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PILOT STUDY OF THE IMPACT OF SPORTING COMPRESSION GARMENTS ON COMPOSITION AND VOLUME OF NORMAL AND LYMPHEDEMA LEGS

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ABSTRACT

Once clinically manifested as a swollen limb, lymphedema can be difficult to manage. Our focus thus must shift from reactive treatment to proactive management and prevention. On the basis of strong evidence in the literature, lymphedema specialists now encourage exercise as it can improve lymphatic drainage through muscle pump action. However, exercise may increase the lymph load on the vulnerable limb. We aimed to examine whether low level sporting compression is a reasonable recommendation for those with early stage lymphedema by measuring whether sporting compression (SC) tights decrease limb extracellular fluid as measured by Bio-impedance Spectroscopy (BIS) and Perometry in legs following exercise in both healthy controls and those with early stage lymphedema. A group of normal subjects (n=10) and a group of Stage 1 (ISL) lymphedema patients (n=9) were enrolled. Efforts were made to match participants in each group. For those with unilateral lymphedema, the non-affected leg was used as a control. All were measured using BIS, Perometry and Indurometry before and after exercise both with and without sporting compression clothing. The exercise regime was standardized and involved treadmill walking at increasing rates within each person's activity limitation. SC tights were shown to significantly decrease the fluid build up caused by exercise in lymphedema-affected limbs as measured with BIS (p=0.0302). Perometry measurements showed that SC caused a significant decrease in limb volume post exercise of the whole cohort (p=0.0081) and of the control Group B (p=0.0348). Our findings support the notion that SC may provide a socially acceptable and effective means of lymphedema control during exercise for early lymphedema management.

Keywords: leg lymphedema, sporting compression, leg volumes, bioimpedance spectroscopy, perometry

The US National Lymphedema Network recommends appropriate exercise and a general healthy lifestyle as important components of lymphedema management (1). The International Lymphedema Framework (ILF) recommends that those with lymphedema should exercise wearing a compression garment to decrease the fluid build up that is known to occur through stronger forms of exercise (2). During (and immediately after) exercise, the blood supply to skeletal muscles increases. Venous drainage tends to compensate for this increased supply but there remains an increased interstitial fluid load (with a higher concentration of large molecules including cytokines, lymphokines, etc.) that the lymphatic system must remove. When the lymph drainage pathway is hypoplastic (some forms of primary lymphedema) or has been damaged by surgery or radiotherapy (secondary lymphedema), this extra fluid can add to an already overloaded system and lead to temporary worsening of symptoms and appearance through the failure of the lymphatics to remove the increased load. The general consensus is that compression alleviates this problem in two ways. Firstly, by wearing compression garments the pressure is transferred to the vessels and tissues within the leg, altering the Starling forces, which ultimately leads to less fluid leaking into the interstitial space. Secondly, the pressure variation through muscular movement against the compressive garment leads to more fluid being loaded into the lymphatics and removed from the area.

Many people are reluctant to wear off-the-shelf or made to measure medical compression garments. This is especially the case when exercising as these traditional garments are reported to be hot, uncomfortable and difficult to don and doff. The use of sporting compression (SC) garments has become commonplace in the Australian and world-wide sporting scene with many high level sports people using SC for training and competitions.

The sports literature suggests that SC improves peak sporting performance (3), reduces recovery time (4) and reduces post-exercise muscle soreness (5). SC is often anecdotally recommended to those with early stage lymphedema or who are at risk of developing lymphedema. To date, no information is available about the effectiveness of SC on the fluid levels of limbs post exercise and particularly whether SC can provide a socially accepted, economically viable alternative to medical compression garments during exercise. This pilot study aimed to evaluate the effect of SC on lower limb volume and composition post-exercise in both healthy volunteers and those with early stage unilateral secondary lymphedema.

METHODS

The Flinders Medical Centre Clinical Research Ethics Committee, Adelaide, Australia, approved the study, and informed consent was obtained from each participant.

A group of 9 healthy subjects (4 males, 5 females) and a group of 9 individuals (4 males, 5 females) with unilateral secondary early stage lymphedema were recruited. Any applicants with underlying lipedema, primary lymphedema, myxedema, uncontrolled hypertension, recurrent cancer, cellulitis or any who had recently (<1 month) undergone surgery or treatment for their lymphedema were excluded from the study. Participants were required to be able to walk on a treadmill and not use any other compressive garments for at least 12 hours prior to each session. They were also required to have relatively normal-shaped limbs to enable good contact and even pressure with the SC tights. The exercise sessions were scheduled as much as practicable for the early morning to minimize difference in activity levels before the session. Care was taken to ensure relatively empty bowels and bladders to ensure all were at a normal state of hydration.

Background participant details were collected using a short general questionnaire where those with lymphedema were also asked to disclose the etiology of their lymphedema and other relevant co-morbidities.

Each participant then took part in two sessions: the first session involved wearing regular non-compressive clothing, while in the second session the participants wore full length sporting compression tights (provided by SKINs™). The SC industry doesn't have a standardized compression scale as the compression offered depends greatly on the fit of the garment to the individual. The tights utilized in this study are similar to those used by Scanlan et al (6) who measured the compression as approximately 19mmHg at the ankle, gradually decreasing to 9mmHg at the buttocks.

Measurements of limb volume and composition were taken before and after exercise. Following the exercise, BIS measurements were performed at 3-minute intervals for 21 minutes. Indurometry and perometry measurements were taken after the BIS measurements, at approximately 22-30 minutes post exercise.

Total limb fluid volume was measured using Multi frequency Bio-impedance Spectroscopy (BIS) (Inbody Korea). BIS measures total limb fluid from groin/lateral abdominal margin downwards including the foot. As intravascular fluid and intracellular fluid are fairly static, changes in BIS measurement reflect changes of fluid volume in the extracellular compartment (7-9). Opto-electronic Perometry (Pero systems; Germany) was utilized to assess total limb volume (excluding the foot), which includes volumes of fat, fluid, and muscle. However, due to the short time frame over which this study was conducted, changes in perometry measurements would not reflect changes in fat or muscle but just those in total limb fluid between the upper thigh and the malleoli area of the ankle (8). Both the Perometry and BIS measurements therefore reflect changes in limb fluid volume even though the techniques are different. Comparing the outcomes from the two techniques can provide valuable information about fluid accumulation in the groin area as this is measured by BIS only. Tissue hardness was assessed by the Indurometer (previously called a Tonometer) (Biomedical Engineering Flinders Medical Centre) 15cm above the patella anteriorly, 15cm above and below the popliteal crease posteriorly, and at the midline of the limb (8-10).

Following the exercise, BIS measurements were performed at 3-minute intervals for 21 minutes. Indurometry and perometry measurements were taken after the BIS measurements, at approximately 22-30 minutes post exercise. Perceived exertion was scored using a Borg Scale 1-10, where 1 represents very little exhaustion and 10 represents extreme exhaustion that forces the person to rest.

The exercise session consisted of a Sub-maximal treadmill exercise test where every 3 minutes either the speed or the percentage of incline increased. The starting pace was 3.2km/hour at 0% incline; the maximal level possible was 7.2km/hour at 15% incline. Heart rate was recorded every minute throughout the exercise, and the exercise was ceased when the participant's heart rate reached 85% of their maximal heart rate as calculated by their age (220 - age x 0.85).

TABLE 1
Group Demographics

Demographic	Group A	Group B	P Value
Number in group	9	10	-
Average Age	56	29	<0.001
Average BMI	31	28	0.0955
Male	4	5	-
Female	5	5	-

RESULTS

The lymphedema cohort (Group A), were significantly older ($p<0.05$), but similar (n.s.) in their body mass indices to the normal subjects Group B (see *Table 1*).

Bio-Impedance Spectroscopy (BIS)

BIS measurements include the whole limb from the toes to the groin and include the lateral groin region. Exercise caused an increased limb volume in all participants with average increase of 253ml ± 138. The whole cohort of 253ml ± 138. The use of SC during exercise decreased the fluid build-up by an average of 35ml per limb. Lymphedema affected limbs and Group B's limbs benefitted the most from SC with average volume decreases of 47 and 49ml, respectively. The non-affected leg of Group A's participants didn't have any reduction in volume as a result of SC; in fact, a very slight average increase in volume of 8ml was noted (see *Table 2*). *Tables 3 and 4* provide individual data for Group A and B, respectively.

TABLE 2
Mean (Mean ± SD) Measurements of Limb Volume Increase After Exercise

Population	Number of limbs	Without SC		With SC		Benefit SC			
						BIS		Pero	
		BIS (mls)	Pero (mls)	BIS (mls)	Pero (mls)	mls	P Value	mls	P Value
Whole Cohort	38	253±138	181±67	218±89	88±129	35±75	0.2275	93±162	0.0036
Group A	18	207± 93	197±203	187±67	92 ±153	19±59	0.1283	105±190	0.0886
LO Affected Limb	9	238±110	174±171	191±86	136±150	47±54	0.0302	38 ±180	0.6242
LO Unaffected Limb	9	176±63	220±239	183±47	48±150	-8±52	0.9088	172±186	0.0886
Group B	20	295±160	165±129	246±98	65±119	49±87	0.1784	100±163	0.0152

TABLE 3
Demographics and Limb Volume Changes After SC in Group A (With Lymphedema)

Participant	Sex	Age	BMI	Limb	Lymphedema Duration and limb	Perometry Volume change (ml) post exercise with SC	BIS Volume change (ml) post exercise with SC
L1	M	47	39	Left	-	-86.5	-50
				Right	6yrs	-128.5	-160
L2	M	53	33	Left	15 yrs.	84	0
				Right	-	-78	+20
L3	M	59	32	Left	17 yrs.	-353	-80
				Right	-	-275.5	+40
L4	M	50	28	Left	16 yrs.	-227	-70
				Right	-	-605	+40
L5	F	53	38	Left	-	-239	+40
				Right	4 yrs.	-37	-40
L6	F	74	25	Left	1 yr.	-6	-60
				Right	-	-2.5	-90
L7	F	63	28	Left	-	-154	+70
				Right	1 yr.	179.5	+10
L8	F	54	28	Left	3 yrs.	-44.5	-30
				Right	-	-34	-30
L9	F	48	33	Left	17 yrs.	191	+10
				Right	-	-73.5	+30
Mean Value +/- Standard Deviation		55 yrs ± 0.7	31.6 Kg/m^2 ± 4.07		8.8 yrs.± 7.17	- 105 mls ± 190	19mls ± 59

TABLE 4
Demographics and Limb Volume Changes After SC in Group B (Without Lymphedema)

Participant	Sex	Age	BMI	Limb	Perometry Volume change (ml) post exercise with SC	BIS Max Volume change post exercise (ml)
S1	F	38	27	Left	-94.5	-20
				Right	-102.5	-40
S2	F	30	28	Left	16	-70
				Right	-368.5	-70
S3	F	31	27	Left	-298	-20
				Right	-108	-80
S4	F	23	23	Left	-149	-50
				Right	-65.5	-50
S5	F	25	25	Left	-46.5	-10
				Right	161	-90
S6	M	22	34	Left	24.5	-70
				Right	63.5	-100
S7	M	36	32	Left	-11.5	+50
				Right	-488	-30
S8	M	26	29	Left	-167	+30
				Right	-109	+50
S9	M	25	29	Left	2.5	-260
				Right	154	-250
S10	M	26	23	Left	-178.5	+60
				Right	-234	+50
Mean Values +/- Standard Deviation		28.2 years +/- 5.4	28 kg/m^2 +/- 3.14		-100 mls ± 163	-49 mls ± 87

Analysis of the relative volume change of both legs in Group A participants with and without SC showed no statistically significant decrease in limb volume (p=0.1283). When the analysis was limited to the lymphedema-affected limb, a significant limb volume decrease when wearing SC to exercise was found (p=0.0302). Group B and the non-affected limbs only of Group A failed to show a significant benefit of SC (p=0.1784 and p=0.9088, respectively).

The behavior of the non-affected limbs in Group A was compared with that of Group B, as both classes of limbs are supposedly "normal" and as such should behave in a similar fashion in response to exercise. The limb volumes post exercise were compared (t-test) and without SC these limb subgroups behaved significantly differently (p=0.0032), with the non-affected limbs of Group A accumulating less fluid than the normal legs of Group B. When this same relationship was compared when wearing SC it was found to no longer be the case (p=0.2025), the SC causing the non-affected limbs of Group A to increase in post-exercise volume and in doing so behave similarly to the normal limbs in Group B.

Plotting post-exercise relative to pre-exercise volume with and without the SC was

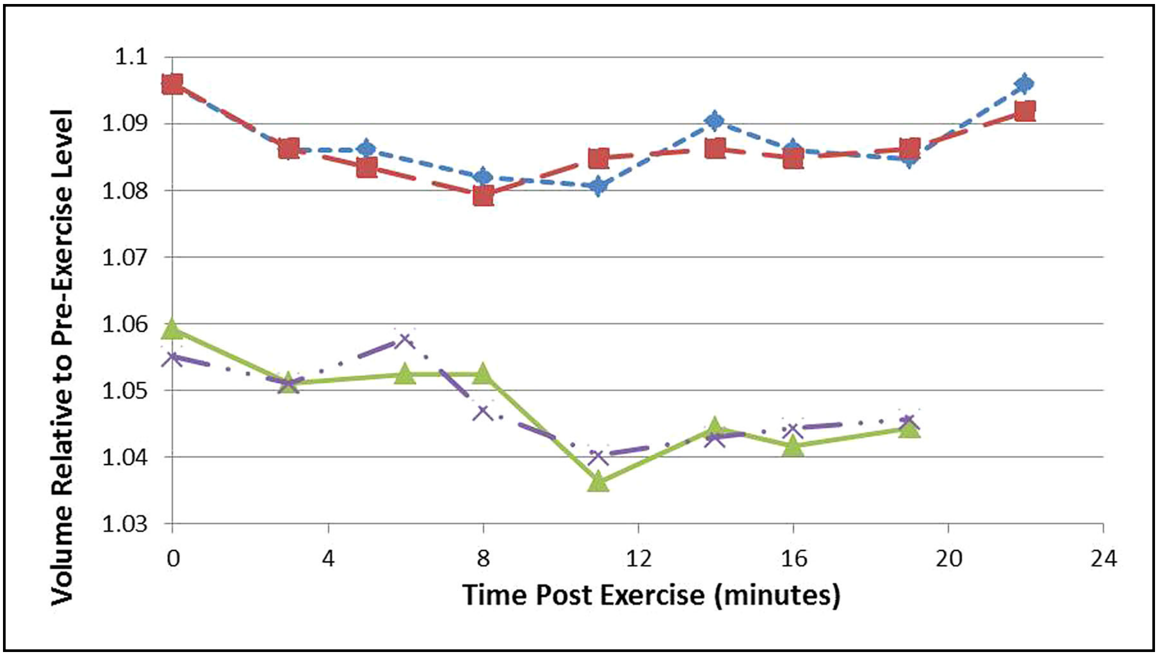

Fig. 1. BIS measurements were used to calculate pre-exercise to post-exercise relative volume changes in a normal subject with and without SC use. The top curves display values for the subject without SC use (squares for the left leg and diamonds for the right). The bottom curves display values for the subject with SC use (x for the left leg and triangles for the right). Total limb volume reduction due to SC use averaged 4% over the course of the measurements.

used to graphically illustrate changes due to SC use. *Fig. 1* displays fluid movement trends post-exercise in a selected representative normal individual. Total limb volume reduction due to SC use averaged 4% over the course of the measurements. Similar though often not as clear outcomes were observed in other participants. Variations between individuals seemed to be linked with the level of induration (as measured by Indurometry).

Perometry

Perometry measures only from the ankle malleoli to mid upper thigh. Perometry measurements did show a statistically significant decrease in post-exercise limb volumes when wearing SC for Group B (p=0.0152) and when all participants were grouped together (p=0.0036). Group A and its subgroups did not show a significant volume reduction as a result of SC (see *Table 2*).

The mean volume reduction was significantly greater in the thigh region than the calf region (p=0.0053) for all participants.

Indurometry

Indurometry readings were significantly higher in the limbs with lymphedema when compared to the other non-affected limb (p=0.0226) suggesting that the lymphedema was correlated with epifascial induration.

Borg Scale

There was a slight trend of participants reaching higher levels of exercise tolerance when wearing SC garments, and participants were often able to reach higher grades on the treadmill while still reporting similar Borg exertion scores.

DISCUSSION

As demonstrated in both *Tables 3 and 4*, the effectiveness of the SC varied greatly between participants and at times between participant's limbs. This variation calls for a larger study group to gain a true representation of the overall effects of SC.

An examination of the data for indications as to why this variation occurred provided no clear associations. Multiple factors contribute to the effectiveness of the SC with likely influence from current and historical lymphedema management, BMI, normal exercise levels, SC fit, etc. One hypothesis is that the effect difference between the participants might be related to varied leg circumferences resulting in variation in compression applied by the SC tights with higher pressure being present on larger limbs. This difference may explain why the unaffected limb of the lymphedema group did not show a decrease in fluid build-up when wearing SC because the garment was necessarily loose on the non-affected limb to enable the affected leg to fit into the garment. Furthermore, one would expect greater compression to lead to larger volume reductions but that was not the case. It has been postulated that lymphedema develops in those with inherently increased capillary filtration rates which puts these people at greater risk of exceeding the maximal sustainable lymphatic flow (11,12). Other factors including tissue hardness, pre-exercise loads of the lymphatic system, and lymphatic filtration rates (11,12) may be contributory.

When measured by Perometry, SC generally had their greatest fluid reducing effect in the thigh region, perhaps explaining why BIS failed to show any significant reductions in limb volume in the subgroups other than lymphedema-affected limbs. It appears that the fluid may be shifting from the thigh area into the groin region through wearing the SC tights. The lower lateral groin region is included in the BIS measurements but not in those of Perometry, perhaps underlying apparent inconsistency in measurement findings. Had the BIS measurements been performed post-exercise over a longer period of time and after multiple bouts of exercise, it may have shown the fluid moving from the groin into the abdomen with concomitant significant decreases in limb volume when SC is worn by those without lymphedema, as was found with Perometry.

The decreased effectiveness of SC on lymphedema affected limbs as opposed to healthy limbs could be due to the increased tissue hardness that occurs epifascially as lymphedema progresses and is often associated with the surgical and radiotherapy induced scar area. The indurometer measurements were consistently higher in the group with lymphedema (despite its early stage), which indicates that their tissues had already started to undergo induration secondary to lymphedema. Since complex manual therapy and low level laser therapy can soften indurated tissues, the prior treatment of these cases may have improved the outcomes of the SC by freeing up the movement of fluids through the extracellular space.

It seems the popularity of SC garments is due to subjective reports of increased performance (13) and decreased muscle soreness following exercise (14,15). The overwhelming majority of subjective feedback from participants wearing SC in this study was very positive. The true value in the use of SC in those affected by lymphedema may be that they help to remove the barriers to healthy exercise. If SC helps to get people with lymphedema up and exercising then that on its own is of great potential benefit.

Group A participants who had been exposed to medical grade compression garments in the past reported SC tights as being very comfortable, supportive, and overall enjoyable to wear. Some of the participants struggled with donning the garments but as this was their first attempt it is thought that their technique would improve with practice. Of note, the SC tights are much easier to don and doff than the medical compression grade garments. The increased exercise tolerance observed by the

Borg Score results is likely due to increased comfort with the exercise regime and treadmill walking in general. It may also reflect increased exercise tolerance as participants reported feeling more athletic and capable when wearing SC.

The discrepancy between the demographics of the two groups was not ideal as preferably the participants with lymphedema would be in the early stages of the disease and without or with only minimal fibrotic induration. Prior to commencement of the study, it was thought that those with long-standing lymphedema wouldn't respond well to SC. However, interestingly, there are several who responded very well, e.g., L3 who has suffered with lymphedema of his left leg for 17 years, experienced a 6.9% decrease in his post-exercise Perometry measurement. A future study would include both short term and long-term lymphedema-affected limbs to explore whether the chronicity of the disease affects the response to exercise and SC.

There was difficulty in data collection because the measuring techniques cannot be performed simultaneously, and therefore differences in time of acquisition create discrepancies between participants. In addition, the maximum fluid increase seen post exercise is only one way of analyzing the BIS data. It may also be valuable to look at whether there is increased speed of return to pre-exercise volumes when wearing SC garments.

This study has shown that SC tights are of some benefit to those with leg lymphedema, however its relative effectiveness in relation to the gold standard medical grade compression remains to be established. Future studies comparing SC to the current medical standard compression garments would be valuable, and also examining more closely both the psychological and physiological effects of SC in the medium to long term.

CONCLUSION

SC tights may have a role to play in the treatment and prevention of early or latent lower limb lymphedema. Greatest benefits were observed when tissue induration was minimal or normal levels. The garments generally are more acceptable to their users and easy to don and doff compared to medical compression garments. This finding does not suggest that medical compression garments are redundant, but rather that sporting compression garments may have a place in lymphedema management programs when a patient is exercising. SC garments decrease the fluid buildup caused by exercise as measured by BIS and Perometry. Based on this effect, they should be considered in the management options for early stage lymphedema particularly when patients are undertaking any exercise or activity program.

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