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Apparatus and method for non-invasively measuring digit volumetric changes

Field of the invention

The present invention relates to an apparatus and a method for non-invasively detecting and/or measuring volumetric changes of a digit.

Background of the invention

The sympathetic nervous system has a key role in cardiovascular homeostasis and it appears to contribute significantly to the pathogenesis of cardiovascular diseases. The sympathetic nervous system is part of the nervous system that serves to accelerate the heart rate, constrict blood vessels, and raise blood pressure. In particular, the hand is densely supplied by sympathetic nerve fibres. Vasomotor control is the action of sympathetic nerve fibres in maintaining arterial blood pressure and blood flow to different tissues depending on their demands. Therefore, a loss in vasomotor control may be used in diagnosing diseases associated with sympathetic nerve functions.

At present, there are several methods of assessing the presence of vasomotor control. One such method is skin thermometry. In this method, the surface temperature is used as an indicator of changes in skin blood flow, and infrared images, in the form of thermograms, reflect the microcirculatory dynamics of the skin surface. However, the practical disadvantage of this method is that it requires an environment in which the ambient temperature and humidity are kept constant.

Another method is the Doppler ultrasound. In this method, a Doppler flow rate probe and an echo Doppler are used to measure relative changes in flow velocity and brachial artery calibre respectively, before, during and after the

application of an occluding pressure. The results following the release of the pressure cuff are compared to the pre-occlusion state. If there is sufficient increase in flow velocity and artery calibre, the patient is considered to have normal sympathetic nerve function. However, this test requires expensive apparatus and specialised personnel, and is also very uncomfortable to the subject since the pressure cuff is very tight around the subject's arm or leg.

Alternative apparatus and methods of measuring volumetric reduction of a digit have been described in PCT publications WO 02/34105 and WO 98/04182 (herein incorporated by reference). The method described in these PCT publications comprises applying an occluding pressure by means of an occlusion cuff, to a predetermined part of an arm or leg of the patient to occlude arterial blood flow, so as to determine an increase of volume of the digit downstream the occlusion pressure; maintaining the occluding pressure for a predetermined time period; removing the occlusion pressure to restore blood flow; and monitoring a digit of the arm or leg for changes by measuring changes in gas pressure of a rigid chamber connected to a detecting chamber in which the digit is inserted.

Accordingly, the method and apparatus described in WO 02/34105 and WO 98/04182 is limited to the detection of volumetric reduction of the digit. A problem with this apparatus is that very small volumetric reductions might not be detected due to the low sensitivity in the measurement of changes of gas pressure. Further, the method and apparatus requires the use of a cuff, which may create discomfort on a patient.

Therefore, it can be seen that there is a need to develop alternative and/or improved apparatus and methods of measuring volumetric changes of a digit in a non-invasive and accurate way.

Summary of the invention

The present invention addresses the problems above and provides an efficient apparatus, as well as a method, for non-invasively detecting and/or measuring volumetric changes of a digit. In particular, the method of detecting and/or measuring volumetric changes of a digit is indicative of the presence of abnormalities in sympathetic nerve functions.

According to a first aspect, the present invention provides an apparatus for non-invasively detecting and/or measuring volumetric changes of a digit comprising:

- a detecting device comprising:

    - a chamber for receiving a digit or a portion thereof; and

    - a jacket comprising at least a resilient portion,

wherein the chamber and the jacket are arranged such that when a liquid is placed between the chamber and the jacket, the liquid is sealed therein; and

- a means for detecting and/or measuring a volumetric change in the device.

In particular, the jacket may comprise at least a portion (of the jacket) made of resilient material. The chamber may also be a resilient chamber or at least a portion of the chamber is made of resilient material.

According to a further aspect, the detecting device may comprise a liquid, which is sealed between the chamber and the jacket. In particular, the liquid may be water.

The means for detecting and/or measuring a volumetric change may be a sensor. In particular, it may be a pressure sensor. Alternatively, a strain gauge may be used. In some instances, a differential pressure sensor may be used.

According to a further aspect of the present invention, the apparatus may further comprise a reference device. In particular, the reference device may be a rigid reference device and may comprise a liquid which exerts a constant pressure on the walls of the reference device.

In particular, when the apparatus comprises a reference device, the means for detecting and/or measuring a volumetric change is a differential pressure sensor.

The liquid comprised in the reference device may be the same, of the same kind or similar to the liquid comprised in the detecting device. In particular, the liquid in the reference device is water.

According to another aspect, the present invention provides an apparatus comprising:

- a detecting device comprising:
    - a chamber for receiving a digit or a portion thereof;
    - a jacket comprising at least a resilient portion; and
    - a liquid,

  wherein the liquid is sealed between the chamber and the jacket;

- a rigid reference device comprising a liquid which exerts a constant pressure on the walls of the reference device; and
- a pressure sensor for detecting and/or measuring a volumetric change in the device;

wherein a change in pressure exerted by the resilient portion of the jacket on the liquid in the detecting device, caused by volumetric changes of the digit, is

compared to the constant pressure exerted by the liquid on the walls of the reference device to determine the extent of volumetric change of the digit.

In particular, the pressure sensor is a differential pressure sensor.

In particular, the chamber may be a resilient chamber.

Further, the liquid comprised in the reference device may be the same, of the same kind or similar to that in the detecting device. In particular, the liquid comprised in the detecting device may be water.

Another aspect of the present invention is a method for non-invasively detecting and/or measuring volumetric changes of a digit comprising the steps of:

- inserting a digit or a portion thereof into a chamber of a detecting device, the detecting device comprising the chamber and a jacket comprising at least a resilient portion;

- adding a liquid such that the liquid is sealed between the chamber and the jacket, wherein the liquid is added before or after the step of inserting the digit; and

- detecting and/or measuring volumetric changes of the digit for a pre-determined period.

In particular, the chamber may be a resilient chamber.

In particular, the volumetric changes are detected by a pressure sensor which detects changes in pressure exerted by the resilient portion of the jacket on the liquid in the detecting device. More in particular, the volumetric changes are detected by a pressure sensor which is in contact with the liquid.

Alternatively, the volumetric changes are detected by a strain gauge which detects changes in strain exerted by the liquid on the resilient portion of the jacket of the detecting device.

The step of adding the liquid comprises adding the liquid until the pressure exerted by the resilient portion of the jacket on the liquid in the detecting device reaches a pre-determined pressure.

The step of adding the liquid may alternatively comprise adding the liquid until the strain exerted on the resilient portion of the jacket by the liquid in the detecting device reaches a pre-determined strain.

According to a further aspect, the step of detecting and/or measuring volumetric changes of the digit may be carried out by a pressure sensor or a strain gauge. In particular, the pressure sensor may be a differential pressure sensor.

According to a further aspect, the method further comprises the step of calibrating a rigid reference device comprising a liquid to a pre-determined pressure such that the liquid exerts a constant pressure on the walls of the reference device, the step of calibrating the reference device being carried out prior to the step of inserting the digit into the chamber of the detecting device.

According to yet a further aspect, the volumetric changes of the digit within a pre-determined period are indicative of the presence of abnormalities in sympathetic nerve functions. The abnormalities include, but are not limited to, polyneuropathy, in particular diabetic polyneuropathy, small nerve fibre disease, in particular, idiopathic small nerve fibre disease, restless legs syndrome and carpal tunnel syndrome.

According to a further aspect, the digit may be wrinkled prior to the step of inserting the digit into the chamber. In particular, the digit may be treated with a digit wrinkling cream or is wrinkled by immersion in a liquid.

Brief description of the figures

Figure 1 shows a schematic arrangement of the apparatus of the invention.

Figure 2 shows a schematic diagram according to a particular embodiment of the invention.

Figure 3 shows a schematic diagram according to a particular embodiment of the invention.

Figure 4 is a typical calibration curve showing output voltage varying against volume change in the detecting device.

Figures 5A and 5B show the results of the recovery of digit volume that occurs after the induction of wrinkling of the digit tip brought about by the application of EMLA cream for 10 minutes (Figure 5A) and 60 minutes (Figure 5B), the results were obtained using the apparatus of the present invention.

Figure 6 shows digit volumetric variation measured using the apparatus of the present invention, corresponding to a respiratory gasp that causes reduction of blood flow into the digit.

Figure 7 shows a mould to be used with the present invention for more accurate results.

Detailed description of the invention

The whole content of any bibliographic references mentioned in the present specification is herein incorporated by reference.

One aspect of the present invention relates to an apparatus for non-invasively detecting and/or measuring volumetric changes of a digit comprising:

- a detecting device comprising:

    - a chamber for receiving a digit or a portion thereof; and

    - a jacket comprising at least a resilient portion,

wherein the chamber and the jacket are arranged such that when a liquid is placed between the chamber and the jacket, the liquid is sealed therein; and

- a means for detecting and/or measuring a volumetric change in the device.

In particular, the chamber and the jacket are arranged such that the chamber and the jacket are capable of sealably disposing a liquid between them.

For the purposes of this invention, a chamber may be defined to be an enclosed space or a body comprising a cavity. For example, the chamber may be in the form of a sleeve, wherein a sleeve is defined as a tubular piece that is shrunk into a cylindrical bore to reduce its bore or a case into which an object fits. In particular, the digit, whose volumetric changes are to be measured, is inserted into the cavity of the chamber or into the sleeve.

A jacket may be defined to be any exterior covering or casing. For the purposes of this invention, the jacket of the detecting device forms a casing for the chamber of the detecting device, leaving the cavity of the chamber uncovered. In particular, the space between the jacket and the chamber may be filled with a liquid, such that the liquid is sealed between the jacket and the chamber.

The chamber may be made of any suitable material which is sensitive to changes in the size of the digit as a result of the volumetric changes of the digit. In particular, the chamber may be a resilient chamber. A resilient material is one which is capable of regaining its original shape or position after bending,

stretching, or other deformation. For example, the chamber may be made of a flexible material. In particular, the material used for the chamber is elastic and has a low bending stiffness and elastic modulus. Preferably, the elastic modulus is in the range of about 10^6 N/m^2 or lower. The elastic modulus of a material represents the relative stiffness of the material within the elastic range and can be determined from a stress-strain curve by calculating the ratio of stress to strain. The chamber may be of any suitable material. For example, the chamber may be made of latex, nitrile or polyurethane or a combination of materials thereof.

The jacket comprises at least a resilient portion. According to one aspect, only a portion of the jacket is made of a resilient material, while the rest of the jacket is rigid. Alternatively, the entire jacket could be made of a resilient material. The definition of a resilient material is as described above. Any suitable resilient material may be used for the resilient portion of the jacket for the purposes of the invention. In particular, the resilient portion of the jacket has a high level of elasticity and a low elastic modulus. A material that is said to have a high level of elasticity is one which responds to bending or stretching by returning to its original shape. Preferably, the elastic modulus of the resilient portion of the jacket is in the range of about 10^8 N/m^2 or lower, more preferably in the range of about 10^7 N/m^2 or lower, and even more preferably in the range of about 10^6 N/m^2 or lower. Examples of resilient material that may be used include, but are not limited to, latex, nitrile or polyurethane or a combination of materials thereof. The jacket may be of any suitable shape. For example, the jacket is spherical to provide a uniform strain at all parts of the jacket.

The apparatus further comprises a liquid, which is added between the chamber and the jacket of the detecting device. The liquid may be any liquid suitable for the purposes of the present invention. In particular, the liquid may be, but is not limited to, water. The apparatus may or may not comprise a liquid initially. Accordingly, the liquid may be added between the chamber and the jacket

before or after the insertion of the digit into the chamber. In particular, the liquid is added after the digit to be measured is inserted into the chamber. The chamber seals the liquid in the jacket. Accordingly, the present invention also provides a detecting device and/or an apparatus comprising the detecting device according to the invention, without the presence of liquid. The liquid may be added at the time of the use of the device in detecting and/or measuring the volumetric changes of the digit.

The chamber and the jacket of the detecting device may be transparent for convenience. For example, it would be convenient to note that the right amount of liquid is being added between the chamber and the jacket to ensure that the apparatus works efficiently.

The apparatus may be arranged such that a volumetric change of the digit inserted into the chamber causes the chamber to comply with the change in shape of the digit. For example, the means for detecting and/or measuring volumetric changes of the digit in the device may be a sensor. In particular, the means for detecting and/or measuring volumetric changes may be a pressure sensor. Alternatively, a strain gauge may be used.

According to one aspect, when there is a volumetric change of the digit in the chamber, the chamber complies with the change in shape of the digit as a result of the volumetric change of the digit, which in turn causes a change in the pressure exerted by the liquid on the resilient portion of the jacket. As a result, the resilient portion of the jacket expands or contracts accordingly. This expansion or contraction results in a corresponding increase or decrease of pressure exerted by the resilient portion of the jacket on the liquid. The change in pressure exerted by the resilient portion of the jacket on the liquid is detected by the pressure sensor.

According to another aspect, when there is a volumetric change of the digit in the chamber, the chamber complies with the change in shape of the digit as a

result of the volumetric change of the digit, which in turn causes a change in the pressure exerted by the liquid on the resilient portion of the jacket. As a result, the strain on the resilient portion of the jacket changes. The change in strain exerted on the resilient portion of the jacket is detected by a strain gauge. In particular, the strain gauge detects the contraction or elongation of the resilient portion of the jacket. An example of the apparatus of this aspect is shown in Figure 3. Figure 3 comprises a detecting device **25** comprising a jacket **26** with a resilient portion **31**, a resilient chamber **28**, a liquid inlet **30**, a first switch valve **29**, a pressure valve **32**, a second switch valve **33** and a calibration volume valve **34**. A liquid **27** is filled between the jacket **26** and the chamber **28**. The detecting device **25** is connected to a strain gauge **35**.

Accordingly, the chamber is made of a suitable material to be able to accommodate a digit of different shapes and sizes. This will enable the digit to be tightly fitted within the chamber so that any volumetric change in the digit can be detected more easily. For example, the chamber is made of a resilient material. In particular, the chamber should be flexible enough to allow variation in the shape of the digit resulting from the volumetric changes of the digit. Further, the chamber should not pose any restrictions on the digit. Even more in particular, the chamber is made of a material with an elastic modulus in the range of about 10^6 N/m^2 or lower.

Further, the chamber may be of any size. For example, the apparatus may be given sizes according to the size of the chamber. This would enable a subject to choose an apparatus comprising a chamber that better suits the size of the digit to be measured. The chamber may even be in the form of a sleeve, wherein the sleeve comprises an opening for the insertion of the digit. Accordingly, the jacket may also be of any shape and size. In particular, the jacket may be of any suitable shape and size to be able to form a casing for the chamber.

The thickness of the material used for the chamber and the resilient portion of the jacket affects the sensitivity of the chamber and the jacket to react to volumetric changes of the digit and the change in pressure exerted by the liquid on the resilient portion of the jacket respectively. Accordingly, it is preferable that the chamber and the resilient portion of the jacket of the detecting device have a thickness within the range of about 1-10 μm. More preferably, the thickness is within the range of about 1-5 μm.

The type of material chosen for the resilient portion of the jacket may be an important factor. For example, if a material which has a high elasticity, and therefore a low elastic modulus, is used, the resilient portion will expand or contract more freely, but the measurement resolution will be lower. On the other hand, if a less elastic material with a high elastic modulus is used for the resilient portion, the expansion or contraction will be less, but the measurement resolution will be higher. Therefore, it would be evident to a person skilled in the art which type of material would be best suited for the purposes of the present invention.

The area of the resilient portion may also need to be considered. For example, for a higher measurement resolution, a larger area of the resilient portion is preferred. Further, the range of the volumetric change that can be measured is also proportional to the area of the resilient portion.

Any suitable means for detecting and/or measuring volumetric changes of the digit may be used for the purposes of the present invention. For example, the means for detecting and/or measuring volumetric changes may be a sensor. In particular, the sensor is a pressure sensor to detect changes in the pressure exerted by the resilient portion of the jacket on the liquid in the detecting device as a result of volumetric changes of the digit. In particular, the pressure sensor may be in contact with the liquid. The pressure sensor may be an optical, electrical or mechanical pressure sensor. Alternatively, the means for detecting

and/or measuring volumetric changes may be a strain gauge to detect changes in the strain of the resilient portion of the jacket as a result of volumetric changes of the digit.

However, it would be evident to a person skilled in the art which means for detecting and/or measuring volumetric changes should be used to suit a particular method of detecting volumetric changes of the digit.

According to a further aspect, the means for detecting and/or measuring a volumetric change may be connected to a processor which utilises the output from the means for detecting and/or measuring a volumetric change and converts the output into a change in volume of the digit. According to a particular aspect, the processor is connected to the pressure sensor to convert the pressure exerted by the resilient portion of the jacket on the liquid in the detecting device to a suitable output which can be used to determine the volumetric change of the digit being measured. According to another particular aspect, the processor is connected to the strain gauge to convert the strain exerted on the resilient portion of the jacket by the liquid to a suitable output which can be used to determine the volumetric change of the digit being measured. For example, the output may be in the form of an electric voltage output signal. The processor may be an output voltage indicator. The electric voltage output signal may be converted to a measure of change in volume of the digit by using a calibration curve showing the relationship between the voltage output signal and volumetric change.

For the purposes of the present invention, the digit to be inserted into the chamber may be a finger of a hand or a toe of a foot.

According to a further aspect, the apparatus may comprise a mould. The mould may be used for resting the hand or the foot comprising the digit being measured to reduce the movement of the digit. For example, excessive movements of the digit may bring about momentary changes in the shape of the

digit, bringing about changes in pressure exerted by the resilient portion of the jacket on the liquid in the detecting device, and therefore indicating volumetric changes of the digit. However, this would not be a true indication of a volumetric change of the digit. Therefore, having a mould would minimise the effects of digit movement on the detection and/or measurement of the volumetric change of the digit being measured. The mould may be of any shape and size so that it may better rest the hand or foot of the digit being measured. Further, the mould may be made of any suitable material such that the mould is able to resist the weight of the foot or hand without breaking. An example of a mould is shown in Figure 7.

According to a further aspect, the apparatus may further comprise a reference device. The reference device may comprise a liquid, wherein the liquid in the reference device may be the same, of the same kind or similar to the liquid comprised in the detecting device. In particular, the liquid comprised in the detecting device and in the reference device is the same liquid. The liquid comprised in the reference device may be any suitable liquid that may be used for the purposes of the present invention, such as, but not limited to, water. The reference device may be a rigid reference device, comprising a liquid which exerts a constant pressure on the walls of the reference device. Any suitable liquid may be used in the reference device. In particular, the liquid in the reference device is water.

The means for detecting and/or measuring a volumetric change in the device may be connected to the detecting device, as well as the reference device. According to one aspect, the means for detecting and/or measuring a volumetric change may be a sensor. In particular, the sensor is a pressure sensor. Even more in particular, the pressure sensor is a differential pressure sensor. When there is a change in the pressure exerted by the resilient portion of the jacket on the liquid in the detecting device as a result of a volumetric change of the digit being measured, this change in pressure is compared to the

constant pressure exerted by the liquid on the walls of the reference device to determine the extent of the volumetric change of the digit.

According to a particular aspect, an apparatus for non-invasively detecting and/or measuring volumetric changes of a digit comprises:

- a detecting device comprising:

    - a chamber for receiving a digit or a portion thereof;

    - a jacket comprising at least a resilient portion; and

    - a liquid,

wherein the liquid is sealed between the chamber and the jacket;

- a rigid reference device comprising a liquid which exerts a constant pressure on the walls of the reference device; and

- a pressure sensor for detecting and/or measuring a volumetric change in the device;

wherein a change in the pressure exerted by the resilient portion of the jacket of the detecting device on the liquid in the detecting device, caused by a volumetric change of the digit, is compared to the constant pressure exerted by the liquid on the walls of the reference device to determine the extent of the volumetric change of the digit.

The pressure sensor may be connected to both the detecting device and the reference device. In particular, the pressure sensor is a differential pressure sensor.

The apparatus may further comprise a processor. The processor is connected to the differential pressure sensor to convert the difference in the pressure exerted by the resilient portion of the jacket on the liquid in the detecting device

and the pressure exerted by the liquid on the walls of the reference device to a suitable output which can be used to determine the extent of volumetric change of the digit being measured. For example, the output may be in the form of an electric voltage output signal. The processor may be an output voltage indicator. The electric voltage output signal may be converted to a measure of change in volume of the digit by using a calibration curve showing the relationship between the voltage output signal and volumetric change of the digit.

An example of an arrangement of the apparatus of the present invention is shown in Figure 1. Figure 1 shows a detecting device comprising a digit. Accordingly, the pressure exerted by the liquid on the resilient portion of the jacket of the detecting device at a particular point in time is P2. This pressure will cause a corresponding pressure (P2') to be exerted by the resilient portion of the jacket on the liquid. The liquid in the reference device exerts a constant pressure P1 on the walls of the reference device. Pressures P1 and P2' are transmitted to the sensor, which then measures the difference between the two pressures (i.e. P2'-P1). An output voltage corresponding to this pressure difference is obtained, which in turn is converted by means of a converter into a volumetric change. The same will be further described in Figure 2.

Figure 2 shows a more specific arrangement of the present invention. The apparatus in Figure 2 comprises a rigid reference device **1**, which is fully filled with a liquid **2**. The reference device **1** is equipped with a liquid inlet **16**, a first switch valve **17**, a pressure valve **19** and a second switch valve **20**. The reference device **1** is connected to a differential pressure sensor **4** through a connector **3**. The apparatus also comprises a detecting device **23** comprising a jacket **6** with a resilient portion **13**, a resilient chamber **8**, a liquid inlet **14**, a first switch valve **15**, a pressure valve **18**, a second switch valve **21** and a calibration volume valve **22**. A liquid **7** is filled between the jacket **6** and the chamber **8**. The detecting device **23** is connected to the differential pressure sensor **4** by a connector **5**. The differential pressure sensor **4** is in turn connected to a

processor **24** which comprises a signal amplifier **9**, an output voltage indicator **10**, a voltage-volume converter **11** and an output volume display and control panel **12**.

The use of a liquid between the resilient chamber and the resilient jacket of the detecting device enables sensitive and efficient detection of volumetric changes of the digit being measured.

According to a further aspect, the apparatus of the present invention may be a portable device. The detecting device may also be disposable such that the detecting device is disposed after use to maintain hygiene and prevent the rupture of the chamber and/or the jacket. The reference device may also be disposable.

According to another aspect, the present invention provides a method for non-invasively detecting and/or measuring volumetric changes of a digit comprising the steps of:

- inserting a digit or a portion thereof into a chamber of a detecting device, the detecting device comprising the chamber and a jacket comprising at least a resilient portion;

- adding a liquid such that the liquid is sealed between the chamber and the jacket, wherein the liquid is added before or after the step of inserting the digit; and

- detecting and/or measuring volumetric changes of the digit for a pre-determined period.

The chamber may be made of any suitable material which is sensitive to changes in the size of the digit as a result of the volumetric changes of the digit. In particular, the chamber may be a resilient chamber. In particular, the chamber may be a resilient chamber. A resilient material is one which is

capable of regaining its original shape or position after bending, stretching, or other deformation. For example, the chamber may be made of a flexible material. In particular, the material used for the chamber is elastic and has a low bending stiffness and elastic modulus. Preferably, the elastic modulus is in the range of about 10^6 N/m^2 or lower. The elastic modulus of a material represents the relative stiffness of the material within the elastic range and can be determined from a stress-strain curve by calculating the ratio of stress to strain. The chamber may be of any suitable material. For example, the chamber may be made of latex, nitrile or polyurethane or a combination of materials thereof.

The jacket comprises at least a resilient portion. According to one aspect, only a portion of the jacket is made of a resilient material, while the rest of the jacket is rigid. Alternatively, the entire jacket could be made of a resilient material. The definition of a resilient material is as described above. Any suitable resilient material may be used for the resilient portion of the jacket for the purposes of the invention. In particular, the resilient portion of the jacket has a high level of elasticity and a low elastic modulus. A material that is said to have a high level of elasticity is one which responds to bending or stretching by returning to its original shape. Preferably, the elastic modulus of the resilient portion of the jacket is in the range of about 10^8 N/m^2 or lower, more preferably in the range of about 10^7 N/m^2 or lower, and even more preferably in the range of about 10^6 N/m^2 or lower. Examples of resilient material that may be used include, but are not limited to, latex, nitrile or polyurethane or a combination of materials thereof. The jacket may be of any suitable shape.

The chamber and the jacket of the detecting device may be transparent for convenience. For example, it would be convenient to note that the right amount of liquid is being added between the chamber and the jacket to ensure that the apparatus works efficiently.

The chamber is made of a suitable material to be able to accommodate a digit of different shapes and sizes. This will enable the digit to be tightly fitted within the chamber so that any volumetric change in the digit can be detected more easily. For example, the chamber is made of a resilient material. In particular, the chamber should be flexible enough to allow variation in the shape of the digit resulting from the volumetric changes of the digit. Further, the chamber should not pose any restrictions on the digit. Even more in particular, the chamber is made of a material with an elastic modulus in the range of about 10^6 N/m^2 or lower.

Further, the chamber may be of any size. For example, the apparatus may be given sizes according to the size of the chamber. This would enable a subject to choose an apparatus comprising a chamber that better suits the size of the digit to be measured. The chamber may even be in the form of a sleeve, wherein the sleeve comprises an opening for the insertion of the digit. Accordingly, the jacket may also be of any shape and size. In particular, the jacket may be of any suitable shape and size to be able to form a casing for the chamber.

The thickness of the material used for the chamber and the resilient portion of the jacket affects the sensitivity of the chamber and the jacket to react to volumetric changes of the digit and the change in pressure exerted by the liquid on the resilient portion of the jacket respectively. Accordingly, it is preferable that the chamber and the resilient portion of the jacket of the detecting device have a thickness within the range of about 1-10 μm. More preferably, the thickness is within the range of about 1-5 μm.

The step of adding a liquid may be carried out by any standard method known in the art. For example, the jacket may comprise a valve which may serve as an inlet for filling up the jacket with the liquid. Alternatively, the liquid could be added by using a syringe and a needle arrangement, wherein the needle is

injected into the area between the chamber and the jacket and the liquid is released from the syringe.

The liquid may be any liquid suitable for the purposes of the present invention. In particular, the liquid may be, but is not limited to, water.

The liquid may be added before or after the insertion of the digit into the chamber. According to a particular aspect, the step of adding the liquid is carried out after the step of inserting the digit into the chamber. Further, the step of adding the liquid comprises adding the liquid until the pressure exerted by the resilient portion of the jacket on the liquid reaches a pre-determined pressure.

It would be evident to a person skilled in the art that the step of detecting and/or measuring volumetric changes of the digit may be carried out by any suitable means for detecting and/or measuring volumetric changes. The means for detecting and/or measuring volumetric changes is chosen or used to suit a particular method of detecting volumetric changes of the digit. According to a particular aspect, a volumetric change of the digit may be detected in the form of pressure changes measured by a means for detecting and/or measuring volumetric changes. For example, the volumetric changes of the digit may be detected by changes in pressure exerted by the resilient portion of the jacket on the liquid in the detecting device. Accordingly, the step of detecting and/or measuring volumetric changes of the digit may be carried out with a sensor. In particular, the sensor may be a pressure sensor. Examples of pressure sensors include optical, electrical and mechanical pressure sensors.

The changes in pressure exerted by the resilient portion of the jacket on the liquid in the detecting device are brought about by the changes in shape of the chamber in order to comply with the changes in the shape of the digit as a result of the volumetric changes of the digit. The changes in pressure are detected by the pressure sensor.

According to another particular aspect, a volumetric change of the digit may be detected in the form of changes in the strain of the resilient portion of the jacket by the liquid in the detecting device. The changes in the strain of the resilient portion of the jacket may be measured by a means for detecting and/or measuring volumetric changes. Accordingly, the step of detecting and/or measuring volumetric changes of the digit may be carried out with a strain gauge.

The changes in strain of the resilient portion of the jacket by the liquid in the detecting device are brought about by the changes in shape of the chamber in order to comply with the changes in the shape of the digit as a result of the volumetric changes of the digit. The changes in strain are detected by the strain gauge. In particular, the strain gauge detects the contraction or elongation of the resilient portion of the jacket.

The method may further comprise the step of converting the pressure change or strain change into a measure of volumetric change. For example, the pressure sensor may be connected to a processor which utilises the output from the pressure sensor and converts it into a change in volume of the digit. In particular, the processor is connected to the pressure sensor to convert the pressure exerted by the resilient portion of the jacket on the liquid to a suitable output which can be used to determine the volumetric change of the digit being measured. Alternatively, the strain gauge may be connected to a processor which utilises the output from the strain gauge and converts it into a change in volume of the digit. In particular, the processor is connected to the strain gauge to convert the strain of the resilient portion of the jacket on the liquid to a suitable output which can be used to determine the volumetric change of the digit being measured. The output may be in the form of an electric voltage output signal. The processor may be an output voltage indicator. The electric voltage output signal may be converted to a measure of change in volume of

the digit by using a calibration curve showing the relationship between the voltage output signal and volumetric change.

As a further aspect of the present invention, the method comprises a step of calibrating a reference device. The reference device may be a rigid reference device, comprising a liquid. Any suitable liquid described above may be used in the reference device. The liquid comprised in the reference device may be the same, of the same kind or similar to the liquid comprised in the detecting device. The liquid comprised in the reference device may be any suitable liquid that may be used for the purposes of the present invention such as, water.

The step of calibrating the reference device comprises calibrating the reference device to a pre-determined pressure, such that the liquid in the reference device exerts a constant pressure on the walls of the reference device. In particular, the calibration is carried out prior to the step of inserting the digit into the chamber of the detecting device.

Preferably, the pressure exerted by the liquid on the walls of the reference device is made equal to the pressure exerted by the resilient portion of the jacket on the liquid in the detecting device prior to the step of detecting and/or measuring volumetric changes of the digit being measured.

The means for detecting and/or measuring volumetric changes may be connected to the detecting device and the reference device. In particular, the means for detecting and/or measuring volumetric changes is a pressure sensor connected to the detecting device and the reference device. Even more in particular, a differential pressure sensor is connected to the detecting device and the reference device.

According to one aspect, when the digit is inserted into the chamber, volumetric changes of the digit causes the chamber to comply with the changes in shape of the digit and thereby causing changes in the pressure exerted by the liquid

on the resilient portion of the jacket, which causes the jacket to expand or contract. This expansion or contraction results in a corresponding increase or decrease of pressure exerted by the resilient portion of the jacket on the liquid in the detecting device. The change in pressure exerted by the resilient portion of the jacket on the liquid is detected by the pressure sensor. The change(s) in pressure of the detecting device is compared to the constant pressure exerted by the liquid on the walls of the reference device to determine the extent of volumetric change of the digit. In particular, the difference in pressure exerted by the resilient portion of the jacket on the liquid in the detecting device and the constant pressure exerted by the liquid on the walls of the reference device is detected by the differential pressure sensor.

The differential pressure sensor may be connected to a processor, wherein the processor converts the difference in pressure into a measure of volumetric change of the digit being measured. For example, the processor may be connected to the differential pressure sensor to convert the difference in pressure between the pressure exerted by the liquid on the walls of the reference device and the pressure exerted by the resilient portion of the jacket on the liquid in the detecting device to a suitable output which can be used to determine the volumetric change of the digit being measured. For example, the output may be in the form of an electric voltage output signal. The processor may be an output voltage indicator. The electric voltage output signal may be converted to a measure of change in volume of the digit by using a calibration curve showing the relationship between the voltage output signal and volumetric change.

For the purposes of the present invention, the digit to be inserted into the chamber may be a finger of a hand or a toe of a foot.

According to a further aspect, the volumetric changes of a digit over a pre-determined period are used as an indication of the presence of abnormalities in

sympathetic nerve function. For example, the time taken for a digit to recover from a reduction in blood flow to the digit may be indicative of the presence of abnormalities in sympathetic nerve function. Alternatively, a lack or reduced recovery in digit volume (compared to the original volume of the digit) as a result of a sympathetic stimulus would also indicate the presence of abnormalities in sympathetic nerve function. If a treatment is carried out on the digit, for example by wrinkling the digit by immersing the digit in water or by using a wrinkling cream on the digit, the original volume of the digit refers to the volume of the digit prior to the treatment of the digit. Abnormalities associated with sympathetic nerve function include, but are not limited to polyneuropathy, small nerve fibre diseases (including idiopathic small nerve fibre disease), restless legs syndrome and carpal tunnel syndrome. Polyneuropathy may refer to types of polyneuropathy that affect the sympathetic nerve fibres. In particular, polyneuropathy may refer to diabetic polyneuropathy. Accordingly, the method of the present invention may be used to monitor the status of a patient. In particular, it may be used to detect abnormalities in sympathetic nerve function or any abnormality associated with sympathetic nerve function as mentioned above.

The volumetric changes of a digit may also be monitored over a period of time to monitor the status of sympathetic nerve function in a continuous fashion. For example, the volumetric changes of a digit may be monitored while the subject whose digit is being measured is in a state of rest. This may be particularly useful in the detection of carpal tunnel disease. For example, the apparatus of the invention may be particularly useful in eliciting why people suffering from carpal tunnel disease commonly have more symptoms at night. This may in fact be related to circadian changes in sympathetic discharges which in carpal tunnel may become dysfunctional. Nocturnal symptoms may be found to be due to impaired nocturnal vasoconstriction and so producing symptoms. According to one aspect, the invention provides a method for detecting and/or measuring

volumetric changes of the digit of a person while the person is sleeping at night for more accurate detection of carpal tunnel disease.

According to one aspect, the environment in which the subject whose digit is being measured may be a controlled environment. For example, the temperature of the environment may be regulated between 24 and 26°C. By controlling the temperature, "background vasoconstrictor responses" are reduced. Temperature fluctuations bring about natural fluctuations of sympathetic activity, thus causing background fluctuations. Accordingly, it would be preferred to minimise background responses. Further, the subject may be made to adapt to the environment by resting, seated in a chair for 10 minutes prior to the detection and/or measurement of volumetric changes of the digit. As temperature is the main regulator of digit tip blood flow (Charkoudian N., Mayo Clin Proc, 2003, 78(5):603-612), the temperature within the apparatus may be controlled at room temperature.

According to one aspect, the method according to the present invention comprises inducing a reduction in the volume of the digit, for example by inducing a reduction in blood flow to a digit in order to measure the time taken for the blood flow in the digit to return to normal. For example, the digit to be measured may be subjected to skin wrinkling procedures so as to reduce the volume of the digit or a portion thereof, prior to its insertion into the chamber of the detecting device. Any standard method known in the art may be used to wrinkle the finger.

Skin wrinkling is a result of loss in blood volume in the digit tip due to vasoconstriction induced by sympathetic nerves. For example, blood flow to the digit tip can be massively reduced through sympathetic nervous activation of vasoconstriction (Wilder-Smith E and Adeline Chow, Muscle and Nerve, 2003, 27:307-311; Wilder-Smith E and Chow A, J. Microvascular Research. 2003, 66: 68-72; Wilder-Smith EPV, Clinical Autonomic Research, 2004, 14:125-131).

Experiments have shown that blood flow in the digit tip can be reduced with sudden sympathetic activation (Eds T Bennett and S Gardiner, Nervous control of blood vessels Harwood Academic Publishers, Amsterdam, Netherlands, 1996, pages 1-59).

For example, a skin wrinkling cream such as an EMLA cream (Wilder-Smith E and Chow A, J. Microvascular Research, 2003, 66:68-72) may be applied to the digit. The cream may be applied by covering the distal tip of the digit and firmly occluding the digit with a plaster or an adhesive bandage (for example, a Johnson & Johnson's Band-aid) for a period of time, in particular, for 30 minutes.

Another way to wrinkle the digit is by immersing the digit into a liquid for a period of time. In particular, the arm comprising the digit to be measured is immersed in the liquid with the liquid level being close to the middle of the forearm. In particular, the level of the immersed hand is at the level of the heart and the subject whose hand is immersed is sitting in an upright position. For example, the digit may be inserted into a water bath maintained at 40°C for a period of 30 minutes. It has been indicated that 40°C is the optimum temperature for skin wrinkling (Cales L and Weber RA, J Hand Surg [Am], 1997, 22(4):747-749). In particular, the liquid may be a salt solution with salt concentration of about 0.5 mol/L (Tsai N. and Kirkham S., J Hand Surgery [Br], 2005, 30(3):273-275). It has been shown that at this concentration, rapid and clear skin wrinkling of the digit was achieved.

The wrinkled digit is then inserted into the chamber of the detecting device and the volumetric changes of the digit as a result of the digit recovering from the wrinkling may be measured.

According to a specific aspect is a method for using the arrangement as shown in Figure 2. The rigid reference device **1** is filled with liquid **2** through the inlet **16**, while switch valves **17** and **20** are open. As the liquid **2** is filled and the

pressure in the reference device **1** reaches a pressure P1 under the control of pressure valve **19**, switch valves **17** and **20** are closed such that pressure P1 is kept constant. The digit to be measured is then inserted into the resilient chamber **8**, which acts as the media between the digit and the liquid **7** in the jacket **6**. The jacket **6** is then filled with the liquid **7** while switch valves **15** and **21** are open. The liquid **7** is filled until the pressure in the jacket **6** reaches pressure P2, wherein P1 and P2 are equal values. Switch valves **15** and **21** are then closed. The volumetric changes of the digit are then detected and/or measured.

An increase in digit volume will cause an expansion (inflation) of the resilient portion **13** of the jacket **6** by liquid **7**. The expansion is caused by an increase in stress and strain of the resilient portion **13** of the jacket **6**. The resilient portion **13** of the jacket **6** in return supplies a larger force to liquid **7** and this increases the value of pressure P2. Accordingly, the difference is pressure between P1 and P2 will be detected by the differential pressure sensor **4**. As the difference between the two pressures (i.e. P2–P1>0) is a positive value, the differential pressure sensor **4** gives a positive voltage output signal to the signal amplifier **9**, which amplifies the signal and passes it to the output voltage indicator **10**.

Consequently, a decrease in the digit volume will result in the contraction (deflation) of the resilient portion **13** of the jacket **6** by liquid **7** as a result of a decrease in stress and strain of the resilient portion **13** of the jacket **6**. Accordingly, resilient portion **13** of the jacket **6** returns a smaller force to liquid **7** and decreases the value of pressure P2. The differential pressure sensor **4** therefore receives a negative pressure difference (i.e. P2–P1<0), giving a negative voltage output signal to the signal amplifier **9**. The output signal is then transmitted to the output voltage indicator **10**.

The amplified voltage signal received by the output voltage indicator **10** is converted into a digital form and passed to the voltage-volume converter **11**

where the digital voltage output is converted into a corresponding volume signal. The converted volume signal in digital form is sent to the output volume display and control panel **12** for displaying the extent of the volumetric changes of the digit. Using the information displayed, a person skilled in the art may then be able to determine whether any action needs to be taken or whether the subject whose digit is being measured suffers from abnormalities of sympathetic nerve functions.

In particular, the resilient portion **13** of the jacket **6** is made of a material which is highly elastic such that its stress-strain property is highly linear. Suitable material that can be used for the resilient portion **13** of the jacket **6** are as described above.

As at an initial state pressure P2 is made equal to pressure P1, the determination of pressure P1 depends on the material properties of the resilient portion **13**. For example, pressure P1 is determined such that the initial state of pressure P2 is sufficient to stress the resilient portion **13** to a linear stress-strain state of the stress-strain curve of the material of resilient portion **13**.

Further, the resolution of the detecting device **23** depends on the material and dimensions of the resilient portion **13** as described previously. For example, for high resolution and linearity of measurement, the material should be highly elastic with a low elastic modulus and the total size of the resilient portion **13** should be large.

The detecting device **23** is calibrated using a calibrated fixture set having a volume valve **22** that increases or decreases the volume of the jacket **6**. The calibration resolution is controlled by the diameter, as well as the displacement resolution of the volume valve **22**. For example, the smaller the diameter of the volume valve **22**, the higher is its resolution. During calibration, the volume valve **22** is displaced and the volume of the jacket **6** is increased or decreased accordingly, which translates to the contraction or expansion of the resilient

portion **13** of the jacket **6** by liquid **7**, and the resilient portion **13** in turn decreases or increases its force acting on liquid **7** such that pressure P2 decreases or increases. The differential pressure sensor **4** then gives a corresponding calibration voltage output. In this way, a calibration curve of the output voltage varying against a change in volume of the jacket **6** may be obtained. An example of a calibration curve is shown in Figure 4. A volume decrease in jacket **6** from 0 to 100 μL shows a change in output voltage from 0 to 4.2 V in a linear fashion.

The digit to be measured is wrinkled prior to its insertion into chamber **8**. The digit may be wrinkled using EMLA cream (AstraZeneca). For example, approximately 0.5 g of EMLA cream is applied to the distal digit tip of the 4th finger and the finger is then firmly covered with a Tegaderm (3M) plaster for 30 minutes. 0.5 g of cream amply covers the surface of the distal digit segment. In particular, the 4th and 5th digits are used as these digits show the clearest and most pronounced skin wrinkling. Figures 5A and 5B show the recovery of digit volume that occurs after induction of digit tip wrinkling with application of EMLA cream for 10 and 60 minutes respectively. The volumetric changes of the digit were measured using the arrangement of the apparatus of Figure 2. From Figure 5A, it can be seen that about 20 μL of re-expansion of the digit tip occurs, while from Figure 5B it can be seen that the increase in volume of the digit is about 30 μL after 60 minutes application of EMLA cream.

Alternatively, a volumetric change in the digit may be induced by an inspiratory gasp. An inspiratory gasp activates the sympathetic nerves to elicit the vasoconstrictor reflex of the digits of both the hands and the feet (Einar P Wilder-Smith et. al., Journal of Microvascular Research, 2005, 69:101-105). The subject, whose digit is being measured, takes a deep rapid breath in order to perform an inspiratory gasp. This causes vasoconstriction of the digit tip in the 2 to 4 seconds following the gasp. The vasoconstriction is followed by a brief compensatory increase in blood flow. Figure 6 shows the reduced blood flow

that is measured using the apparatus of Figure 2. The reduction of digit tip volume (approximately 10 μL) is almost equal to the reduced blood flow when measured using a laser Doppler.

The apparatus and the method of present invention would prove to be especially useful for research in neuropathies and to neurologists. For example, a volumetric reduction of a digit, in response to a sympathetic stimulus, lesser than the normal reduction expected of a digit of a healthy subject would indicate the presence of an abnormality in sympathetic nerve function. Alternatively, if the digit is wrinkled prior to the detection and/or measurement of volumetric change of the digit, a reduction in volume of the digit, as a result of the wrinkling, lesser than the volumetric reduction brought about by wrinkling of a digit of a healthy subject would indicate the presence of an abnormality in sympathetic nerve function. For example, the normal range of a digit volume reduction after a stimulus of an inspiratory gasp is about 8-10 μL. The normal reduction of digit volume after the application of EMLA cream to a digit tip is about 10-20 μL. Therefore, a digit volume reduction of less than these values would be indicative of the presence of sympathetic nerve function abnormalities. The time taken for the restoration of digit volume to normal digit volume may also be used as an indication for the presence of sympathetic nerve function abnormalities. For example, when using the inspiratory gasp method to induce a decrease in volume of blood flow in the digit, the time within which the digit volume returns to normal in a healthy person would be 5-10 seconds. However, the time taken for a person with diabetic neuropathy may be considerably longer than that, depending on the degree of seriousness of the abnormality.

Accordingly, arrangements of the invention other than that shown in Figures 1 to 3 are possible, and consequently the particularity of the figures is not intended to be limiting of the present invention.

EXAMPLES

A dry and clean distal 4th digit tip of a hand was covered with EMLA cream (AstraZeneca). About 0.5 g of EMLA cream was used. The digit tip was then covered with a Tegaderm plaster (3M) for about 10 minutes to ensure that the cream penetrated into the distal digit tip tissue. During this time, the subject remained at rest and the environment temperature was maintained between 24 and 26°C.

The finger was then cleaned to ensure that no cream remained on the distal digit tip after the removal of the Tegaderm plaster. The digit tip was then inserted into the chamber **8** of the detecting device **23** as shown in Figure 2 and kept immobile by resting the hand on the mould (see Figure 7) for about 15 minutes to detect and/or measure volumetric changes of the digit.

The results of the volumetric changes of the digit are shown in Figure 5 (A, B). It can be seen from Figures 5A and B that with 10 minutes application of EMLA cream on the digit, the increase in volume of the digit is about 20 μL (Figure 5A) while with 60 minutes application of EMLA cream on the digit, the increase in volume of the digit is about 30 μL (Figure 5B).

Claims

1. An apparatus for non-invasively detecting and/or measuring volumetric changes of a digit comprising:

   - a detecting device comprising:

      - a chamber for receiving a digit or a portion thereof; and

      - a jacket comprising at least a resilient portion,

   wherein the chamber and the jacket are arranged such that when a liquid is placed between the chamber and the jacket, the liquid is sealed therein; and

   - a means for detecting and/or measuring a volumetric change in the device.

2. The apparatus of claim 1, wherein the device comprises a liquid sealed between the chamber and the jacket.

3. The apparatus of claims 1-2, wherein the means for detecting and/or measuring a volumetric change is a pressure sensor or a strain gauge.

4. The apparatus of claims 1-3, further comprising a reference device.

5. The apparatus of claim 4, wherein the reference device is a rigid reference device comprising a liquid which exerts a constant pressure on the walls of the reference device, and wherein the means for detecting and/or measuring a volumetric change is a pressure sensor.

6. The apparatus of claim 5, wherein the pressure sensor is a differential pressure sensor.

7. The apparatus of claim 3, wherein a volumetric change of the digit causes the chamber to comply with the change in shape of the digit and thereby causing a change in the pressure exerted by the liquid on the resilient portion of the jacket, which causes the resilient portion to expand or contract which in turn causes the resilient portion of the jacket to exert an increased or decreased pressure on the liquid and wherein the change in pressure on the liquid is detected by the pressure sensor.

8. The apparatus of claims 5-6, wherein the constant pressure exerted by the liquid on the walls of the reference device is compared to a change in pressure exerted by the resilient portion of the jacket on the liquid to determine the extent of volumetric change of the digit.

9. The apparatus of claims 2-8, wherein the liquid is water.

10. The apparatus of claim 3, wherein a volumetric change of a digit causes the chamber to comply with the change in shape of the digit and thereby causing a change in pressure exerted by the liquid on the resilient portion of the jacket which in turn results in a change in strain of the resilient portion of the jacket and wherein the change in strain is detected by the strain gauge.

11. The apparatus of claim 1, comprising:

- a detecting device comprising:

  - a chamber for receiving a digit or a portion thereof;

  - a jacket comprising at least a resilient portion; and

  - a liquid,

wherein the liquid is sealed between the chamber and the jacket;

- a rigid reference device comprising a liquid which exerts a constant pressure on the walls of the reference device; and

- a pressure sensor for detecting and/or measuring a volumetric change in the device;

wherein a change in the pressure exerted by the resilient portion of the jacket on the liquid in the detecting device, caused by volumetric changes of the digit, is compared to the constant pressure exerted by the liquid on the walls of the reference device to determine the extent of volumetric change of the digit.

12. The apparatus of claim 11, wherein the pressure sensor is a differential pressure sensor.

13. A method for non-invasively detecting and/or measuring volumetric changes of a digit comprising the steps of:

- inserting a digit or a portion thereof into a chamber of a detecting device, the detecting device comprising the chamber and a jacket comprising at least a resilient portion;

- adding a liquid such that the liquid is sealed between the chamber and the jacket, wherein the liquid is added before or after the step of inserting the digit; and

- detecting and/or measuring volumetric changes of the digit for a pre-determined period.

14. The method of claim 13, wherein the volumetric changes are detected by changes in pressure exerted by the resilient portion of the jacket on the liquid in the detecting device.

15. The method of claims 13-14, wherein the step of adding the liquid comprises adding the liquid until the pressure exerted by the resilient portion of the jacket on the liquid reaches a pre-determined pressure.

16. The method of claim 14, wherein the changes in pressure exerted by the resilient portion of the jacket on the liquid are brought about by the changes in shape of the chamber in order to comply to the changes in the shape of the digit as a result of the volumetric changes of the digit.

17. The method of claims 13-16, further comprising the step of calibrating a rigid reference device comprising a liquid to a pre-determined pressure such that the liquid exerts a constant pressure on the walls of the reference device, the step of calibrating the reference device being carried out prior to the step of inserting the digit into the chamber of the detecting device.

18. The method of claim 17, wherein the step of detecting and/or measuring volumetric changes of the digit is carried out by a pressure sensor, and wherein the pressure sensor is connected to the reference device and the detecting device and measures the difference in the pressure exerted by the resilient portion of the jacket on the liquid and the constant pressure exerted by the liquid on the walls of the reference device.

19. The method of claim 18, wherein the pressure sensor is a differential pressure sensor.

20. The method of claim 13, wherein the volumetric changes are detected by changes in strain of the resilient portion of the jacket by the liquid in the detecting device.

21. The method of claim 20, wherein the changes in strain of the resilient portion of the jacket by the liquid are brought about by the changes in shape of the chamber in order to comply to the changes in the shape of the digit as a result of the volumetric changes of the digit.

22. The method of claims 13-21, wherein the step of detecting and/or measuring volumetric changes of the digit is carried out by a pressure sensor or a strain gauge.

23. The method of claims 13-22, wherein the digit is treated with a digit wrinkling cream or is wrinkled by immersion in a liquid, prior to the step of inserting the digit into the chamber.

24. The method of claims 13-23, wherein volumetric changes of the digit within a pre-determined period are indicative of the presence of abnormalities in sympathetic nerve functions.

25. The method of claim 24, wherein the abnormalities in sympathetic nerve functions comprise polyneuropathy, small nerve fibre disease, restless legs syndrome and carpal tunnel syndrome.