Effect of Lower Body Positive Pressure on Fluid Turnover in Human Legs

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We have developed a device for walking rehabilitation which has a treadmill in a lower body positive pressure (LBPP) chamber to unload the lower extremities. In this review, we summarize the present knowledge of effects of gravity, LBPP, and walking on leg fluid turnover in standing human. Prolonged standing caused swelling in the legs due to an effect of hydrostatic pressure. Circumferences of leg gradually increased during standing still and reached a plateau level after 30-40 minutes. Exposure to LBPP significantly improved the swelling in the thigh, suggesting that the LBPP possibly reduces fluid filtration by decreasing transmural pressure gradient in the capillaries and/or increases lymphatic outflow from the tissue. Walking also decreased the leg swelling by muscle pump activity, and this effect was further enhanced by applying LBPP. These results suggest that applying LBPP can change the body fluid turnover, resulting in a decrease in the tissue fluid of the legs in standing and walking human.

Key Words: Lower Body Positive Pressure, Walking, Rehabilitation, Fluid Turnover, Leg Circumference

1. Introduction

Many patients after orthopedic surgery or stroke have difficulty in walking due to muscle weakness, partial paralysis and/or leg pain. Various devices for gait training including canes, walkers, parallel bars and suspension harnesses are used for unloading the lower extremities during walking rehabilitation. Their main objective is to start rehabilitation as early as possible. Hargens and his colleagues reported that applying lower body positive pressure (LBPP) could reduce ground reaction force (GRF), or apparent body weight, in upright human.

The device not only reduces GRF, but also possibly affects body fluid turnover in the legs because applying LBPP around the legs may decrease capillary filtration rate and/or increase lymph drainage from the tissues. In this paper, we discuss usefulness of our device and influence of LBPP on fluid turnover in the lower extremities of standing and walking human.

2. LBPP Device for Walking Rehabilitation

Figure 1 shows our device reported previously. The device has a treadmill in a LBPP chamber made of nylon sheet (Showa Denki Co. Ltd., Japan). Subjects wear a waist seal with running pants and enter into the chamber through a steel ring (60 cm diameter) on the top of the chamber as shown in Fig.1. The waist seal fastens over a lip of the ring and covers the ring hole. Height of the ring is adjustable and fixed to the level of the anterior superior iliac spine of the subjects. They can walk on the treadmill at a speed up to 8 km/h. The pressure inside the LBPP chamber can be adjusted between 0 mmHg and 22.5 mmHg above atmospheric pressure by controlling the airflow using a blower. Applying the positive pressure bulges the chamber and the waist seal, and then elicits buoyancy which decreases the GRF of subjects. We tested the relationship between the level of LBPP and the net GRF. The net GRF decreased in a linear manner during graded application of LBPP. The slope of the regression line was -2.2 kgw/mmHg. The reduction of GRF is greater than that of other device because the ring size of our device is bigger than that.

Subjects who need walking rehabilitation are generally elderly patients. A potential risk of cardiovascular events typically increases with advancing age. Therefore, safety assessments of the rehabilitation device are necessary. Our LBPP chamber can effectively unload with relatively low level of LBPP compared to other device. Also our previous data showed that LBPP did not significantly change the local...
and systemic circulation\textsuperscript{1)}, suggesting a low risk of undesirable cardiovascular side effects. Therefore, our LBPP device will be a safe and useful tool for clinical use.

3. Gravity and Fluid Turnover in the Legs

Standing still causes leg swelling, which is produced by fluid leakage from the capillary into the interstitial spaces\textsuperscript{4}). Chester and colleagues\textsuperscript{5)} showed that the calf circumference increased by 1.7 % after standing for 90 minutes. In our previous study, it increased by 1.8 % and reached nearly plateau after 30- to 40-minutes standing\textsuperscript{3}). Starling force explains fluid shifts between interstitial spaces and capillary fluid. Capillary filtration rate can be expressed as

\begin{equation}
Filtration = K_f \times \left(P_c - P_i - \pi_c + \pi_i\right)
\end{equation}

where $K_f$ is the capillary filtration coefficient, $P_c$ is the capillary hydrostatic pressure, $P_i$ is the interstitial hydrostatic pressure, $\pi_c$ is the capillary plasma colloid oncotic pressure, and $\pi_i$ is the interstitial oncotic pressure\textsuperscript{4}). The equation (1) indicates that a rise in the capillary hydrostatic pressure due to gravitational force increases the capillary filtration\textsuperscript{6}). A part of the fluid that is filtered out of the capillary is reabsorbed into the venous end of the capillary. The remaining fluid (net filtration) returns to the circulation though the lymphatic outflow\textsuperscript{4}). For the reasons mentioned above, when the net filtration increases and/or lymphatic outflow decreases in the lower extremities, the interstitial fluid increases. In addition, muscle pump activity elicited by walking or cycling affects fluid turnover in the legs of upright human\textsuperscript{6}). Muscle contraction during leg movement propels the blood in the vein toward the heart, which lowers the venous pressure\textsuperscript{5}). Then, capillary hydrostatic pressure drops, which in turn decreases fluid in the interstitial space.

4. Effect of LBPP on Leg Swelling

We discuss here the effect of LBPP on swelling in the legs of upright human. We examined changes in the leg circumference after 10 minutes of LBPP at 15 mmHg\textsuperscript{3}). Circumferences of the thigh decreased significantly after the exposure to LBPP, suggesting that the tissue fluid in the legs decreased. In the present study, we showed that walking can also shorten the circumference in the legs, and that the decrease in the circumference was greater in walking subjects with LBPP than those without LBPP. Taylor and colleagues reported the relationship between interstitial fluid pressure and lymphatic flow in the dog legs\textsuperscript{7}). They demonstrated that the lymphatic flow increased more than 20-fold as the pressure rises from -6 to 0 mmHg (atmospheric pressure). Thus, if an application of LBPP raises the interstitial pressure, lymphatic flow will increase markedly. Accordingly the decrease in the tissue fluid during LBPP is probably attributable to an increase in lymphatic outflow and/or to a decrease of the capillary filtration, the mechanism of which is different from muscle pump activity during walking\textsuperscript{6}). These results suggest that applying LBPP and walking respectively prevent gravity-induced leg swelling in upright human. LBPP will provide a useful tool for walk-training in elderly people and/or patients especially with edema in the legs.

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References