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Assessment of lower limbs edema in healthy workers who are exposed to long-term gravity

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Abstract

The aim of this study is to establish changes in leg volumes in healthy subjects (HS) after prolonged standing and prolonged lying. The study was carried out on two HS groups: the group A (20 subjects) included physicians and nurses who underwent a water plethysmography test, before and after eight hours of standing still in the operating room. The group B (20 subjects) included volunteers who were assessed before and after 10 h of supine resting. Group A: baseline leg volume was 1857.5 mL±196.9 on the right and 1850 mL±194.7 on the left limb. After eight hours of hydrostatic pressure action the two lower limbs volume was significantly increased to 1945 mL±209.6, and to 1940 mL±216.2, respectively ($P<0.0001$). The increased volume is significantly correlated with time ($R^2=0.95$, $P<0.0001$). Group B: baseline leg volume was 1875 mL±175.1 on the right, and 1862.5 mL±166.9 on the left limb. After ten hours of resting supine the volume was 1770 mL±195.6, and to 1757.5 mL±194.2, respectively ($P<0.0001$). The decreased volume is significantly but inverted correlated with time ($R^2=-0.98$, $P<0.0001$). This study demonstrates how the hydrostatic pressure is a main determinant for fluid accumulation in the lower extremity. To counteract the gravitational gradient becomes the mandatory prophylactic approach for healthy individuals who are exposed to an increased chronic venous disease risk.

Introduction

Echo-color Doppler and phlebography, are a diagnostic methods adopted to assess where in the venous tree is present a problem of obstruction or reflux; on the other hand, there are different diagnostic methods used to quantify the venous function.[1]

Still nowadays, the venous pressure measurement during and after walking represents the gold standard for a quantitative reliable and standardized test.[2]

Nevertheless, this is an invasive technique that requires the intravascular pressure measurement while standing. This is a procedure can be uncomfortable, especially for the subject, and that requires a considerable technical effort. Therefore, less invasive techniques were developed for patients' assessment with lower limbs edema.

The diagnostic test is based on a volumetric assessment that is able to detect both the leg and foot volumetric changes. The more common methodologies are air[3] and/or water plethysmography (WP). The latter is an evolution of all the previous rare investigations about volumetric variation assessments for the venous system evaluation that were limited to a single segment of the calf.[4-7]

WP allows the total volume determination expressed in milliliters of both the leg and the foot. In literature it is now a validated method for the venous function and edema assessment.[8]

The WP is able to provide a non-invasively, easily, repeatable and economic measure of the distal portion of the lower limbs edema, reaching an objective measurement that is more precise and simple than the volumetric assessment of the limb circumference in centimeters. Aim of the present study is to objectively assess the physiological lower limbs volume changes during an ordinary day of work in subjects exposed or not to the hydrostatic pressure, by the means of WP.

Materials and Methods

Study population

The study took place in a period of six months: the evaluated population was constituted by 40 healthy subjects (HS), who were previously screened for the absence of either chronic venous insufficiency (CVI) or lymphedema by validated clinical and ultrasonography criteria.[9]

Particularly, duplex protocol to assess absence of reflux and/or obstruction in greater and small saphenous vein, as well as in the main deep veins, was used to exclude CVI.[10-12]

To exclude lymphedema we also used high resolution B-mode imaging of soft tissue to detect enlargement of lymphatic collectors, as well as faded images typical edema of the subcutaneous tissue.[13-15]

Two groups were selected and each one was composed by twenty subjects of both. Overall, 480 WP measurements were carried out. The first group (group A) was composed by surgeons and nurses (12 females and 8 males) who voluntarily underwent the test, before and after 8 standing still working hours in the operating room. The mean age was 32.7±7.7 years old.

The second group (group B) was composed by volunteers (12 females and 8 males) who underwent the same WP assessment with an interval of at least ten hours between the first (at 7 a.m.) and the second evaluation (at 5 p.m.), while resting supine in the meantime. Elastic stockings were forbidden in order to avoid inconsistencies in the measurements. The mean age was 24.1±3.9 years old.

Leg volume assessment

The WP permits the foot, ankle and calf volume measurement. Thirteen liters of water are poured into the WP with reference points at every 50 mL. The water temperature ranged between 28-30° C and was monitored by an electrical thermometer.

The WP container is filled up to a level of 13 L. Subsequently, the 3000 mL transparent container is placed under the draining spout in order to contain the water that will leak once the lower limb will be inserted into the instrument. The patient slowly inserts the foot into the water inside the WP until putting the foot sole on the base of the instrument. The subject has to maintain a sitting posture of 90° between the thigh and the leg so that that the latter is perpendicular to the base of the WP.

Once the leg has been inserted inside the instrument, the exceeding water discharge is expected at the blowhole spout where inside the 3000 mL transparent container was previously

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Key words: edema, posture, circadian variability, gravity, water plethysmography.

Contributions: MT, SG, design, data acquisition, analysis and interpretation, manuscript drafting; EM, MZ, AMM, data acquisition; MP, RM, analysis and interpretation; PZ, design, analysis and interpretation, manuscript revision.

Conflict of interests: the authors declare no potential conflict of interests.

Received for publication: 20 May 2013.
Revision received: 1 July 2013.
Accepted for publication: 4 July 2013.

Veins and Lymphatics 2013; 2:e19
doi:10.4081/vl.2013.e19

placed. The collected water volume will give the measurement of the same inserted leg volume and will be expressed in milliliters. These values were reported in a database. The assessments were consecutively repeated for three times for the left limb and three times for the right limb for each subject for reproducibility assessment. During the examination the patient must keep the most absolute immobility in order to allow water level stabilization. The measurements duration is approximately 15 min for each subject. The procedure was equally performed on the two recruited populations.

Experiment in workers exposed to a prolonged gravitational gradient

The first cohort of 20 HS was previously screened for comorbidities. Then they underwent leg volume assessment at 7.00 a.m., immediately after their arrival at the hospital. Subsequently, they have been working for 8 h in the operatory theatre, in a condition of prolonged standing posture. Right after they underwent WP once again at 3.00 p.m. All the measurements were performed right outside the operating room with the same temperature (23°C).

Experiment in volunteers exposed to prolonged clinostatism in morning hours

The second cohort of 20 HS was previously screened for comorbidities. Then they underwent leg volume assessment at 7.00 a.m. immediately after their arrival at the hospital. Subsequently, they spent 10 h lying in a tilting bed for 10 h, in a condition of prolonged supine posture. At 5 p.m. they underwent a second WP assessment. All the measurements were performed in the same room and temperature (23°C).

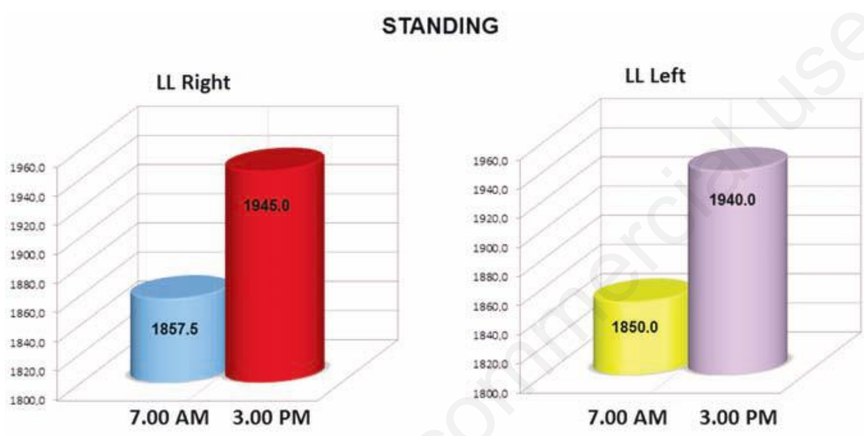

Figure 1. Lower limbs (LL) volume significant increase after 8 h of prolonged standing in an operating room without wearing any elastic stocking.

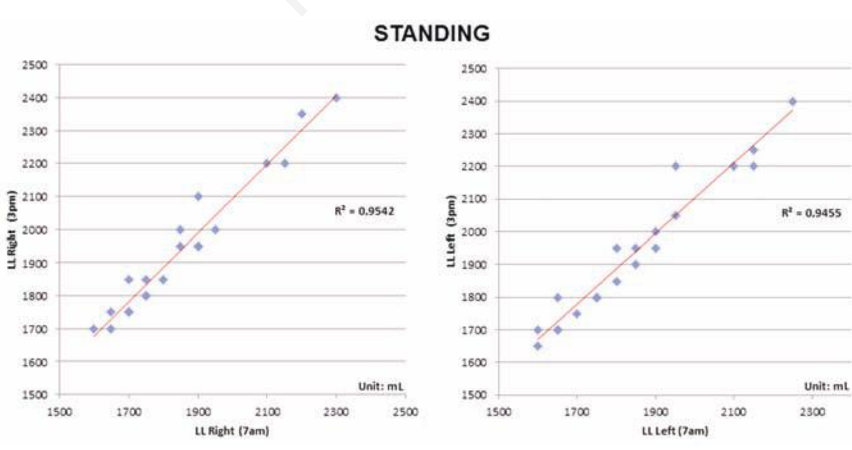

Figure 2. Strong linear correlation among lower limb (LL) volume respect to the time variable in standing conditions.

Statistical analysis

The data were analyzed with the program InStat® version 3.0 (GraphPad Software Inc., La Jolla, CA, USA) for Macintosh and are expressed as mean±standard deviation. For the statistical comparison of the 2 different measurements respectively on the 2 groups of subjects the paired T-Student test was used. The linear regression analysis between time and leg volume was performed with the Pearson test. Values $P<0.05$ were been considered significant.

Results

Analysis of the experiment in workers exposed to a prolonged gravitational gradient

The right lower limb baseline volume was 1857.5 mL±196.9 and resulted to be totally comparable with the left leg volume (1850 mL±194.7). The volume ranged from 1600 mL to the maximum volume of 2300 mL.

In the measurement after eight hours of standing the two limbs volumes were respectively 1945 mL±209.6 for the right leg and 1940 mL±216.2 for the left leg. The minimum volume was 1650 mL and the maximum volume was 2400 mL.

The difference between both the right and the left limbs in the morning and the same limb after the prolonged gravitational exposure was respectively of 87.5 mL and of 90 mL. This delta was found to be highly significant to the T-Student test ($P<0.0001$).

Moreover, the variation of fluids increase in the venous-lymphatic compartment results to linearly and strongly correlate with the time spent under gravity forces for working purpose, with a high significance (R^2=0.95, $P<0.0001$).

Figures 1 and 2 clearly show the legs volume increase overtime, together with the robust linear correlation respect to the time variable, respectively.

Analysis of the experiment in volunteers exposed to prolonged lying during morning hours

In group B the baseline volume value was 1875 mL±175; 1 on the right and 1862.5 mL±166.9 on the left. The lowest value was 1500 mL while the highest was 2150 mL. After ten hours of lying supine, the right limb volume was 1770 mL±195.61 while the left one was 1757.5 mL±194.2. The lowest volume was 1300 mL while the highest was 2050 mL.

Even in this cohort the difference between the 2 measurements resulted to be extremely significant ($P<0.0001$).

Analyzed by a linear regression (Pearson index), the leg volume was inversely related to the time that was spent in a supine position (R^2=−0.98, P<0.0001).

In Figure 3 the lower limbs volume reduction overtime is well apparent for the supine position.

Finally, Figure 4 provides this volume reduction inverted and extremely significant correlation overtime.

Discussion

The main outcome of this study is to point out how in human physiology the gravity is responsible for significant increases in lower limbs volume. It is very interesting to note how this increase appears related to the absolute time variable, resulting in a nearly perfect linear correlation when considering the volumetric gains measured before and after exposure to the hydrostatic gradient.

The demonstration of leg volume increase by standing was never assessed by plethysmography in healthy subjects but only in CVI patients.

To the contrary, in the absence of any hydrostatic overload, the lower limbs tend to shrink significantly in volume. This is likely to be the consequence of the fluid volume redistribution over the other body compartments, in accordance with the communicating vessels law.[9]

As further confirmation of the pivotal role of the gravity force, there is an inverse correlation between the limb volume reduction and the time spent in absence of the variable hydrostatic pressure exposure.

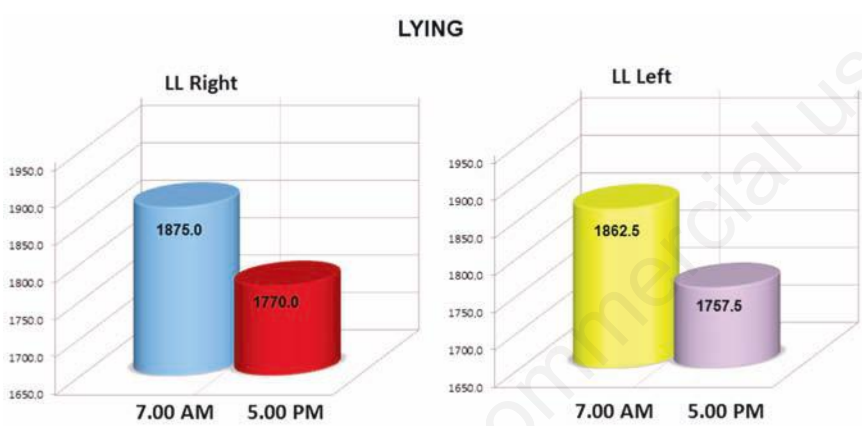

Figure 3. Lower limbs (LL) volume reduction overtime after a prolonged supine resting.

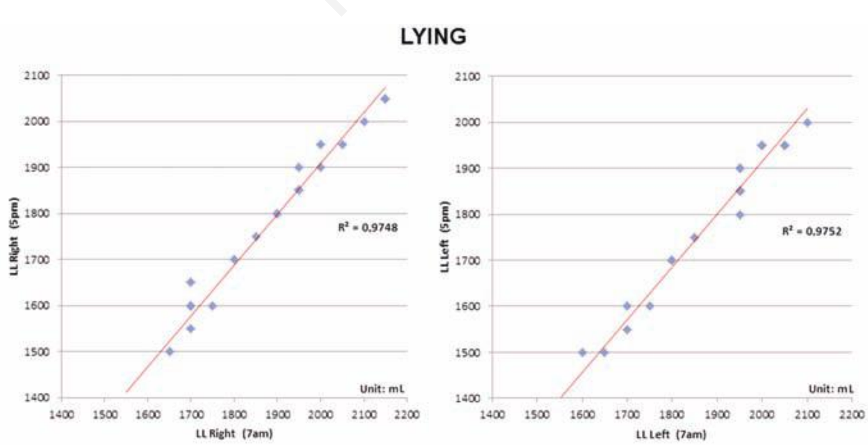

Figure 4. Lower limbs (LL) volume reduction presenting an inverted and extremely significant correlation with time.

What are the practical implications of our experiment?

The first comment is that even a subject with a fully functional phlebo-lymphatic apparatus, to maintain the, fixed orthostatic position, whether sitting or standing, tends to accumulate overtime fluids and macromolecules in the phlebo-lymphatic sector and in the interstitium as well.

The pivotal importance of the hydrostatic pressure was confirmed by the volume reduction, which was measured in the supine position. Our experimental observation represents an objective assessment of the old postural therapy for the prevention and treatment of the lower limbs edema. Our interpretation of the phenomenon is that the absence of hydrostatic pressure tends to equally redistribute the fluid in the other compartments of the body. Furthermore, it has been recently hypothesized that the vascular tone can be regulated by new molecules.[16,17] However, the experiment in supine seems to exclude the presence of regulatory molecules for the very strong inverted correlation found, suggesting the pivotal role of gravity respect to regulatory molecules. The variation of leg volume along time in workers exposed to long term gravitational gradients is confirmed in medical literature.[18-21] Gravitational exposure for working reasons might facilitate an overload on the vascular walls along days, months and years.[22-24]

The observed phenomenon, as well as the strong relationship with the time of exposure to a well-known risk factor for CVI, opens new questions for prevention. For instance, in long-time exposed to gravity workers are wearing prophylactic elastic stockings going to significantly change their risk of developing CVI? Further studies are warranted.

Conclusions

Hydrostatic pressure demonstrated to be a main determinant in lower limbs volumes variations also in healthy subjects. The observed phenomenon is directly related to the time of exposure to the gravitational pressure. Thus, a prophylactic counterbalance of a prolonged working time in a standing still position by means of elastic compression results to be mandatory also in healthy lower limbs.

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