Evaluation of the Effects of Compression Stockings Using Venous Plethysmography in Persons With Spinal Cord Injury

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Abstract

Background/Objective: To examine the effect of graduated compression stockings (GCS) on the properties of the venous vascular system, as characterized by venous capacitance (VC) and venous outflow (VO), in the lower extremities of individuals with spinal cord injury (SCI), according to injury level.

Methods: Nine male subjects with SCI (5 with low paraplegia [LP], 4 with high paraplegia [HP]) performed 2 plethysmography tests: with and without graduated compression knee-length stockings (pressure of 21 mm/Hg). The VC, VO, and cardiovascular parameters (heart rate and blood pressure) were evaluated with and without GCS.

Results: The VC and VO were lower in patients with HP than in those with LP. For all subjects, VC was significantly lower (−14%) with GCS than without (1.77 ± 1.18 vs 1.53 ± 1.09 vol%, $P < 0.01$). On the contrary, VO did not differ significantly when wearing or not wearing GCS.

Conclusions: This study demonstrated that 21-mm/Hg knee-length GCS are sufficient to prevent venous distension in individuals with SCI, even those with longstanding paraplegia, by significantly decreasing venous capacitance. This intervention may help to prevent deep vein thrombosis.

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Key Words: Spinal cord injuries; Paraplegia; Venous stasis; Compression stockings; Plethysmography

INTRODUCTION

Elastic compression stockings are typically used in physical medicine and rehabilitation to support the blood circulation in individuals with spinal cord injury (SCI) (1). Improvement of lower-extremity circulation is a desirable goal in the acute, as well as in the long-term, management of SCI. Motor and sensitive deficiencies of the lower limbs in SCI affect lower-extremity circulation and lead to venous pooling (2). Several investigators have reported various characteristics of diminished lower-extremity blood flow and general circulatory dysfunction in survivors of chronic SCI: reduced arterial diameter size (3), reduced blood flow (2,4,5), decreased vascular reactivity (3), and increased vascular resistance (6). Finally, venous competence with complete SCI manifests

by decreased venous capacity and distensibility (4). Venous emptying rate was significantly lower (−60%) and, hence, venous flow resistance was significantly higher (+75%) than for able-bodied individuals (4).

Measures to combat blood stasis, increase venous distensibility, and decrease flow resistance are required and can be provided in part by compression therapy (7). It has been demonstrated that graduated compression stockings (GCS) improve venous hemodynamics. The GCS work by increasing the ejection fraction, decreasing reflux and reducing the residual volume fraction, and heightening the linear velocity of venous outflow, which prevents stasis and venous distension and enhances emptying of the valvular cusps (8). Although the effect of limb compression on venous return seems to be well established in pathological populations, its effects on venous hemodynamics in SCI remain not well documented. The beneficial effects of elastic stockings on venous hemodynamics have been evaluated with various methods, including ambulatory venous pressure measurements (9), strain-gauge plethysmography (10), foot volumetry (11), photo-plethysmography (12), isotope clearance (13), and air-plethysmography (14). Among these methods, strain-gauge plethysmography is a

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simple, noninvasive, and sensitive method to identify limbs with suspected venous incompetence and was often employed to evaluate peripheral circulation in SCI (4,6,15–17) or to measure the effects of GCS in healthy subjects or subjects with chronic venous insufficiency (18). However, this method was never employed to evaluate venous hemodynamic in SCI while wearing GCS, whereas this prevention therapy is commonly prescribed. The purposes of this study were therefore to examine the properties of the venous vascular system, as characterized by venous volume variation and venous emptying rate, in the lower extremities of individuals with SCI and to evaluate the effect of knee-length compression stockings usually prescribed in this population.

METHODS

Participants

Nine men with traumatic SCI participated in this study. Written informed consent was obtained from each participant, and the protocol was approved by the institutional Ethics Committee. All participants were at least 2 years postinjury and underwent a preparticipation medical examination, including medical history, screening questionnaire, and cardiac and pulmonary auscultation, as well as neurological assessment. None of the participants had cardiovascular, pulmonary, or metabolic diseases or took medications likely to interfere with the cardiovascular system or to affect the study results. Individuals with a history of phlebitis, venous insufficiency, deep venous thrombosis (DVT), or lower-extremity trauma were also excluded. Their anthropometric and neurological characteristics are reported in Table 1.

Participants were separated into 2 groups according to the level of injury: one group of 4 individuals with high paraplegia (HP) with neurological lesion levels between T4 and T6, and one group of 5 individuals with low paraplegia (LP) with neurological lesion levels between T10 and L1. This subdivision was based on the rationale that the sympathetic innervation of the lower limbs is achieved by nerve fibers emerging between levels T10 and L2. Thus, the HP subjects had no sympathetic control in their legs from higher brain centers, whereas the LP subjects had at least partially intact sympathetic innervation of their lower limbs. Neurological data were obtained at the time of the evaluation using the standards of the American Spinal Injury Association. No significant differences in age, weight, height, activity level, or time of injury were evident between the two groups.

Protocol

All participants performed 2 plethysmography tests. One test was done with GCS and the other without. The GCS were microfiber tights with grip-top graduated compression knee-length stockings (Olympique, Tournier-Bottu S.A., Gibaud Products, Saint-Etienne, France). The stockings were knitted to create the greatest amount of elastic pressure at the ankle, with pressure decreasing up

the leg. Pressure levels generated by the stockings varied from 21 mm/Hg (at the ankle) to 15 mm/Hg (at the top of the calf). The size worn was adapted to the ankle, calf, and thigh circumferences of the participants. The tests were assigned in random order under a counter-balanced design and were conducted the same day, 1 hour apart.

For all participants, the last meal was taken 2 hours before the test. At least 8 hours prior to each test, the subjects refrained from caffeine, alcohol, and nicotine, and were asked to avoid vigorous activity for 24 hours before the tests. Room temperature was controlled between 21 and 23°C. Subjects emptied their bladder 1 hour before the test to minimize the possible affect of any sympathetic activity on the peripheral vascular tone as a consequence of bladder filling.

A venous occlusion plethysmography test was performed with a Diadop 300 PC plethysmograph (Diatecnic, Labège, France). This technique was chosen because it is a noninvasive technique for the measurement of limb blood flow and the detection of venous thrombosis (15–17). A pneumatic cuff encircling a limb was inflated to a pressure high enough to occlude the veins underneath the cuff, causing blood to pool within the limb distal to the cuff. Two mercury-in-rubber strain gauges were positioned at maximal calf circumference and detected change in limb blood volume from unimpeded arterial inflow while venous outflow was stopped. As the strain gauge stretched, the electrical resistance increased proportionally to the increase in calf circumference, reflecting the change in calf volume (17). This change was recorded until a steady state was reached. The information obtained was used to calculate the venous capacitance (VC), which reflects the ability of the veins to distend and fill. The cuff was then deflated, allowing the pooled blood to flow back out of the limb. The decrease in calf volume was recorded and used to calculate the venous outflow (VO), which reflects the ability of the veins to empty.

Participants rested in a supine position for 15 minutes prior to testing. During this period, ankle, calf, and thigh circumferences were measured at the thickest part while the muscles were relaxed, and adapted stockings were worn according to randomization. The left leg was elevated and supported horizontally with the foot approximately at the level of the heart. Experiment pressure cuffs were placed on the leg at midthigh, centimeters proximal to the popliteal vein, and strain gauges were positioned.

Venous occlusion was performed by rapidly inflating the thigh cuff (within 2 seconds) to a pressure of 60 mm/Hg, which compresses the venous system but leaves the arterial system open. After stabilization of the congested limb, a plateau was established, and the cuff was instantly deflated (within 0.3 seconds).

Before testing, blood pressure was measured manually with a standard sphygmomanometer.

Table 1. Anthropometric and Neurological Characteristics of Study Participants

Patients	Age (y)	Weight (kg)	Height (cm)	ASIA Score	Lesion	Injury Level	Time Since Injury (y)	Tonus	Practice
LP Group									
Patient 1	53	58.0	175	A	Complete	T12	34	Flaccid	Basketball
Patient 2	33	75.0	184	A	Complete	T10	14	Spastic	Basketball
Patient 3	25	82.0	177	A	Complete	L1	9	Flaccid	Basketball
Patient 4	24	60.0	170	A	Complete	T12	4	Flaccid	Skiing
Patient 4	31	63.5	179	B	Incomplete	L1	2	Flaccid	Swimming
Mean $\pm$ SD	33.2 $\pm$ 11.7	67.7 $\pm$ 10.4	177 $\pm$ 5				12.6 $\pm$ 12.8		
HP Group									
Patient 1	27	63	175	A	Complete	T5	4	Spastic	Basketball
Patient 2	34	61	176	A	Complete	T5	9	Flaccid	Racing
Patient 3	27	105	181	A	Complete	T5	10	Spastic	None
Patient 4	41	68.7	185	A	Complete	T4	22	Spastic	Basketball
Mean $\pm$ SD	32.3 $\pm$ 6.7	73.3 $\pm$ 24.8	179 $\pm$ 5				11.3		
Total Mean $\pm$ SD	32.8 $\pm$ 9.3	70.7 $\pm$ 15.0	178 $\pm$ 5				12.0 $\pm$ 10.2		

Statistical Analysis

Values are given as the mean plus or minus the standard deviation. The 2 groups were compared using the Mann-Whitney *U* test for nonparametric independent data. The Wilcoxon rank sum test for paired random data was used to determine differences between the 2 tests, with and without GCS. The level of significance was set at $P < 0.05$.

RESULTS

No significant differences were observed in resting heart rate and blood pressure for either group or either experiment (Table 2).

Plethysmography recordings are reported in Table 3. Concerning the level of spinal cord lesion: VC and VO were lower in HP patients than in those with LP, but there was a statistically significant difference between the 2 groups only in VC when wearing GCS ($P < 0.05$).

Concerning the effect of GCS: in the LP and HP groups, VC values were lower with GCS than without (-7% and -27% respectively), but without significant differences. However, with taking account of all subjects, whatever the level of injury, VC was significantly lower (-14%) with GCS than without (1.77 ± 1.18 vol% vs 1.53 ± 1.09 vol%, $P < 0.01$). On the contrary, VO did not differ significantly when wearing or not wearing GCS, for LP participants, HP participants, or all participants taken together.

DISCUSSION

Elastic compression stockings are typically used during acute rehabilitation after spinal cord lesion to prevent DVT and to contribute to cardiovascular adaptations. No studies were found that quantified lower-extremity blood flow changes in individuals with SCI at rest without GCS and while wearing GCS. This report examined the effect of GCS on VC and VO in individuals with SCI by means of strain-gauge plethysmography.

Influence of Injury Level

Our results confirm low VC and VO in individuals with SCI compared with able-bodied individuals, as showed in previous studies. For Hopman et al (4), venous volume variation, venous capacity, and venous emptying rate are significantly lower in paraplegics compared with able-bodied subjects, -45% , -50% , and -60% , respectively. For Frieden et al (17) subjects with SCI have an average maximum VO (32.5 ± 2.57 mL/min/100mL) and an average VC (2.3 ± 0.17 mL/100mL) statistically lower than those in the able-bodied group. In accordance with Hopman et al (4), two explanations are proposed. First, this is due to the sympathetic denervation below the lesion, the damage to the sympathetic vascular muscle innervation, and the absence of muscle pump action. All these factors result in a continuously dilated venous system, which causes venous pooling in the legs. Consequently, the venous system will have less space left for blood to accumulate, and venous volume variation remains low. Second, muscle atrophy below the spinal cord lesion level and the possibility of a concomitant vascular atrophy associated below this lesion may result in a decrease of the venous vascular volume, and consequently, the space to accumulate blood and venous volume variation will be limited.

Wecht et al (16) demonstrated that VC and total VO are significantly lower in individuals with SCI than in the able-bodied, and lower in those in the tetraplegia than in the paraplegia group. This relation to spinal cord lesion level is in accordance with our results, comparing lesions above T6 and lesions below T10. The cardiac and vascular responses of those in the LP group are different from those of the HP group because subjects in the latter group have more paralyzed muscle groups, interruption of sympathetic pathways, and damage to sympathetic vascular muscle innervation. Vascular tone, regulated by the sympathetic system, humoral agents (catechol-

Table 2. Heart Rate and Blood Pressure Responses With and Without GCS According to Injury Level

	HR (bpm)		SBP (mm/Hg)		DBP (mm/Hg)	
	Without GCS	With GCS	Without GCS	With GCS	Without GCS	With GCS
LP group	81.4 ± 20.3	79.4 ± 14.1	131.0 ± 20.7	147.8 ± 29.0	78.0 ± 15.5	88.2 ± 24.1
HP group	75.0 ± 10.7	76.5 ± 17.9	141.8 ± 14.3	126.0 ± 15.7	93.7 ± 14.8	85.7 ± 13.4
All subjects	78.6 ± 16.1	78.1 ± 14.9	135.8 ± 18.0	138.1 ± 25.4	85.0 ± 16.4	87.1 ± 20.0

HR, heart rate; bpm, beats per minute; SBP, systolic blood pressure; DBP, diastolic blood pressure.

amines), or muscle reflexes, can be deficient in people with high spinal lesions. In lesions above T6, this vascular maladaptation manifests itself in rapid and uninhibited accumulation of blood in the abdominal area and lower limb caused by the inability of the blood vessels in the viscera to constrict due to deprivation of control from the roots of the splanchnic nerves. This results in a decreased blood supply to the central veins and an insufficient return of venous blood that may lead to a decrease in the venous vascular volume and a loss of distensibility. Indeed, the sympathetic nervous system cannot contract smooth muscles of veins, which results in a decreased stiffness of the vessel wall and makes the veins more distensible. This greater venous dilation in HP patients may limit the increase in blood volume and venous distensibility after venous occlusion. The VC is reduced in HP patients due to a reduction in the expansion capacity of the vessels. Because the autonomic nervous system is partially intact in LP patients, other compensatory mechanisms such as production of catecholamines by the adrenal medulla may be used to control their hemodynamics (19).

Influence of Compression Stockings

It is well-documented that GCS provide an effective, safe, inexpensive, and convenient means of preventing DVT. The GCS increase the linear velocity of VO, prevent stasis and venous distension, enhance emptying of valvular cusps, reduce the amount of both venous reflux and venous volume, and improve the calf muscle pump function and ambulatory venous pressure in limbs with chronic venous insufficiency (7,8). These beneficial

hemodynamic effects of elastic compression stockings have been demonstrated in chronic venous insufficiency with various kinds of compression (thigh and knee lengths) (18) and different levels of pressure (20), using ambulatory venous pressure measurements and various methods of plethysmography (14,17,20,21), and always in subjects with an intact muscle pump and without motor impairment. However, its influence in individuals with no vasomotor control and amyotrophic lower limbs has not been evaluated. With commonly used 15 to 21 mm/Hg GCS, our study showed no effect on VO. The GCS seem to decrease lower limb venous distensibility without affecting venous emptying. The applied pressure is probably too low to produce hemodynamic effects in the deep veins. Our results showed that GCS with a pressure of 21 mm/Hg may decrease the caliber of superficial veins in SCI, but without increasing deep venous flow enough to affect VO. This could be due to partial obstruction of the deep venous system with increased venous resistance. Indeed, Hopman et al (6) mentioned that vascular resistance is dramatically increased in the paralyzed legs of individuals with SCI. This may be caused by structural changes (eg, a decrease in the number of arterioles and capillaries and/or a decrease in the diameter of the resistance of the resistance vessels), as well as by functional changes (eg, changes in endothelium-derived factors and/or sympathetic vascular regulation). Further investigations using duplex scanning would provide additional results on the effect of GCS on deep vein blood flow velocity.

However, our results demonstrated a diminished VC for each group, but this was statistically significant only

Table 3. Results of Venous Occlusion Plethysmography in Participants With LP and HP due to SCI

	VC (vol%)			VO (vol%)		
	Without GCS	With GCS	Difference With/Without	Without GCS	With GCS	Difference With/Without
LP group	2.14 ± 1.44	1.99 ± 1.27†	−7%	61.00 ± 36.99	58.40 ± 32.60	−4%
HP group	1.30 ± 0.64	0.95 ± 0.48†	−27%	40.00 ± 15.23	36.00 ± 21.91	−10%
Difference HP/LP	−39%	−52%		−34%	−38%	
All participants	1.77 ± 1.18*	1.53 ± 1.09*	−14%	51.67 ± 29.89	48.44 ± 29.17	−6%

* $P < 0.05$: significantly different between GCS and without GCS.

† $P < 0.05$: significantly different between groups.

when the 2 groups were taken together. A further study would require a larger number of participants in each group to corroborate this trend statistically. These data suggest that knee-length graded elastic compression stockings help preserve venous caliber and prevent dilation in the superficial and perforating venous systems of the lower leg in individuals with SCI with low as well as with high spinal cord lesions, which could prevent DVT.

Practical Aspects

If our study and current data seem to suggest that GCS help to decrease venous dilation and then could prevent DVT in individuals with SCI, actually in practice the choice of GCS length and pressure is not resolved. The visible signs of chronic venous insufficiency generally develop in the distal rather than proximal part of the lower limbs. Therefore, the beneficial effects of local compression need to be concentrated below the knee (21). Partsch et al (21) suggested that calf-length stockings that have been shown to improve the efficiency of the calf muscle pump are sufficient for most patients, compared with thigh-length compression stockings. In the same way, previous studies (8,18) suggested that below-knee stockings are as effective as above-knee stockings in the prevention of postoperative DVT. However, no data were published on individuals with SCI. Furthermore, amyotrophy of lower limbs, particularly at thigh level, makes difficult the containment of thigh-length compression stockings in individuals with SCI.

With respect to the pressure applied, our study suggests that knee-length compression stockings with pressure levels varying between 21 mm/Hg (at the ankle) and 15 mm/Hg (at the top of the calf) significantly reduce venous volume variation in individuals with longstanding SCI. The GCS with strong pressure (30 mm/Hg) can cause adverse reactions, including skin trauma in sensitive individuals. Thus, when choosing the type of compression stocking to treat the lower leg in SCI, we suggest that knee-length, 21-mm/Hg compression pressure stockings would be a good choice initially, as they are cheaper, easier to put on, and can provide beneficial therapeutic effects comparable to 30-mm/Hg compression stockings. DVT and pulmonary emboli, which remain the major complications in SCI (7), are associated with systemic venodilation (8). Therefore, if reducing venous distension contributes to preventing DVT, wearing standard GCS with a pressure of 21 mm/Hg (leading to a decreased VC) could be beneficial in individuals with SCI because of the stockings' effect on the superficial venous system. If we assume that individuals with longstanding lower motor neuron injury have greater fibrosis, less muscle metabolic activity, and reduced flow when compared with individuals having spastic paralysis, this study showed that compression therapy may be as beneficial to individuals with long-

standing SCI who suffer from muscle spasticity as it is to those who suffer from muscle flaccidity.

However, it would be interesting to assess whether the effects found in this study could affect and improve cardiovascular responses in individuals with SCI during exercise by improving venous return or to assess whether pressure exerted by the GCS remains sufficient to prevent orthostatic intolerance in early SCI.

Such a study would require a larger number of subjects and a wider variety of measurements, such as venous pressure, venous volume, ejection volume, or ejection fraction. Furthermore, as shown in blood circulation research in individuals with SCI, because the time since injury may influence vascular properties, further studies are required to evaluate the effects of GCS in SCI during the acute phase of rehabilitation vs chronic SCI. This could lead to guidelines for properly adapting pressure stockings according to the different phases of rehabilitation in SCI.

CONCLUSION

This study demonstrated that 21-mm/Hg, knee-length compression stockings prevent venous distension in individuals with chronic SCI by significantly decreasing VC. This effect may be as beneficial in individuals with LP as in those with HP who have a compromised autonomic nervous system and may not be able to adjust hemodynamically, and it may be as valuable in individuals with flaccid paralysis as in those with spastic paralysis.

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