Optimal intermittent pneumatic compression in lymphedema

Marzanna T. Zaleska, Waldemar L. Olszewski, Mariusz K. Kaczmarek

Central Clinical Hospital, Dept. of General and Vascular Surgery, Mossakowski Medical Research Center, Dept. of Applied Physiology, Polish Academy of Sciences, Warsaw, Casimir the Great University, Dept. of Engineering, Bydgoszcz, Poland

Introduction

Compression therapy for lymphedematous tissues is based on application of force per area of the affected limb.[1,2] This applies to manual drainage, bandaging, stockings and intermittent pneumatic compression (IPC). The knowledge of hydromechanics of the edema fluid in tissues under compression is required for an efficient protocol of application of all these methods. The physical laws of tissue fluid movement are the same irrespective of the used methods. The conditions to be met for proximal movement of edema fluid are: level of exerted force to generate flow, timing sufficient to evacuate excess fluid, tonicity of skin and subcutaneous tissue (hydraulic conductivity). Moreover, sites of accumulation of edema fluid in the limb (distribution of soft tissues, subplantar and popliteal space, inguinal crease resistance) should be taken into account when applying local compression.

In compression procedures the externally applied force is disseminated according to the surface area and is resisted in epidermis by keratinocytes, basal membrane, blood capillaries and lymph in the subepidermal plexus and in dermis by elastic and collagen fibers, fibroblasts and adipocytes, blood vessels, and interstitial fluid between cells and fibers (Figure 1). Moreover, the tissue structure differs at various limb levels.

Aim

To measure the hydromechanics parameters in and under the compressed skin and visualize edema fluid mobilization.

Materials and Methods

Near infra-red indocyanine green (ICG, fluorescence level) and isotopic lymphographies (fluid location and flow, radioactivity level), in-tissue angio contrast medium distribution (tissue channels), and ultrasonography and MRI imaging (Figure 2) (mobile fluid to solid tissue ratio, tissue structure) were applied in 50 patients with obstructive lymphedema of limbs. Skin dielectric constant (water concentration, %), tissue bioimpedance (Ldex index), stiffness measured with durometer (1.25 mm depth, newtons), and deep tissue tonometry (10.0 mm depth, kg/sq.cm), tissue fluid pressure (wick-in-needle method, mmHg), tissue fluid mobilization force test (volume) (Figure 3).[3-6]

Correspondence: Waldemar L. Olszewski, Central Clinical Hospital, Dept. of General and Vascular Surgery and Mossakowski Medical Research Center, Dept. of Applied Physiology, Polish Academy of Sciences, Warsaw, Poland.
E-mail: waldemar.l.olszewski@gmail.com

Acknowledgments: this work was partially supported by the National Science Centre in Poland under grant UMO-2013/11/B/ST8/03589.

Conference presentation: International Compression Club (ICC) Meeting, Rotterdam, 2018.

Veins and Lymphatics 2018; 7:7985
doi:10.4081/vl.2018.7985

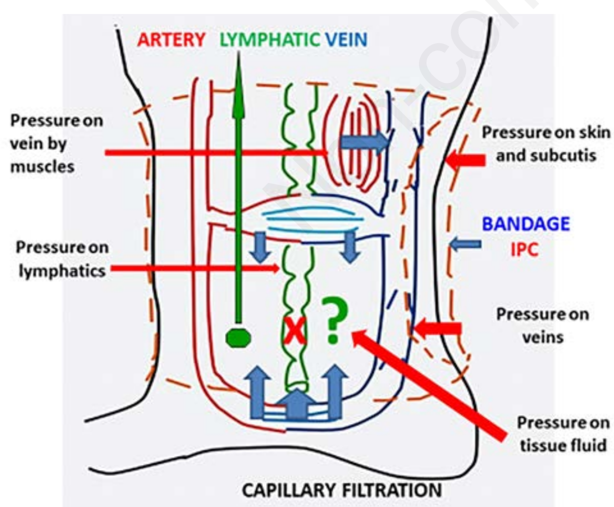

Figure 1. Schematic presentation of leg tissue structures during therapeutic compression and division of applied forces. The compression force is dissipating being absorbed by solid tissue structured and only a portion of it, after deformation of tissue skeleton, can move edema fluid. This points to the necessity to use high compression pressures in order to obtain tissue fluid pressures high enough to overcome the tissue hydraulic resistance.

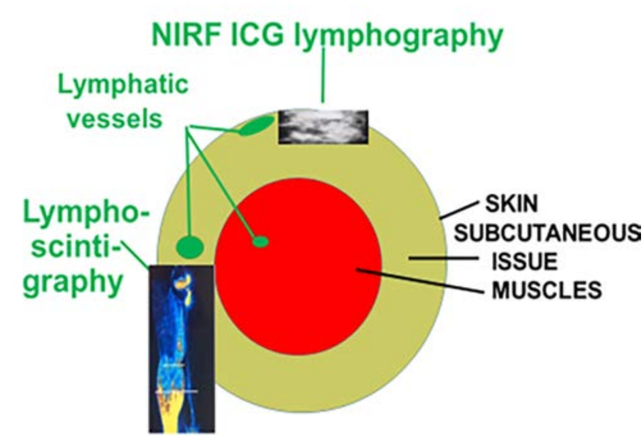

Figure 2. Imaging techniques showing *lymphatic space* (tissue space and lymph vessels lumen/volume), complimentary to each other, in order to obtain full information on edema fluid distribution and movement after compression procedure.

Results

The following results can be summarized: i) tissue fluid pressures were lower than those applied by IPC device; ii) the higher the applied compression force the larger was flow volume; iii) skin stiffness (superficial tonometry) decreased mainly in the calf, whereas, subcutaneous tissue (deep tonometry) was observed at all limb levels; iv) skin water concentration (dielectric constant) was only insignificantly decreased but subcutaneous extracellular water (bioimpedance Ldex index, fluid movement force test) was effectively moved away to limb proximal regions; v) imaging tissue (edema) fluid flow pathways on lymphoscintigrams (Figure 4) and real time flow on NIRF ICG video (Figure 5) could be observed and was evaluated semi-quantitatively (Figure 6).

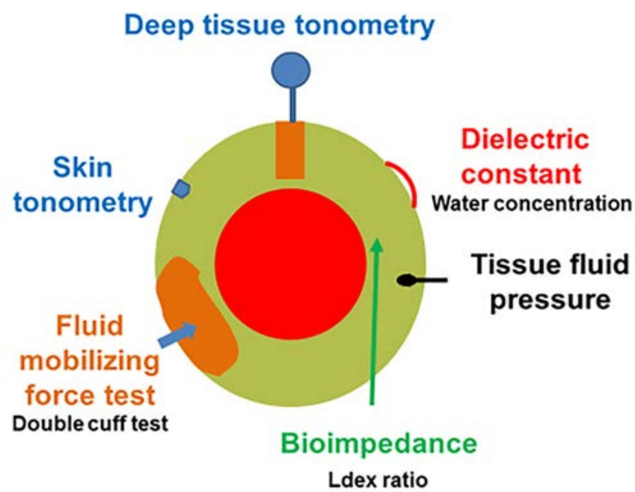

Figure 3. Measurement techniques for evaluation of tissue fluid hydromechanics, complimentary to each other, in order to obtain full information on edema fluid distribution and movement after compression procedure.

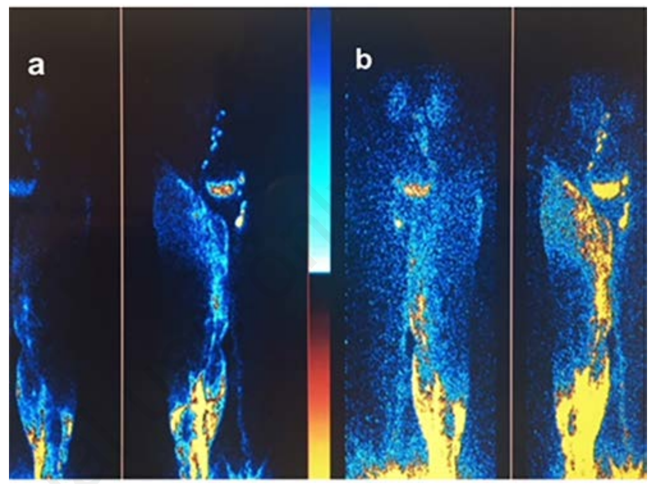

Figure 4. Lymphoscintigram showing relocation of tissue (edema) fluid after IPC therapy for 3 months. A) before therapy - accumulation of tracer in the calf reaching inguinal crease (posterior-anterior view); B) after therapy tracer moved to the thigh and gluteal region. Evidence for effectiveness of IPC method.

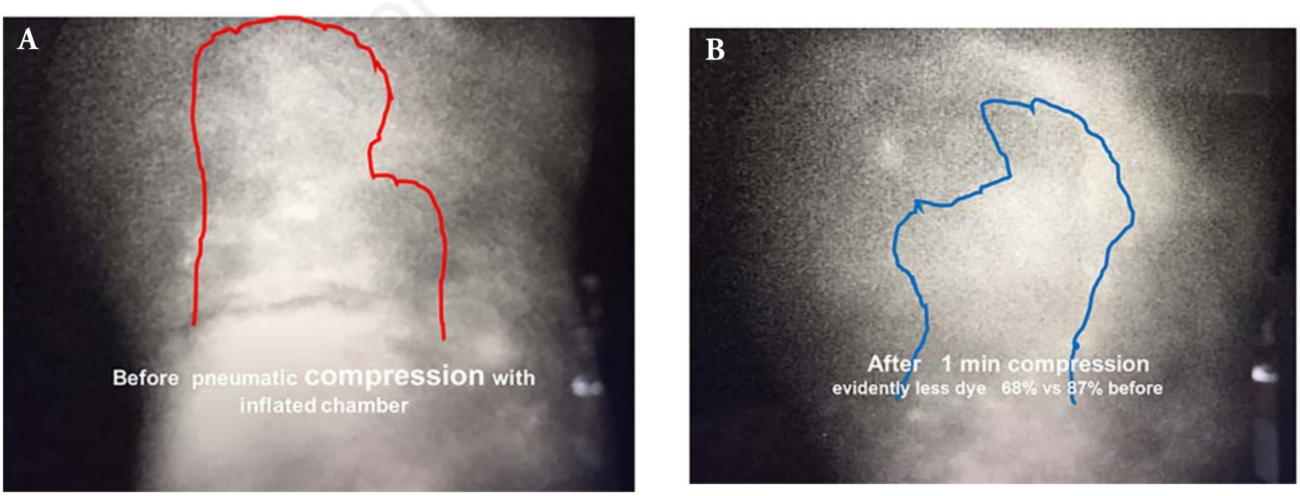

Figure 5. A and B) Indocyanine green near infra-red fluorescence pictures before and after 1 min inflated chamber compression of the calf. This method provides the therapist an actual picture of effectiveness of compression and allows immediate adjustment of pressure/time compression to obtain more fluid evacuation.

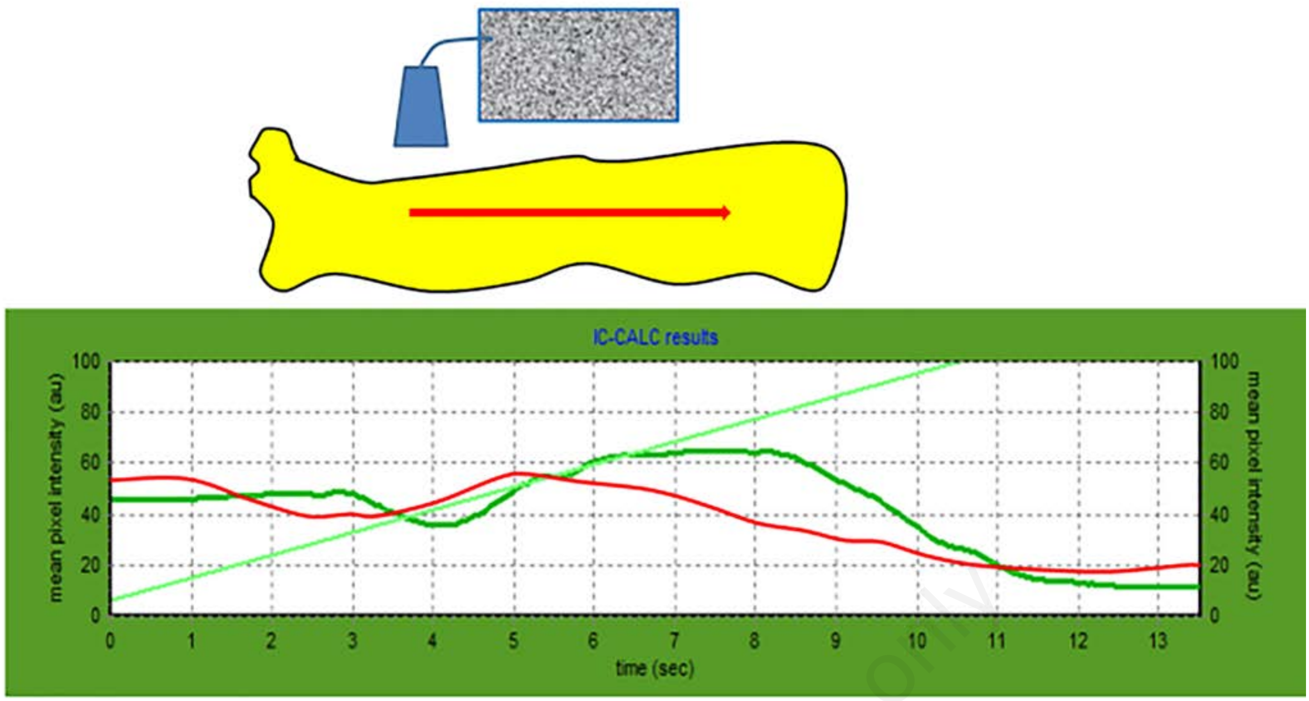

Figure 6. Recording of edema fluid movement under the inflated sleeve during IPC. Camera moving along the limb from foot to groin within 13 sec displaying distribution of fluorescent dye ICG 15 mm deep (image) and showing fluorescence level curve (fluorescence %). Important remain the direction of movement (wave) and the limb level ICG has reached. Red line - before, green line - after a 30 min IPC session, fluid moved from the calf to the thigh.

Conclusions

Adjustment of compression parameters to tissue stiffness, fluid accumulation volumes, and fluid movement ability (hydraulic conductivity of tissues) at various limb levels is indispensable for effective therapy.[7] Redesigning of compression devices will be needed to enable applying differentiated compression pressures and prolonged timings at various limb levels.

References

1. Zaleska M, Olszewski WL, Jain P, et al. Pressures and timing of intermittent pneumatic compression devices for efficient tissue fluid and lymph flow in limbs with lymphedema. Lymphat Res Biol 2013;11:227-32.
2. Rockson SG. Accruing evidence for a beneficial role of pneumatic biocompression in lymphedema. Lymphat Res Biol 2010;8:3-4.
3. Lahtinen T, Seppälä J, Viren T, Johansson K. Experimental and analytical comparisons of tissue dielectric constant (TDC) and bioimpedance spectroscopy (BIS) in assessment of early arm lymphedema in breast cancer patients after axillary surgery and radiotherapy. Lymphat Res Biol 2015;13:176-85.
4. Sun D, Yu Z, Chen J, et al. The value of using a SkinFibroMeter for diagnosis and assessment of secondary lymphedema and associated fibrosis of lower limb skin. Lymphat Res Biol 2017;15:70-6.
5. Zaleska MT, Olszewski WL, Durlik M, et al. Tonometry of deep tissues for setting effective compression pressures in lymphedema of limbs. Lymphat Res Biol 2017 [Epub ahead of print].
6. Zaleska MT, Olszewski WL. Indocyanine green near-infrared lymphangiography for evaluation of effectiveness of edema fluid flow under therapeutic compression. J Biophotonics 2017 [Epub ahead of print].
7. Zaleska M, Olszewski WL, Durlik M. The effectiveness of intermittent pneumatic compression in long-term therapy of lymphedema of lower limbs. Lymphat Res Biol 2014;12:103-9.