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SHORT REPORT

The Feasibility of Underwater Computerised Strain Gauge Plethysmography and the Effects of Hydrostatic Pressure on the Leg Venous Haemodynamics

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Background: Strain gauge plethysmography (SGP) is employed to evaluate venous drainage of the lower leg.
Methods: In this study, SGP was used to evaluate the effects of the hydrostatic pressure (HP) of water on venous volume (VV), expelled volume, and ejection fraction (EF) in 22 healthy legs before and during immersion in water.
Results: HP reduced VV by 100% and even more during underwater (UW) exercise, making calculation of the UW EF possible.
Discussion: UW SGP is feasible and indicates that HP improves venous haemodynamics. This study suggests that including UW leg exercise in the rehabilitation protocols of patients with chronic venous disease may be useful.
Keywords: Strain gauge plethysmography, Underwater compression, Underwater ejection fraction, Underwater venous volume.

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INTRODUCTION

In 1952, strain gauge plethysmography (SGP) was reported to be effective in leg volume measurements,[1] but it was only in 2006 that Poelkens et al. validated SGP in the measurement of the venous ejection fraction (EF) from the lower leg in critical situations.[2] The same protocol was then adopted to measure the EF from the lower leg in patients with superficial venous incompetence and the effects of different kinds of compression therapy on the impaired EF.[3]

Water immersion is anecdotally considered beneficial for venous return, but no study has evaluated the effects of the compression exerted by the hydrostatic pressure (HP) of water on venous haemodynamics and leg volume during immersion. A recent study of under water (UW) sonography showed that pool immersion can effectively reduce the calibre of deep and superficial veins and venous reflux in varicose veins, and increase spontaneous venous outflow.[4]

The aim of the present study was to evaluate the feasibility of SGP during water immersion and to assess whether compression by HP is effective in improving venous haemodynamics.

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METHODS

The SGP probe was modified to make it waterproof (Fig. 1), and its accuracy and sensitivity was previously confirmed by laboratory tests. In 22 legs of 11 volunteers (seven women, four men; mean $\pm$ standard deviation age 48 $\pm$ 5 years) not affected by axial superficial or deep venous incompetence/obstruction as assessed by duplex examination, venous volume (VV) in the standing position, and expelled volume (EV) after 20 steps were assessed out of water (OOW) and UW by SGP as previously described (Fig. 2).[2,3] VV and EV are expressed as a percentage of the calibration value. EF was calculated according to the formula EF $=$ 100 $\times$ EV/VV. Water HP and intravenous pressure (IVP) were also calculated roughly. HP was calculated by measuring the distance between the level of the water surface in the pool and the probe. IVP was calculated by measuring the distance between the heart and the probe according to the formula 1 359 cmH_2O $=$ 1 mmHg. The pool water depth was 110 cm and the water temperature 32°C.

This work was an observational study involving normal volunteers. Italian authorities do not require ethical approval for this type of study. All volunteers gave their informed consent to be enrolled in the study, which was performed according to the principles of the Declaration of Helsinki.

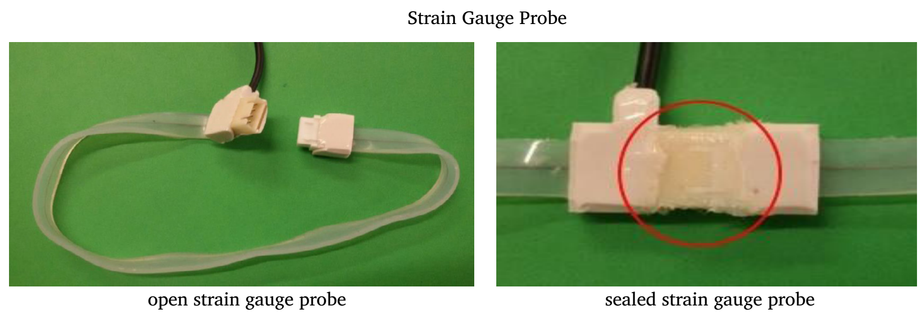


Figure 1. (A) The strain gauge plethysmography probe. (B) Sailed probe. Note the liquid metal embedded in a silicon band (arrow).

Statistical analysis

Median values and interquartile ranges (IQRs) are given. For data comparisons, the Friedmann test with multiple comparison was used. Differences with a p value of $< .05$ were considered statistically significant. The graphs and the statistical evaluations were generated by Graph Pad Prism, version 7 (GraphPad, San Diego, CA, USA).

Figure 2. Patient standing into the pool with strain gauge probe at mid calf.

RESULTS

In the baseline examination OOW, the VV increased when changing from a lying to standing position by a median value of +4.8% (IQR 4.4% – 6.1%). EF was normal (i.e., > 60%)[3] in all the volunteers (median value 82%, IQR 70.7% – 89.2%). VV significantly decreased immediately after immersion to −0.2% (IQR −1.9% – 0.1%). (Figs. 3 and 4A). Walking in the pool further decreased the VV to −1.7% (IQR −2.6% – 0.7%) leading to a measurable EF (+68.9%, IQR 39.8% – 155.4%) (Figs. 3 and 4B). IVP was estimated to be 70 mmHg (IQR 68 – 70 mmHg). HP was estimated to be 60 mmHg (IQR 59 – 60 mmHg)

DISCUSSION

This is the first study to demonstrate the feasibility of computerised SGP in UW conditions and its ability to assess leg volume changes and EF. Of note, compression by HP is extremely effective in dramatically reducing VV. Actually, the very small difference between HP and IV leads to almost complete venous occlusion.[4] As bone and soft tissue cannot be modified by a few seconds of immersion, the reduction in limb volume is entirely due to the reduction in VV. Despite this almost complete venous occlusion, UW exercise further increases the blood outflow from the lower leg, making EF measurable.

Study limitations

SGP measures the volume variations of an approximately 1 cm thick slice of the calf and cannot provide data on the volume of the entire leg. However, HP is evenly distributed on all the leg and there is no reason to doubt that it is effective on the entire leg volume. Unfortunately, air plethysmography, which could provide a global evaluation of leg volume, cannot be used in UW conditions because HP would make the air cuff collapse.

CONCLUSION

UW SGP is feasible and allows measurement of VV, EV, and EF during immersion. It showed a significant decrease of VV immediately after entering into the pool, as well as

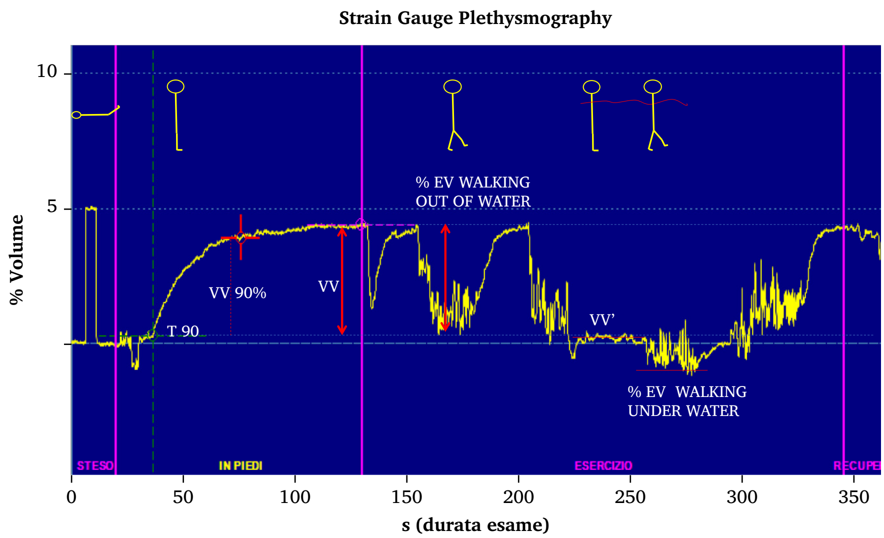
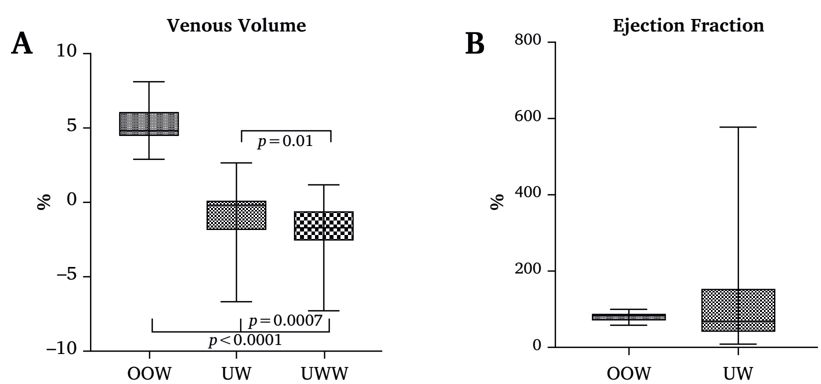


Figure 3. Strain gauge plethysmography tracing. The left part of the curve records the venous volume (VV) increase while standing out of water. VV is the VV calculated out of water (1). From this time on, the patient starts to walk and ejection fraction (EF) out of water is calculated. Then, the patient enters into the swimming pool reaching a new VV′ while standing still in water (2). Subsequently the patient starts to walk and the VV is further decreased (3), showing that movement is still able to expel blood from the leg and to make the EF measurable.



	OOW	UW	UWW
25% Percentile	4.4	−1.9	−2.6
Median	4.8	−0.2	−1.7
75% Percentile	6.1	0.1	−0.7

	OOW	UW
25% Percentile	70.75	39.82
Median	82	68.88
75% Percentile	89.25	155.4

Figure 4. (A) Median values of venous volume (VV) out of water, standing still into the pool, and during movement into the pool. VV significantly decrease in water compared without of water (OOW) and is further reduced by movement. UW = under water; UWW = under water walking. (B) Ejection fraction is normal in baseline conditions out of water and is maintained under water.

maintenance of EV and EF during walking. These findings correlate with the duplex ultrasound findings previously reported.[4] Further studies are necessary to evaluate the possible inclusion of exercises during pool immersion in the rehabilitation protocols of patients with chronic venous disease.[5]

REFERENCES

1 Whitney RJ. The measurement of volume change in human limbs. *J Physiol* 1953;**121**:1—27.

2 Poelkens F, Thijssen DH, Kersten B, Scheurwater H, van Laarhoven EW, Hopman MT. Counteracting venous stasis during acute lower leg immobilization. *Acta Physiol* 2006;**186**:111—8.

3 Mosti G, Partsch H. Measuring venous pumping function by strain-gauge plethysmography. *Int Angiol* 2010;**29**:421—5.

4 Caggiati A, Lattimer C, Kalodiki E, Oberto S, Bergamo G, Kontothanassis D. The Underwater Compression Group. Underwater sonography of leg veins. *EJVES Short Rep* 2018;**41**:13—5.

5 Caggiati A, De Maeseneer M, Cavezzi A, Mosti G, Morrison N. Rehabilitation of patients with venous diseases of the lower limbs: state of the art. *Phlebology* 2018;**33**:663—71.