the invention also comprises a step of compensating for the movements of the blood vessel, which are due to cardiac pulsations, breathing or other factors.

To this end, an image tracking operation is preferably carried out, which allows evaluating always the same sections integral with the vein as opposed to fixed in space (and therefore affected by the movement of the blood vessel) as in current traditional ultrasounds.

Note that this result is made possible by the fact that a two-dimensional image is examined over time, unlike the prior art, wherein a linear image is used instead.

In other words, vein tracking is made possible, feasible and reliable due to the fact that the processed image concerns a whole area including not only a tract of the blood vessel, but also the surrounding tissues.

This allows identifying points moving integrally by the same distance within a two-dimensional space corresponding to that of the images; this operation can be executed automatically by a computation algorithm, without requiring any manual intervention, in order to establish the distance of reference points, as is the current practice.

Likewise, the scan may proceed in the direction transversal to the vena cava, and then the transversal scan can be processed to compensate for the transversal movements of the vessel V.

Longitudinal and transversal ultrasound scans thus provide a time succession of images or frames, which accurately identify the variations occurring in the mean diameter and/or

shape of the blood vessel.

This series can then be further processed in order to automatically obtain different pulsatility indices. Moreover, the method of the invention allows, by dynamically detecting the trend of the dimensions of the blood vessel, isolating the oscillatory
5 components of respiratory or cardiac nature, resulting in the advantage of eliminating any evaluation errors caused by the different summation of these two components in different respiratory actions, which may alter the blood vessel pulsatility reading by up to 30 %.

In other words, the invention makes it possible to carry out, on the basis of the sequence of ultrasound images acquired, an analysis of the conditions of the blood vessel without
10 requiring any manual measurement or intervention by an operator.

Therefore, the method of the invention provides some important and advantageous results.

First of all, an ultrasound of the vena cava is carried out while compensating for its movements, thanks to the fact that a whole area corresponding to the detected ultrasound
15 image is monitored and processed: this allows eliminating, or at least drastically reducing, the influence of the human factor, unlike the prior art, where this is not possible because movements are evaluated manually by measuring the linear displacements of arbitrary reference points.

The second advantageous result is that a time series or sequence (indicating the
20 instantaneous value of the diameter or area of the vein) is provided, as opposed to single punctual values detected manually. From the time series thus obtained, the contributions due to pressure variations induced by the respiratory and cardiac cycles are then separated.

Furthermore, from the time series or sequence of images or frames it is possible to
25 automatically extract indicators reflecting the pulsatility of the vein in response to the

different respiratory and cardiac forcers, in addition to a global index taking into account the overlapping of these two effects.

Moreover, the method of the invention also allows studying the spectral properties of the time series; for example, oscillations at frequencies higher than the cardiac one may be
5 analyzed, which could provide useful information about the pulsatility of the vein.

The diagrams D1, D2 of Figures 7 and 8 show the variations of the diameter of the vena cava as a function of time, highlighting the respiratory and cardiac components.

In particular, the first diagram depicts the oscillations of a longitudinal tract of a vena cava shown in Figure 5, wherein two reference points are shown (indicated by a small
10 square and connected by a segment), which are subjected to tracking, i.e. their movements are followed over time, along with a bundle of segments along which the position of the edges of the vein, marked by small circles, is identified.

The second Figure, i.e. Figure 8, illustrates the effect of breathing (at low frequency) and the effect of the heartbeat, obtained by extracting the respective filtered components from
15 the diagram of Fig. 7.

Of course, the same operations described for the longitudinal section of the vena cava V or another blood vessel can be carried out in relation to the cross-section thereof, as shown in Figure 6, which illustrates a ultrasound image obtained from the time sequence acquired during a scan.

20 One teaching of the present invention is to study multiple diameters taken in the direction orthogonal to the median line of the vein (evaluated along the longitudinal, or long, axis).

In fact, CI (caval index) estimates obtained when considering a section orthogonal to the vein are more stable.

The reconstruction of both edges of the vein through the algorithm described in this patent
25 application allows estimating the median line: to this end, it is sufficient to calculate the

mean between the estimated upper and lower edges (Fig. 5); different points can then be selected along that line, from which rays orthogonal thereto are made to extend; finally, the intersection points of said rays with the upper and lower edges are estimated, from which the diameters are then estimated (Fig. 6).

5 By subsequently evaluating the vein in the transversal direction (in short axis), it is possible to obtain additional information about the mean pulsatility of the section and the shape of the section of the vein. This aspect is important, in that sometimes the shape of the section is not convex, and this might hinder the correct interpretation of pulsatility along a single direction.

10 More generally, it can be said that the advantages of the present invention, compared to the methods currently in use in the medical/hospital field, are manifold and can be summarized as follows.

In the first place, the compensation of the movements of the vein in a longitudinal or transversal plane, corresponding to that of the section in which the ultrasound probe 3 is
15 oriented: this allows reducing the errors or anyway the alterations caused by the movements of the blood vessel, resulting in more accurate measurements.

A second advantage is the possibility of the method of the invention to carry out vein scans in any direction; in other words, this means that the detection method of the invention is not limited by the direction of the ultrasonic waves emitted by the probe.

20 A third advantage is the reliability of the evaluations obtained as regards the pulsatility of the blood vessel, in that they are based on the evaluation of a whole area in longitudinal or transversal section, which includes a large number of points.

Note that the pulsatility of the inferior vena cava differs among the various tracts of its longitudinal extension, because there are regions where the vein adheres to other tissues,
25 and such adherence sites limit its movements. However, the volemic state gives an overall

effect that can only be evaluated by examining a mean pulsatility of the vein. Moreover, since it is difficult to take measurements on a patient always along the same direction (so that they can be compared), the examination of the mean pulsatility in a sufficiently large region – of the order of 2 or 3 centimeters – can provide more reliable estimates.

5 Similar considerations also apply to detections made transversally to the blood vessel, in that the vena cava may have an irregular shape and its pulsatility changes in the different directions. Evaluating the mean pulsatility on the basis of the area of the section of the vena cava is more advantageous and accurate than just considering a single diameter, as is common practice in the prior art.

10 It must finally be further underlined that the method of the invention is dynamic, i.e. instead of making estimates of punctual values, it executes analyses of time-sequential ultrasound images that reflect the cardiac and respiratory forcers. These forcer contributions can be separated or anyway filtered out, so as to obtain a more accurate detection of the pulsatility of the vein through a caval index relating to each one of the
15 two components, in addition to the general one.

In light of the above explanation, it is possible to understand the operation of the apparatus 1 according to the invention and the detection method implemented by it; such operation is summarized in Figures 10 and 11, which show respective block diagrams of the apparatus 1 and its operating cycle.

20 Therefore, the ultrasound data detected by the probe 5 and pertaining to the longitudinal or transversal section of the vena cava or another blood vessel V are processed by the processing means 4 of the apparatus1 (i.e. the aforesaid processor, memories and other components) on the basis of an appropriate algorithm that can be installed in a portion 7 of the apparatus, such as a local ROM memory; the algorithm may nevertheless be
25 installed remotely, e.g. in server computers, to which the apparatus 1 is connected via a

telecommunications network for data exchange.

This second option is preferable for portable apparatuses, which may be equipped with means allowing them to be connected to a network with other computers.

Independently of this, the data acquired by the ultrasound probe 5, appropriately
5 processed and filtered, concur in forming the sequences of images visible on the screen 3
and the diagrams D1, D2, which will thus provide useful indications about a patient's
volemic state with high precision and accuracy.

From an operative viewpoint, these steps are illustrated in the flow chart of Figure 11.

Anyway, all of these features fall within the scope of the following claims.

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CLAIMS

1. Method for non-invasive detection of images of venous blood vessels (V), such as the inferior vena cava, comprising the steps of:
acquiring ultrasound signals relating to a section of a blood vessel;
- 5 processing said acquired ultrasound signals, in order to display images of said section of a blood vessel (V);
characterized in that at least one of said steps is carried out repeatedly for a plurality of times within a predefined time interval, so as to estimate and/or display in real time a dynamic trend of the conditions of the blood vessel (V) in a whole region (cross-section
10 or longitudinal tract of the vein).
2. Method according to claim 1, wherein the section of the blood vessel is longitudinal and/or transversal.
3. Method according to claims 1 or 2, comprising a step of filtering the time series obtained (diameter and/or area of the vessel section in the different frames), so as to
15 separate the cardiac and/or respiratory components of the conditions of the blood vessel (V).
4. Method according to any one of the preceding claims, comprising a step of compensating for the movements of a blood vessel (V), carried out in real time by tracking the movements of a plurality of homologous points in chronologically successive images.
- 20 5. Method according to any one of the preceding claims, wherein the step of acquiring sonographic information and/or signals is carried out with reference to one section of the blood vessel (V) within said predefined time interval.
6. Method according to any one of the preceding claims, wherein the step of acquiring ultrasound information and/or signals pertaining to a section of a blood vessel and the
25 step of processing said acquired ultrasound information and/or signals in order to display

images of said section of a blood vessel (V) are carried out at a frequency of at least 10 times per second.

7. Method according to any one of the preceding claims, comprising the step of determining different diameters in the direction orthogonal to the median line, in long axis, and/or the area of a section, in short axis, and then the pulsatility and/or another parameter pertaining to the vessel (V), by processing the displayed images.

8. Method according to claim 7, wherein the information extracted from the long-axis and short-axis scans, such as the pulsatility of the vein along different longitudinal sections and the shape of a cross-section of the vessel and its pulsatility in different directions, can be integrated in order to obtain a more reliable estimate of the dynamics of the blood vessel.

9. Apparatus for implementing the method according to any one of the preceding claims, comprising a ultrasound probe (5) for emitting and/or acquiring ultrasonic signals, electronic processing means (4, 7) for processing said signals and the corresponding images, a screen (3) or the like for displaying the images, characterized in that the processing means (4, 7) are adapted to process a succession of ultrasonic signals and/or corresponding images within a predefined time interval.

10. Apparatus according to claim 9, wherein the processing means (4, 7) are adapted to filter out the periodic components, such as the cardiac or respiratory components of a blood vessel (V), from the ultrasonic signals acquired by the ultrasound probe (5).

11. Apparatus according to claims 9 or 10, wherein the processing means (4, 7) are adapted to compensate for the movements of an object reflecting the ultrasonic signals emitted by the probe (5).

Title:

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ABSTRACT

5 The invention relates to a method and an apparatus for non-invasive detection of images of blood vessels (V). To this end, the method provides for acquiring ultrasound signals pertaining to a section of a blood vessel and processing the acquired ultrasound signals in order to display images of the section.

In order to compensate for its movements in the different frames of the acquired
10 ultrasound video, a tracking process is carried out to determine the mean diameter or the area of a section, and then the pulsatility and/or another parameter pertaining to the vessel (V).

One or more of said steps are carried out repeatedly for a plurality of times within a predefined time interval, so as to detect the dynamics of the blood vessel (V).

15 (Figs. 4, 9)