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Intramuscular Pressures Beneath Elastic and Inelastic Leggings

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Leg compression devices have been used extensively by patients to combat chronic venous insufficiency and by astronauts to counteract orthostatic intolerance following spaceflight. However, the effects of elastic and inelastic leggings on the calf muscle pump have not been compared. The purpose of this study was to compare in normal subjects the effects of elastic and inelastic compression on leg intramuscular pressure (IMP), an objective index of calf muscle pump function. IMP in soleus and tibialis anterior muscles was measured with transducer-tipped catheters. Surface compression between each legging and the skin was recorded with an air bladder. Subjects were studied under three conditions: (1) control (no legging), (2) elastic legging, and (3) inelastic legging. Pressure data were recorded for each condition during recumbency, sitting, standing, walking, and running. Elastic leggings applied significantly greater surface compression during recumbency (20 ± 1 mm Hg, mean $\pm$ SE) than inelastic leggings (13 ± 2 mm Hg). During recumbency, elastic leggings produced significantly higher soleus IMP of 25 ± 1 mm Hg and tibialis anterior IMP of 28 ± 1 mm Hg compared to 17 ± 1 mm Hg and 20 ± 2 mm Hg, respectively, generated by inelastic leggings and 8 ± 1 mm Hg and 11 ± 1 mm Hg, respectively, without leggings. During sitting, walking, and running, however, peak IMPs generated in the muscular compartments by elastic and inelastic leggings were similar. Our results suggest that elastic leg compression applied over a long period in the recumbent posture may impede microcirculation and jeopardize tissue viability. On the other hand, inelastic leggings do not compress leg tissues at levels above 20 mm Hg during recumbency. Therefore inelastic leggings may be more effective in improving venous circulation in the legs of patients with chronic venous insufficiency. (*Ann Vasc Surg* 1994;8:543-548.)

Chronic venous insufficiency is caused by venous reflux, venous obstruction, and/or decompensation of the calf muscle pump. Patients with incompetent or genetically absent venous valves suffer from severe orthostatic intolerance.¹ Astronauts also commonly experience orthostatic intolerance following spaceflight, which may be due

in part to microgravity-induced hypovolemia,² decreased baroreflex responsiveness,³ reduced skeletal muscle tone,⁴ increased venous compliance,^{5,6} and subsequent venous pooling in the lower body during return to earth. To improve peripheral circulation and ameliorate orthostatic tolerance in astronauts returning from spaceflight as well as in patients suffering from venous insufficiencies, countermeasures are essential. Leg compression devices can potentially reduce lower body intra- and extravascular fluid accumulation and improve orthostatic tolerance by increasing intramuscular pressure (IMP) and thereby assisting the musculovenous pump. Clinically, leg compression with elastic⁷ and inelastic leggings⁸ has been used to combat venous stasis and to treat venous insufficiency. To our knowledge, information regarding IMP beneath leg compression devices is

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lacking. Therefore the purpose of our study was to compare IMP produced by elastic and inelastic compression leggings during postural changes and during walking and running activities.

Upon moving from upright to recumbent posture, blood shifts out of the legs toward the thorax causing a reduction in calf volume. An elastic legging will continue to exert compression as calf volume decreases whereas a noncompliant (inelastic) legging will not. Thus we hypothesized that an elastic legging generates higher IMP than an inelastic legging in recumbent posture. Exercise-induced muscle contraction increases calf girth. An increase in calf girth within a noncompliant legging should generate higher IMP compared to that produced by a compliant legging. Therefore we also hypothesized that an inelastic legging produces higher IMP oscillations (peak-to-peak amplitude of muscle contraction and relaxation pressures) than an elastic legging during walking and running.

MATERIAL AND METHODS

Subjects

Eleven volunteers (age 31 ± 8 years, weight 68 ± 13 kg, height 170 ± 10 cm; means $\pm$ SD) participated in the study after giving informed written consent. All subjects were in good health as determined by a comprehensive medical examination. Subjects maintained their normal daily activities and refrained from caffeine, alcohol, medications, and strenuous exercise for 24 hours before and during the study. The investigation was approved by the Human Research Experiments Review Board at the NASA Ames Research Center.

Experimental protocol

Prior to muscle catheterization, subjects determined comfortable walking (1.2 ± 0.2 m/sec, mean $\pm$ SD) and running (2.8 ± 0.5 m/sec, mean $\pm$ SD) speeds on a treadmill. IMPs in the soleus and the tibialis anterior were measured with 3 F transducer-tipped Millar catheters (Millar Instruments, Houston, Tex.). Catheters were inserted into the soleus and the tibialis anterior of the left leg in each subject. Under local anesthesia (1.5 ml lidocaine) a 16-gauge, 5.7 cm needle within a Teflon cannula was inserted through the skin at an angle of approximately 30 degrees. After the muscle fascia was punctured, the needle tip was withdrawn into the outer Teflon cannula. The needle and cannula were then bluntly inserted 4 to 5 cm into the muscle to

reduce tissue damage and bleeding. The needle was completely retracted and the transducer-tipped catheter was introduced through the cannula with the pressure sensor facing toward the skin. The Teflon cannula was then withdrawn completely and the catheter was secured in place. Proper placement and function of catheters were confirmed by palpation over the catheter tip and ankle plantar flexion (soleus activation) and dorsiflexion (tibialis anterior activation).

Following catheterization each subject had data recorded in recumbent, seated, and standing postures as well as during walking and running on a treadmill at predetermined speeds. Subjects remained in each posture for 30 seconds prior to data collection; they walked and ran for 1 minute prior to data collection. Pilot studies indicated that those times were adequate for IMP responses to stabilize in each condition. For each legging two levels of compression were applied. Two different elastic leggings (Sigvaris Inc., Branford, Conn.) were worn to provide 20 to 30 mm Hg (level 1) and 30 to 40 mm Hg (level 2) graded compression, with the highest compression at the ankle and the lowest at the knee. The inelastic legging (CircAid Medical Products, Inc., Rumson, N.J.) is adjustable and was tightened to provide 20 mm Hg (level 1) and 30 mm Hg (level 2) compression. The leggings were all applied in the standing posture and in random order. An air bladder was placed over the midcalf position in every subject to measure pressure generated by the leggings. Control data were collected before and after stocking applications.

IMPs in the soleus and the tibialis anterior were recorded on a computer data acquisition system (DAS 20 board, Metrabyte, Taunton, Mass., and Labtech Notebook, Laboratory Technologies Corp., Wilmington, Mass.). Peak, mean, and oscillatory IMPs of the soleus and the tibialis anterior were analyzed for 30 seconds during recumbent, seated, and standing postures and for 15 seconds during walking and running. Data presented for elastic and inelastic tibialis anterior IMPs during running were from 10 subjects only. Data were analyzed using repeated-measures analysis of variance followed by paired *t* tests with significance set at $p < 0.05$. Means $\pm$ SE are reported for all variables.

RESULTS

Table I provides IMP data recorded at each posture and during walking and running without any leg compression. Tables II and III show external calf compression and IMP in the soleus and

the tibialis anterior, as generated by elastic and inelastic leggings, levels 1 and 2, respectively. In the recumbent posture the elastic legging exerts significantly higher compression ($p < 0.05$) as compared with the inelastic legging at both compression levels. Consequently IMPs generated by elastic leggings within the soleus and the tibialis anterior are higher than those produced by inelastic leggings. Although elastic leggings are manufactured to exert two different pressures on the legs for each level of compression, our data indicate that pressure exerted by level 1 compression (19 ± 1 mm Hg) was not significantly different from that applied by level 2 (23 ± 1 mm Hg) compression. Because the inelastic leggings were adjusted during standing to match the standing elastic legging compression, IMPs generated by leggings were similar in the standing posture. During seated posture there was no difference in either the applied compression or the IMP in the soleus and the tibialis anterior produced by either legging at both levels. During walking (Fig. 1) and running (Fig. 2) the IMP oscillations (difference between peak and relaxation pressures) produced in the soleus and the tibialis anterior were similar regardless of legging type or level.

DISCUSSION

During recumbency elastic leggings compress underlying tissues of the leg to a significantly greater degree than inelastic leggings. Calf volume decreases up to 1.5% in the recumbent posture compared to quiet standing.⁹ Despite the reduction in calf volume, the elastic legging continues to apply compression and to elevate IMP because of its compliant nature. A study by Nehler et al.¹⁰ suggests that elevated subcutaneous pressures induced by elastic leggings aid in preventing leg edema in patients with chronic venous insufficiency by promoting resorption of extracellular fluids and diffusion of oxygen and nutrients from the capillaries to the subcutaneous tissue. However, it is important to note that if applied compression exceeds that of the venule pressure so as to impede venular outflow, local tissue perfusion and therefore nutrient exchange may be seriously compromised.

Elastic leggings generate IMPs higher than 20 mm Hg in the soleus and the tibialis anterior muscles; 20 mm Hg leg IMP during recumbency in the absence of a higher blood pressure associated with upright posture impairs venular outflow and therefore decreases local perfusion.¹¹ Furthermore, Reneman et al.¹² demonstrated in rabbits

that when an external positive pressure of only 25 mm Hg is applied to a resting muscle the veins within it are completely collapsed. Our findings suggest that application of an elastic legging during recumbency may compromise microcirculation and risk soft tissue function and viability beneath the legging. Therefore patients should probably be discouraged from lying down with elastic leggings on for long periods of time. In contrast, inelastic leggings impose no such limitations.

During walking and running IMP oscillations, an index of muscle pump function, produced by either elastic or inelastic leggings were similar to those generated without any leggings. This result refutes our second hypothesis and indicates that externally applied compression during dynamic exercise does not significantly enhance muscle pump function in normal persons. Furthermore, there was no significant difference in IMPs produced during locomotion by either elastic or inelastic leggings. Static isometric muscle contraction increases calf girth, yet previous studies indicate that calf volume is decreased by 10% during 10 minutes of cycle ergometer work.⁹ This decrease is attributed to a reduction of venous pressure caused by the muscle pump action and to increased IMP, which limits capillary fluid filtration.⁹ Our data suggest lower peak IMP production by inelastic leggings at both levels of compression during walking and running compared with elastic leggings, indicating that calf volume may have decreased during the first few seconds of exercise. If exercise increased IMP and calf volume, then IMPs generated within the inelastic legging should have been higher than those within the elastic legging.

Our data also indicate that there is no difference between level 1 and level 2 elastic compression of leg muscles in normal subjects. Similarly, Nehler et al.¹⁰ documented no significant difference in subcutaneous tissue pressures produced by level 1 and level 2 elastic compression both in normal subjects and in patients with chronic venous insufficiency. Therefore no physiologic basis exists for prescribing level 1 vs. level 2 elastic leggings.

CONCLUSION

The elastic legging applies significantly greater pressure than the inelastic legging in the recumbent posture. High compression pressures along with reduced leg blood pressure associated with supine posture will impede blood flow in the

capillaries and venules and thereby jeopardize regional tissue perfusion and viability. This work constitutes a baseline study in normal subjects to provide a basis for future studies in patients who use leggings as therapy for chronic venous insufficiency of the lower extremities.

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Table I. IMP without leggings (control values)

Condition	Soleus (mm Hg)	Tibialis anterior (mm Hg)
Supine	8 ± 1	11 ± 1
Seated	5 ± 1	9 ± 2
Standing	37 ± 5	35 ± 3
Walking		
Contraction	152 ± 26	84 ± 12
Oscillation	161 ± 29	83 ± 9
Running		
Contraction	226 ± 36	145 ± 19
Oscillation	242 ± 35	153 ± 19

Table II. IMP and compression applied by level 1 elastic and inelastic leggings

Condition	Elastic legging			Inelastic legging		
	Soleus (mm Hg)	Tibialis anterior (mm Hg)	External compression (mm Hg)	Soleus (mm Hg)	Tibialis anterior (mm Hg)	External compression (mm Hg)
Supine	21 ± 1*	25 ± 1*	16 ± 1*	14 ± 1	8 ± 1	8 ± 1
Seated	25 ± 1	29 ± 1	16 ± 1	23 ± 1	27 ± 2	14 ± 1
Standing	56 ± 5	48 ± 2	19 ± 1	49 ± 5	45 ± 2	17 ± 1
Walking						
Contraction	162 ± 25	95 ± 11	23 ± 1	156 ± 24	91 ± 10	15 ± 1
Oscillation	153 ± 25	79 ± 10	11 ± 1	154 ± 23	81 ± 8	13 ± 1
Running						
Contraction	254 ± 35	144 ± 19	24 ± 1	241 ± 33	149 ± 17	23 ± 2
Oscillation	263 ± 33	145 ± 21	13 ± 1	247 ± 31	152 ± 17	20 ± 1

*Significantly higher than inelastic legging ($p < 0.05$).

Table III. IMP and compression applied by level 2 elastic and inelastic leggings

Condition	Elastic legging			Inelastic legging		
	Soleus (mm Hg)	Tibialis anterior (mm Hg)	External compression (mm Hg)	Soleus (mm Hg)	Tibialis anterior (mm Hg)	External compression (mm Hg)
Supine	25 ± 1*	28 ± 1*	20 ± 1*	17 ± 1	20 ± 2	13 ± 2
Seated	28 ± 1	31 ± 1	20 ± 1	27 ± 1	31 ± 1	20 ± 1
Standing	55 ± 6	50 ± 3	23 ± 1	55 ± 3	53 ± 2	28 ± 1
Walking						
Contraction	174 ± 27	98 ± 10	26 ± 1	159 ± 26	95 ± 11	26 ± 2
Oscillation	164 ± 25	78 ± 9	11 ± 1	155 ± 24	78 ± 9	19 ± 1†
Running						
Contraction	245 ± 32	137 ± 16	29 ± 1	249 ± 38	148 ± 17	37 ± 3†
Oscillation	245 ± 30	140 ± 17	14 ± 1	256 ± 36	169 ± 22	27 ± 2†

*Significantly higher than inelastic legging ($p < 0.05$).

†Significantly higher than elastic legging ($p < 0.05$).

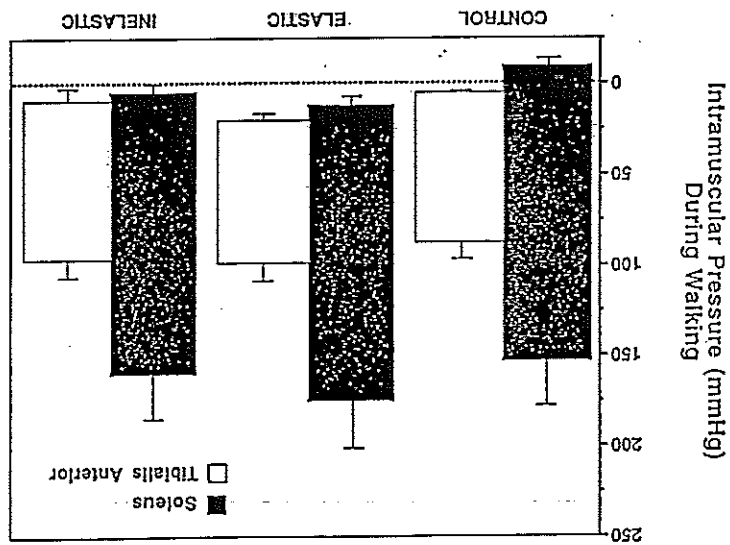


Fig. 1. IMPs (peak pressure at top and relaxation pressure at bottom of each bar) produced in the soleus and the tibialis anterior during walking. IMP oscillation, an index of muscle pump function, is similar under all three conditions.

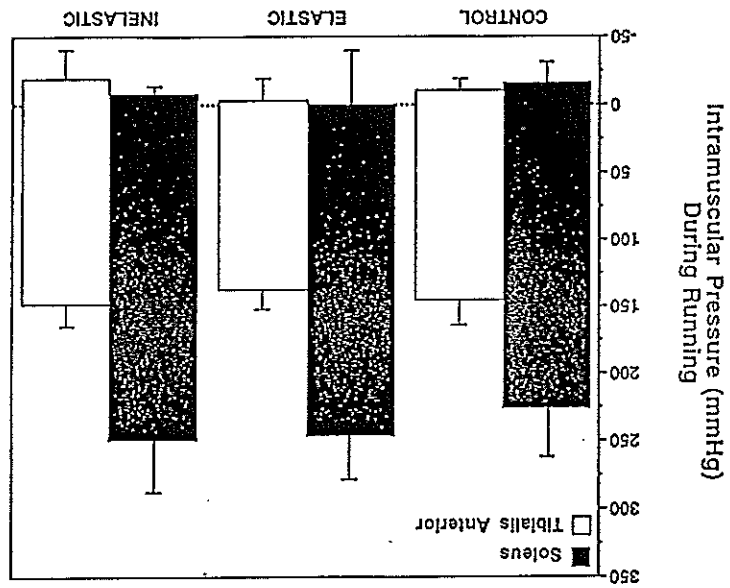


Fig. 2. IMPs (peak pressure at top and relaxation pressure at bottom of each bar) produced in the soleus and the tibialis anterior during running. IMP oscillation, an index of muscle pump function, is similar under all three conditions.