

Volumeter with communicating chambers: presentation of a prototype with reduced dimensions developed for objective assessment of hand volume

Volúmetro com câmaras comunicantes: apresentação de um protótipo de dimensões reduzidas desenvolvido para a avaliação objetiva do volume de mão

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Abstract

Traditional water displacement volumetry, based on Archimedes' principle of buoyancy, is considered the gold-standard for limb volume measurement. However, the routine use of this technique is associated with a series of disadvantages: the method is cumbersome to the patient, messy and unhygienic, and it takes a great amount of the examiner's time. This article presents the prototype of a new piece of equipment designed according to Pascal's principle of communicating vases for the direct evaluation of hand volume.

Keywords: Plethysmography, measurement equipment, extremities, biomedical technology assessment.

Resumo

A volumetria tradicional por deslocamento de água, que utiliza o princípio do transbordamento de Arquimedes, é considerada o padrão-ouro da avaliação do volume de membros, porém tem seu uso rotineiro prescindido por apresentar uma série de desvantagens: o método é embaraçoso ao paciente, pouco prático e desprovido de higiene, além de consumir muito tempo do examinador. Este artigo apresenta o protótipo de um aparelho inédito que utiliza o princípio dos vasos comunicantes de Pascal para a avaliação direta do volume de mão.

Palavras-chave: Pletismografia, equipamentos de medição, extremidades, avaliação da tecnologia biomédica.

Introduction

With the increasing need of validating therapeutic effectiveness, objective measurements are fundamental in current health care.¹ The classical method of volumetry by water displacement, in which the limb is slowly introduced in a tank full of water and the overflowed volume is measured, has several disadvantages: it is not practical and it requires too many operations with the water, thus increasing the possibility of errors; it cannot be used in cases of open wounds or with dressings and skin infection, it may cause embarrassment due to its poor hygiene and it may facilitate the transmission of infections.²⁻⁶

The term 'direct measure' is not adequate for buoyancy, since the method needs the transference of the overflowed liquid to other recipients, or even the weighting of the content displaced, with its equivalence in units of mass. Even if reproducibility of indirect methods is satisfactory, in assuming normality patterns as reference for indication or contraindication of treatment techniques, there is the risk of treating overestimated normal limbs or neglecting segments with an increased volume that could have been assessed as normal volumetric.⁷

The prototype of a new device for appendicular anthropometry, presented here in reduced dimensions for wrist-hand volumetry, was developed as an alternative tool³ for

Study approved by the Research Ethics Committee of the Escola Paulista de Medicina - Universidade Federal de São Paulo, under the protocol CEP n. 1600/04.

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The authors of the article have a part in the patent of the described product. The patent is registered in the INPI under the PI n. 0502899-0 (Núcleo de Propriedade Intelectual da UNIFESP).

Scholarship of the Fundação de Amparo à Pesquisa, State of São Paulo (FAPESP), Brazil, process n. 05/55240-0.

Manuscript received Jan 28 2009, accepted for publication Feb 8 2010.

J Vasc Bras. 2010;9(2):76-80.

the traditional one, which uses the buoyancy principle. The device described here is a volumeter with communicating chambers, whose functioning is based on Pascal's principle of communicating vases and Stevin's principle which relates pressure and water columns of different surfaces.

The principle of flow transmission between compartments, contrarily to the buoyancy principle, allows repeated, reversible and dynamic volumetric readings concomitant with the introduction of the segment, allowing as well the evaluation of different anatomical levels, including the totality of the limb up to the glenohumeral or coxofemoral joint region, in the same procedural moment. The prototype that measures the whole limb is undergoing trials for clinical use.

Equipment description

The prototype was built in glass, according to a technical outline by the manufacturers.

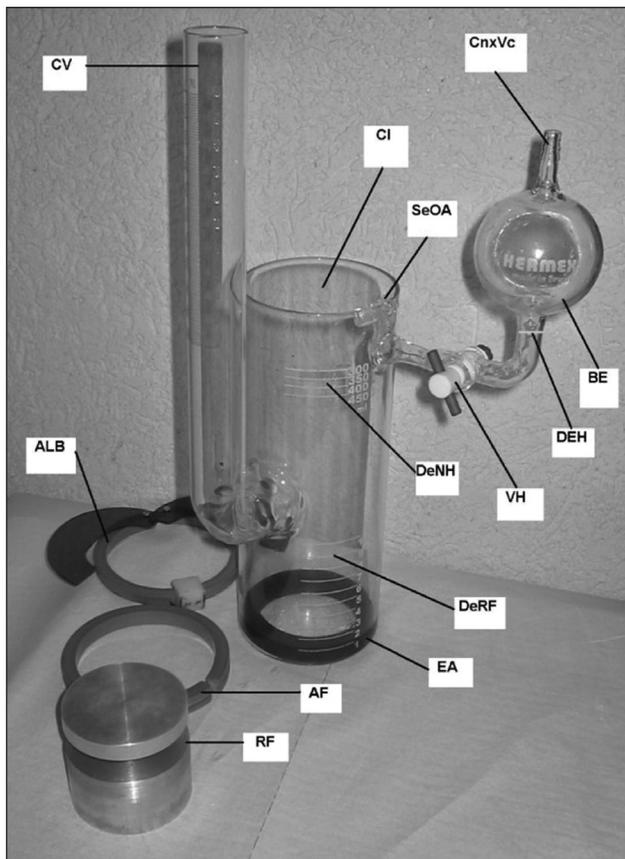


Figure 1 - Picture of the prototype of the volumeter with communicating chambers, displaying, clockwise: DW = dipwell; SeSB = series of suction bores; Cn VU = connection for vacuum unit; SF = spherical flask; HBD = hydrostatic balance delimitation; HV = hydrostatic valve; HLD = hydrostatic levels delimitation; BRD = bottom reference delimitation; AF = adherent foam; FR = fastening ring; BR = Bottom reference; ELR = edge-limiting ring; VC = volumetric column

The device consists of a set of three communicating chambers (Figure 1): one dipwell (DW) for the hand, one volumetric column and one flask for absorbing air residues, composing a hermetic system during the evaluation of the segment, which is protected by a glove coupled with the DW thus sealing the opening for hand introduction.

Pairs of gloves with ambidestrial differentiation in anatomical formats function as an interface between the evaluated segment and the water in the DW. The evaluated patient should wear proper sized gloves, which should be fastened between exams occurring in distinct moments, in order to standardize the volume added by the vestment.

Two polyvinyl chloride (PVC) and acrylic rings, one of them chamfered to fasten the glove's edge and the other to limit the upper expansion of the glove, are used as attachable devices to the DW's upper edge (Figure 1).

A cylindrical aluminum device with threadable upper elevating platform from 5.5 cm of the DW's base is fastened inside this base, with adherent foam, to function as a bottom reference (BR), limiting the immersion of the wrist-hand segment.

A submersible analog thermometer is fastened with a cupping-glass to the DW's internal wall with the objective of monitoring water temperature during measurements. Portable tracheal suction devices can be used as sources of vacuum, as well as vacuum flowmeters whenever available in hospital or out-patient setting.

The device (Figure 2) has the following dimensions: Cylindrical DW with 100 mm of internal diameter and 250 mm of height, with hydrostatic level markings in mL from the upper edge of the tank (300, 350, 400 and 450) and BR in cm from its lower edge (1 to 10).

At the height of 150 cm from the DW's base a cylindrical volumetric column is fastened, communicating with the DW interior and in its external wall, with a resolution of 1 mL, internal diameter of 30 mm, with 175 mm of gradation in mL in relation to the dipwell's upper edge (0 to 100). A spherical flask for absorbing the remaining air between glove and water at submersion of the wrist-hand segment, also in glass, with 66 mm of internal diameter and 150 mL capacity, is fastened in the DW's interior and in its external wall, with an intermediate hydrostatic valve and a connection for vacuum unit in its top.

An intermediate communication cylindrical arm, where the hydrostatic valve was located, arising from the flask base, bends at 90°, 18 mm below the dipwell's upper edge, and extends internally, bending again at 90° close to the larger cylinder's internal wall and arriving near the access to the body segment, in a series of small holes, with a distance

of 6 mm between themselves, throughout 50 mm of the immersion curve (Figure 3).

Methods of measurement

The sequence of procedures for segment volumetric measurement with the prototype is described as follows.

First the person to be evaluated is asked to remove any accessories such as watch, bracelets or rings from hands, wrists and fingers. Then the examiner asks the person to put on a glove in the hand to be measured, partially submerging it in the DW according to the individual weighing hydrostatic level established. The edge-limiting ring is then positioned above the fastening ring previously coupled to the upper edge of the DW.

At this moment, the examiner asks the subject to fasten the hand at the partial submersion level afore mentioned for the glove edge to be inserted in the fastening ring's chamfer. The edge-limiting ring, with its acrylic sheets open, is, then, also coupled to the upper edge of the larger cylinder, on the inserted glove and in the upper position of the fastening ring. The air which remains between the glove and the tank water is, consecutively, removed by vacuum generator linked to the top of the spherical flask by a latex extension. For such, the intermediate valve must be open.

When the remaining air is withdrawn, the examiner should wait until the hydrostatic balance between the three chambers (spherical flask, DW and graded column)

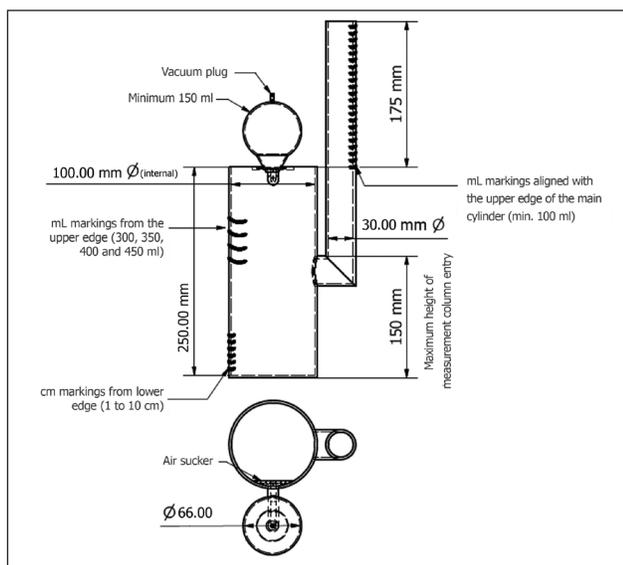


Figure 2 - Frontal (above) and upper (below) perspectives of the volumeter with communicating chambers and its respective dimensions in millimeters

is established, with the diminution of the water level by gravity and smooth alternate immersion and emersion movements of the wrist-hand segment, oriented by the examiner.

The lowering of the water column should be permitted to the delimitation of the hydrostatic balance, in the portion of the cylindrical arm immediately below the spherical flask, when there is meniscus formation. At this moment the valve should be closed.

The acrylic sheets of the edge-limiting ring are closed and the subject is asked to submerge the wrist-hand segment up to the point where the distal extremity of the third finger touches the center of the bottom reference (BR) upper platform (Figure 4).

Finally, volumetric readings are collected.

Discussion

Assessment of limb volume by the volumeter with communicating chambers has some advantages in relation to the traditional volumetry by buoyancy:

- 1) The time needed for evaluation coincides with the time of immersion of the hand/glove in the dipwell water, which may be reutilized, provided that evaporated contents are periodically replaced by the volumetric column opening. As the physical principle used here is water displacement through flow transmission between connected recipients, and not buoyancy, volumetric reading is immediately provided to each immersed portion of the assessed segment, analogously to a weighing scale for measuring body mass.

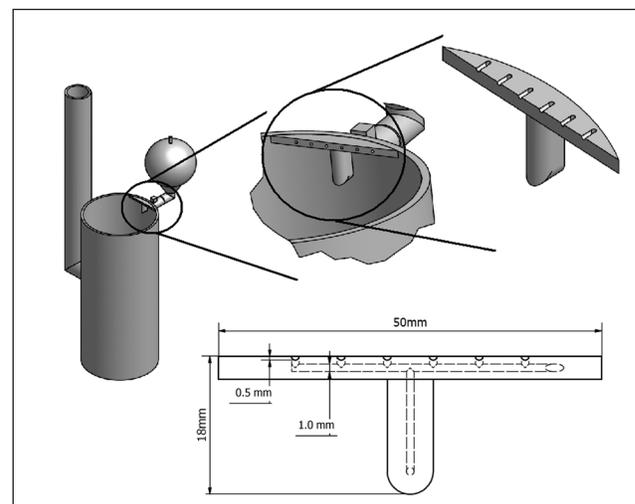


Figure 3 - Detailed schematic representation of successive enlargements of the suction bores series of the volumeter with communicating chambers (tridimensional sketches above)

- 2) Method standardization through strict control of the involved variables, such as water temperature, volumetric losses and segment portion immersed.
- 3) It is a comfortable method for the patient by avoiding, through the use of a glove, the direct contact of the patient's hand with the DW water and, consequently, thermal contrast. a) Normal physiologic characteristics of edema transit and the vascular system's reactivity are maintained, with immersion water temperature kept between 20 and 32 °C⁸ and due also to the reduced examination time and interface protection of the glove between the patient's limb and the water. b) Cutaneous infection risk is avoided, because there is no direct contact of the affected limb with the immersion water.
- 4) The proposed technique virtually ensures that no volumetric losses will occur, since it is a hermetic immersion system. The coupling of the small vacuum generating suction pump (in a hospital setting, network vacuum might also be used) prevents the undesired reading of volumes caught in the space between the glove and the water.
- 5) It enables a better coaptation interface, because the water edge level coincides with the tank's edge during volumetric readings, with no overflow.
- 6) The constant presence of the device in the place of assessment, no need of displacement in each evaluation for deflation, antiseptis or fuelling.
- 7) Maintenance of out-patient setting cleanliness, decreasing the risks of overflows and drops on the floor, once all the water is kept inside the device.
- 8) Measurements are direct (the displaced water does not need to be transferred to other recipients), dynamic (as explained in item 1) and repeated (the volume read for a certain portion of the limb may be reassessed during the same procedural moment, provided the patient emerges his or her limb and, then, submerge it up to the same point).

Acknowledgements

To engineer Cristiano Campozana de Queiroz and engineering technician Wilson Adriani Filho for their invaluable technical contributions during the production of the device.

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Figure 4 - Picture displaying the volumeter with communicating chambers in hermetic situation for collecting segmentary measures, sealed by the glove and edge-limiting rings and fastening rings, as well as the position in which the hand must be during volumetric reading

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Statistic analysis: N/A

Overall responsibility: FMJ

Obtained Founding: FAPESP

* All the authors have read and approved the final version of the article submitted to J Vasc Bras.