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Review article

Compression Garments and Exercise: No Influence of Pressure Applied

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Abstract

Compression garments on the lower limbs are increasingly popular among athletes who wish to improve performance, reduce exercise-induced discomfort, and reduce the risk of injury. However, the beneficial effects of compression garments have not been clearly established. We performed a review of the literature for prospective, randomized, controlled studies, using quantified lower limb compression in order to (1) describe the beneficial effects that have been identified with compression garments, and in which conditions; and (2) investigate whether there is a relation between the pressure applied and the reported effects. The pressure delivered were measured either in laboratory conditions on garments identical to those used in the studies, or derived from publication data. Twenty three original articles were selected for inclusion in this review. The effects of wearing compression garments during exercise are controversial, as most studies failed to demonstrate a beneficial effect on immediate or performance recovery, or on delayed onset of muscle soreness. There was a trend towards a beneficial effect of compression garments worn during recovery, with performance recovery found to be improved in the five studies in which this was investigated, and delayed-onset muscle soreness was reportedly reduced in three of these five studies. There is no apparent relation between the effects of compression garments worn during or after exercise and the pressures applied, since beneficial effects were obtained with both low and high pressures. Wearing compression garments during recovery from exercise seems to be beneficial for performance recovery and delayed-onset muscle soreness, but the factors explaining this efficacy remain to be elucidated.

Key words: Compression garment, venous return, exercise, muscle soreness, recovery, performance.

Introduction

Compression garments on the lower limbs are increasingly popular among athletes. Over a hundred types of compression stocking intended for use among athletes are currently commercially available. However, their beneficial effects have not been clearly demonstrated in the literature. As indicated by MacRae et al. (2011), there is great heterogeneity among experimental studies, in terms of the training status of the subjects, the type of exercise performed, the design of the compression garments tested (knee or thigh-high stockings, waist-down tights, arm sleeves, whole body garments), when they were worn (during and/or after exercise), and the level and spatial distribution of pressure applied. Indeed, in a number of studies, the pressure applied is not reported. It is possible that this heterogeneity between studies results in conflicting results that may mask the true efficacy of compression, which would only become apparent with more restrictive experimental conditions.

We aimed to investigate two questions through a review of the literature, namely: Firstly, what, if any, beneficial effects of compression have been demonstrated in the literature, and under which conditions of use. Among the factors influencing the potential efficacy of compression garments, the timing of their use (i.e. during exercise or/and during recovery) seems to be of major importance. Various mechanisms have been suggested to explain the beneficial effects reported in some studies. During exercise, a support effect has been assumed to reduce microtrauma and muscular damage (Trenell et al., 2006), reduce power expenditure (Bringard et al., 2006b), and improve comfort (Ali et al., 2007). During post-exercise recovery, hypotheses concerning the role of compression focus mainly on the classic effects of the compression, namely improvement of venous return and accelerated removal of metabolic waste (Hirai et al., 2002), limitation of edema (Partsch et al., 2012), increased arterial pulse blood flow (Mayrovitz et al., 2010), and increased oxygen delivery to the tissue (Bringard et al., 2006a). Although the exact mechanisms remain to be elucidated, they likely differ during exercise and during recovery, owing to the different physical conditions. Thus, in our analysis, we categorized studies into three groups, according to when the garment was worn. The type of exercise performed (endurance or resistance) was also taken into consideration.

Secondly, we sought to evaluate whether there is any relationship between the pressure applied and the reported effects. In the context of venous insufficiency, the effects of compression garments depend on the pressure applied, and the strength of compression recommended increases with the severity of disease. It could be assumed that a similar relation may also exist in the field of sports physiology. In practice, the choice of compression garment by athletes is mainly based on personal preferences, and not on the pressure delivered. If a relation were identified between the pressure applied and the benefit yielded, as in the case of venous disease, then this

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could help to better adapt the choice of garments to the expected effects.

Methods

Review of the literature

To identify original research addressing the effects of compression garments on sports performance and recovery after exercise, a computer-based literature search was performed in May 2014 using the electronic databases PubMed, MEDLINE, SPORT Discus, and Web of Science. Literature was searched over a 30-year period (up to and including May 2014). The key words used were: ‘compression’, ‘compressive’‘garment’, ‘stocking’, ‘exercise’, ‘sport’, ‘performance’, ‘recovery’, ‘muscle soreness’ and ‘hemodynamic’.

Studies were eligible for inclusion in the analysis if they were prospective, with a clearly detailed protocol (type and duration of exercise, timing of garment’s wear); included subjects were athletes of any level; the compression garment was applied on the lower body. The pressure garments used had to be described in detail (trademark, model, size) to allow precise identification and allow us to purchase it to evaluate the pressures really exerted. Only the *in vitro* (laboratory conditions) method of measure achieves reproducible measurement conditions, identical to those required for certifying the pressure levels of compression garments by the industry (French standards NFG30 102B). The in vivo measure is a local measure at a specific point, which is influenced by the radius of curvature of the limb at that particular point, and also by the tension of the textile. The in vitro measure is performed using a wooden structure with a circular (constant) radius of curvature. The pressure is indirectly measured on this wooden structure by using the Laplace law. The in vitro measure corresponds to the average pressure in vivo. The data analyses were therefore based either on pressure values indicated in the study (when performed in laboratory conditions), or on values measured in our laboratory with a compression garment identical to that tested in the relevant study (same trademark model, size). Retrospective studies and studies in which the compression garments were worn on the arm or on the whole body were excluded. Selected studies were categorized into three groups according to when the compression garment was worn: i.e. during exercise only, during recovery only, or during both exercise and recovery. The reference sections of all selected studies were manually searched for additional references not found by the initial online database search.

Measurement of the pressures delivered at ankle and calf levels according to the garment used

We were able to purchase one each of 12 garments out of the 24 studies analyzed. For each garment, we evaluated the pressures applied at the ankle and at the calf in laboratory conditions using a single method, which complies with the French standards (NFG30 102B) required for the reimbursement of medical compression garments by the social security system.

The measurements were performed as follows: The garment to be evaluated was placed on a 3D wooden leg template, the dimensions of which correspond to the size of the garment. The areas of interest (i.e. ankle and calf) were marked on the garment. The garment was removed from the template and left at rest for 2 hours to allow it to recover its initial state. Then the garment was placed on a dynamometer in the same strain conditions as those on the wooden leg template in order to measure the textile’s tension under conditions of wear.

The pressure delivered (P) was calculated using Laplace’s law: $P = TxC$, where T is the textile tension, and C the curvature of the template. All measurements were performed in the Biophysics Department of Innothera Laboratories (Arcueil, France).

The full text studies were read and selected by three of the co-authors. One hundred and fifty five original articles were identified, of which 24 fulfilled the criteria for inclusion and were analyzed in detail. Among the 24 articles selected, six reported several protocols, performed on the same subjects, but with different compression levels, yielding diverging results. In order to take this into account, we analyzed the results of each protocol individually. Thus, in this report, the overall number of studies may exceed the number of associated references.

The criteria of evaluation in the studies were classed in two categories, namely (1) variables that measured performance with and without compression, and (2) variables that report the quality of recovery with or without compression. The performance parameters estimated in the studies were: maximal oxygen consumption, energy cost, speed or power reached during the test, heart rate, cardiac output, muscular strength capacity, tissue oxygenation, perception of the difficulty of the exertion (Borg and other scales). The dosage of blood lactate concentration, and blood creatine kinase concentration were also evaluated to study the effects of wearing compression garment during a physical exercise. The effects of wearing compression garments during exercise on the oscillatory movement of the muscle and the leg volume variation were studied. The quality of the recovery phase was studied through the dosage of blood lactate concentration, blood pH, blood creatine kinase concentration and muscle blood flow. Delayed onset muscle soreness (DOMS) (measured by feeling scales or with an algometer) was also evaluated to study recovery with and without compression.

The effects of compression in the various studies were identified and classified in two categories, namely “positive effect”, and “no positive effect” (corresponding to a lack of positive effect or presence of a negative effect) for each parameter.

For the second part of our study, in which we estimate the effect of the pressure applied and the wear time, comparisons were performed for the two parameters that appear to be of greatest importance to athletes, namely improvement of performance recovery, and reduction of DOMS. Since these were evaluated by different methods, the use of a common quantification system is not possible. Thus, each reported effect is characterized in a binary fashion, i.e. either positive effect (significant improvement of performance recovery, or significant reduction of DOMS), or no positive effect (absent or negative).

Results

Effects of lower limb compression in athletes (Table 1)

Effects of compression worn during exercise only: In 20 protocols (Ali et al., 2011; 2007; 2010; Bovenschen et al., 2013; Bringard et al., 2006b; Kemmler et al., 2009; Moehrle et al., 2007; Scanlan et al., 2008; Sperlich et al., 2013b; 2011; Wahl et al., 2012), an endurance trial was used (running or cycling at submaximal or maximal power, for 15 to 45 min), in 2 protocols (Miyamoto et al., 2011) a resistance trial was used (maximal plantar flexion).

Wearing compression garments did not significantly affect heart rate (Ali et al., 2011; 2007; 2010; Bringard et al., 2006b; Kemmler et al., 2009; Moehrle et al., 2007; Scanlan et al., 2008; Sperlich et al., 2011; 2013b; Wahl et al., 2012), oxygen uptake (VO2)(Bringard et al., 2006b; Kemmler et al., 2009; Scanlan et al., 2008; Sperlich et al., 2011; 2013b; Wahl et al., 2012), or plasma levels of lactate or creatine kinase (Ali et al., 2010; Kemmler et al., 2009; Scanlan et al., 2008; Sperlich et al., 2011, 2013b; Wahl et al., 2012) during exercise, as compared with no compression. Use of compression resulted in increased tissue oxygenation in the vastus lateralis during cycling, in one study (Scanlan et al., 2008). Performance was found to be unchanged, regardless of the level of compression (from 15 to 46 mmHg at the ankle) in 9 protocols (Ali et al., 2011; 2007; Moehrle et al., 2007; Scanlan et al., 2008; Wahl et al., 2012). Conversely, performance was significantly improved by compression garments applying 24 mmHg at the ankle in one study(Kemmler et al., 2009).

Performance recovery (jumps, or maximal plantar flexion, performed during recovery) was found to be unaffected by the use of compression garment in five protocols(Ali et al., 2010; 2011; Miyamoto et al., 2011), improved in two protocols in the same article (Ali et al., 2011); even thoughfor these different results, the pressure range used was similar in these seven protocols (15 to 21 mmHg at the ankle).A resistance trial was performed in two of the five protocols with negative results(Miyamoto et al., 2011), an endurance trial was performed in 3 protocols with a negative result (Ali et al., 2010; 2011), and in the two protocols with a positive result (Ali et al., 2011).

In terms of delayed-onset muscle soreness, DOMS experienced after running 40 min (Ali et al., 2010) or 10 km (Ali et al., 2011) were unchanged by compression garments applying 15to 32 mmHg at the ankle in5 studies, but reduced with 25.4 mmHg in another stud (Ali et al., 2007). An endurance trial was performed in all these studies.

The increase of leg volume after exercise was limited by the compression worn during exercise (Bovenschen et al., 2013).

The oscillatory movement of the muscle was decreased with the compression garment (Sperlich et al., 2013b). In this study, the athletes made a 3-min test of simulated alpine skiing in the tuck position accompanied by passive vibration with and without compression garments.

Effects of compression worn during recovery only: In 5 studies(de Glanville and Hamlin, 2012; Driller and Halson, 2013; Menetrier et al., 2012; Sperlich et al., 2013a; Trenell et al., 2006), the exercise was an endurance trial (cycling at maximal power for 20, 30 or 40 min, walking on a 25% downslope treadmill for 30 min); and resistance trials were used in 3 studies (Chatard et al., 2004; Hamlin et al., 2012; Jakeman et al., 2010) (100 jumps in succession, cycling at maximum power for 5 min, rugby-specific circuit test).

Wearing a compression garment during recovery was associated with lower plasma lactate levels in 3 studies (Chatard et al., 2004; Hamlin et al., 2012; Menetrier et al., 2012), but was not associated with any change in creatine kinase levels(Jakeman et al., 2010; Trenell I. et al., 2006).

Performance recovery (jumps, 40-m repeated sprint, isokinetic power, 3-km run, or cycling, performed during recovery) was improved by the use of compression tights applying 9.3 to 20.5 mmHg at calf level in 6 studies (Chatard et al., 2004; de Glanville and Hamlin, 2012; Driller and Halson, 2013; Hamlin et al., 2012; Jakeman et al., 2010; Menetrier et al., 2012). The first (fatiguing) exercise was an endurance trial in 3 studies (de Glanville and Hamlin, 2012; Driller and Halson, 2013; Menetrier et al., 2012), a resistance trial in the 3 other studies (Chatard et al., 2004; Hamlin et al., 2012; Jakeman et al., 2010).

DOMS was found to be decreased by tights or compression garments applying 9.3 to 19.2 mmHg at calf level in 4 studies, of which one was an endurance trial (Menetrier et al., 2012) and three were resistance trials (Chatard et al., 2004; Hamlin et al., 2012; Jakeman et al., 2010). Conversely, DOMS was unchanged by compression tights applying 9.3 to 20.5 mmHg at calf level in 2 studies using an endurance trial (Driller and Halson, 2013; Trenell et al., 2006).

Wearing compression shorts reduces blood flow both in the deep and superficial regions of the thigh muscle tissue during recovery from high intensity exercise (Sperlich et al., 2013a).

Effects of compression worn during both exercise and recovery: In 2 studies (Berry and McMurray, 1987; Rimaud et al., 2010), the exercise was a resistance trial (running and cycling at maximum power); and one study (Menetrier A. et al., 2011) combined endurance with a resistance trial (running at 60% aerobic maximal velocity during 30 min and time to exhaustion at 100% maximal aerobic velocity).

In one study (Menetrier et al., 2011), performance recovery (measured after 15 min recovery from a maximal exercise) was found to be unaltered by compression garments, although their use was associated with an increase in tissue oxygenation in the gastrocnemius muscle. Plasma lactate levels after exercise were found to be decreased when wearing compression garment in one study (Berry and McMurray, 1987), but were shown to be increased in anotherstudy(Rimaud et al., 2010).

Table 1. **Compression garments and exercise. Synthesis of the effects reported.**

Author	Wear EX	Wear REC	Garment type	Experimental protocol	Criteria	Effects	Effects of compression garment
Berry (1987)	yes	yes	socks	Incremental exercise on treadmill	lact	+	Blood lactates during recovery decreased
Chatard (2004)	no	yes	stockings	Maximal exercise during 5 min on an ergocycle	2nd perf	+	Improvement of the second performance
					DOMS	+	Decrease of the DOMS after 24 hours
					lact	+	Decrease of blood lactates during the recovery
Bringard (2006a)	no	yes	tights	Rest	SO2	+	Increase of oxygen saturation in the triceps surae
Bringard (2006b)	yes	no	tights	Incremental exercise on treadmill	perf	+	Decrease of the energy cost of running at 12 km/h
Trenell (2006)	no	yes	tights	Walking 30min on treadmill with negative slope (25%)	DOMS	0	DOMS after recovery were unchanged
Ali (2007)	yes	no	socks	Running 10km	perf	0	No effect on 10km running performance
					DOMS	+	Decrease of DOMS up to 24H
Moehrle (2007)	yes	no	socks	Maximal physical exercise	perf	0	Performance unchanged
					lact	0	Blood lactates during running or cycling unchanged
Scanlan (2008)	yes	no	tights	Incremental exercise on ergocycle	perf	0	No effect on the maximal power of exercise
					lact	0	No effect on lactate blood levels
					SO2	+	Better oxygenation of the vastus lateralis during the cycling exercise
Kemmler (2009)	yes	no	socks	Incremental exercise on treadmill	perf	+	Increase of the maximal speed and duration of the trial
					lact	0	No effect on lactate blood levels
Rimaud (2010)	yes	yes	socks	Incremental exercise on ergocycle	lact	0	Blood lactates during recovery increased
Ali (2010)	yes	no	socks	Running 40 min on treadmill	2nd perf	0	No effect on jumps after the running
					DOMS	0	No effect on the DOMS
					lact / CK	0	No effect on lactate and creatine kinase blood levels
Jakemean (2010)	no	yes	tights	100 jumps	DOMS	+	Decrease of the DOMS at 1, 24, 48 and 72 hours
					2nd perf	+	Decrease of the muscle strength weakening at 24, 48 and 72 hours
Menetrier (2011)	yes	yes	stockings	Running 30min on treadmill with positive slope (12%)	SO2	+	Increase of oxygen saturation in the sural triceps surae during the recovery
					2nd perf	0	Second performance unchanged
Ali (2011)	yes	no	socks	Running 10km	2nd perf	+	Increase of the height of jumps after the running (low and medium compression)
						0	No effect on jumps after the running (high compression)
					DOMS	0	No effect on the DOMS
					lact / CK	0	No effect on lactate and creatine kinase blood levels
					perf	0	No effect on 10km running performance
Sperlich (2011)	yes	no	socks	Running 45min on treadmill	lact	0	Blood lactates unchanged
Miyamoto (2011)	yes	no	socks	Repetition of plantar flexions	2nd perf	0	No effect on the maximal plantar flexion force, measured 3 minutes after the straining exercise
Miyamoto (2011)	yes	no	socks	Repetition of plantar flexions	2nd perf	0	No effect on the maximal plantar flexion force, measured 3 minutes after the straining exercise
Menetrier (2011)	no	yes	stockings	Running 30min on treadmill with positive slope (12%)	2nd perf	+	Increase of the average power produced in a second cycling exercise after recovery
					lact	+	Blood lactates after recovery decreased
					DOMS	+	DOMS after recovery decreased
Wahl (2012)	yes	no	socks	Incremental exercise on treadmill	perf	0	No effect on time-to-exhaustion
					lact	0	Blood lactates during the trial unchanged

Wear EX : Wear during exercise ; Wear REC : Wear during recovery. perf: performance ; DOMS: delayed onset muscular soreness; SO2: Oxygen saturation of the muscular tissue; lact: blood concentration of lactates; Vol leg : leg volume; Borg: Perceived exertion evaluatedwith Borg scale; vibrations: Oscillatory movement of the muscle; Blood flow: blood flow of muscle tissue. 0: no positive effect (absent or negative effect); +: positive effect.

Table 1. **Continued.**

Author	Wear EX	Wear REC	Garment type	Experimental protocol	Criteria	Effects	Effects of compression garment
De Glanville (2012)	no	yes	tights	40 km on ergocycle	2nd perf	+	Improvement of the running time after 24 hours of recovery
Hamlin (2012)	no	yes	tights	Rugby-specific circuit test	2nd perf	+	Improvement of the second performance (40-m sprint, 3-km run)
					CK	0	No effect on creatine kinase blood levels
					lact	+	Decrease of blood lactates during the recovery
					Borg	+	Decrease of the DOMS
Bovenschen (2013)	yes	no	socks	Running 10km	Vol leg	+	Compression limits the increase of leg volume after exercise
					DOMS	0	Decrease of the DOMS
Bovenschen (2013)	yes	no	socks	Incremental exercise on treadmill	Vol leg	+	Compression limits the increase of leg volume after exercise
					DOMS	0	Decrease of the DOMS
Driller (2013)	no	yes	tights	Recovery period between 2 cycling bouts	2nd perf	+	Improvement of the second performance
					DOMS	0	No effect on the DOMS
Sperlich (2013b)	yes	no	tights	3-min test of simulated alpine skiing in the tuck position accompanied by passive vibration	vibrations	+	Oscillatory movement was reduced
					SO2	+	Increase of oxygen saturation in the vastus lateralis muscle
					lact	0	Blood lactates during the trial unchanged
					Borg	+	Perceived exertion was reduced
Sperlich (2013a)	no	yes	tights	Recovery after incremental exercise on ergocycle	Blood flow	0	Blood flow in the muscle tissue was reduced

EX : during exercise ; REC : during recovery. perf: performance ; DOMS: delayed onset muscular soreness; SO2: Oxygen saturation of the muscular tissue; lact: blood concentration of lactates; Vol leg : leg volume; Borg: Perceived exertion evaluatedwith Borg scale; vibrations: Oscillatory movement of the muscle; Blood flow: blood flow of muscle tissue. 0: no positive effect (absent or negative effect); +: positive effect.

Pressures delivered by the garments used in the studies (Table 2)

For 12 studies (Ali et al., 2007; Bringard et al., 2006b; Chatard et al., 2004; de Glanville and Hamlin, 2012; Hamlin et al., 2012; Jakeman et al., 2010; Moehrle et al., 2007; Menetrier et al., 2011; 2012; Rimaud et al., 2010; Scanlan et al., 2008; Trenell et al., 2006), a garment identical to the one used in the study could be acquired, and its mechanical properties were determined as described above.

For the other studies, the garments used could not be acquired. The pressure values reported in these publications had been either directly measured *in vivo* with two devices measuring the interface pressures between the skin and the compression garment: the Kikuhime device (MediGroup, Australia) (Ali et al., 2011; Driller and Halson, 2013) or the SIGaT tester (Ganzoni-Sigvaris, St Gallen, Switzerland) (Sperlich et al., 2011; 2013a; 2013b; Wahl et al., 2012), or derived from the manufacturer's specifications, namely from *in vitro* measurements (Ali et al., 2007; 2010; Berry and McMurray, 1987; Bovenschen et al., 2013; Kemmler et al., 2009; Miyamoto et al., 2011)

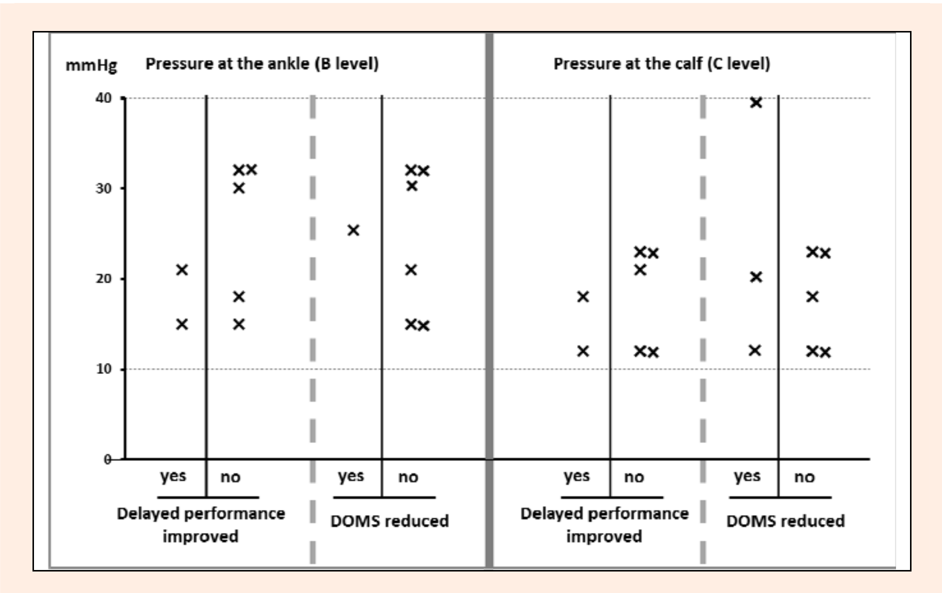

Figure 1. **Comparison of the pressures delivered with the effects reported when the garment is worn during exercise only. Each symbol x represents one study.**

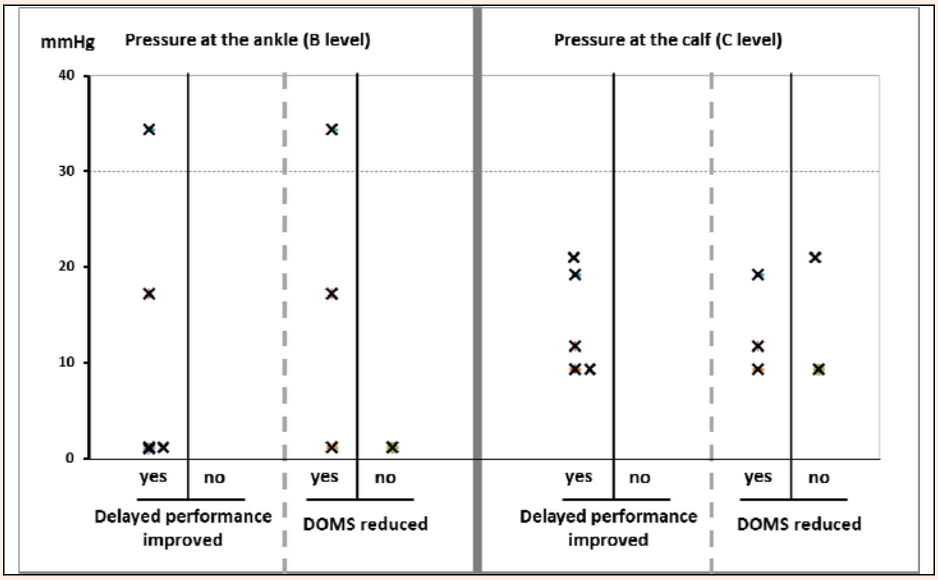

Figure 2. Comparison of the pressures delivered with the effects reported when the garment is worn during recovery only. Each symbol x represents one study.

Table 2. Pressures (mmHg) exerted by the garments at ankle and calf levels.

Study	n	Measured Ankle	Measured Calf	Publication Ankle	Publication Calf
Berry et al., 1987	6			18	8
Chatard et al., 2004	12	34.3	19.2	33	18
Trenell et al., 2006	11	1.1	9.3		17 *
Bringard et al., 2006a	12	5.2	9.3		24.1 *
Bringard et al., 2006b	6	5.2	9.3		
Ali et al., 2007	14	25.4	12.1	20	14
Moehrle et al., 2007	37	31.9	13.1		
Scanlan et al., 2008	12	1.1	9.3	19.5 *	17.3 *
Kemmler et al., 2009	21			24	20
Ali et al., 2010 (1)	10			15	12
Ali et al., 2010 (2)	10			32	23
Jakeman et al., 2010	8	1.1	9.3		
Rimaud et al., 2010	8			12	22
Menetrier et al., 2011	14	10	22	15	27
Ali et al., 2011 (1)	12			15	12
Ali et al., 2011 (2)	12			21	18
Ali et al., 2011 (3)	12			32	23
Sperlich et al., 2011 (1)	15			21 *	13 *
Sperlich et al., 2011 (2)	15			31 *	23 *
Sperlich et al., 2011 (3)	15			39 *	32 *
Sperlich et al., 2011 (4)	15			46 *	39 *
Miyamoto et al., 2011 (1)	9			18	12
Miyamoto et al., 2011 (2)	9			30	21
Menetrier et al., 2012	12	10	22	20	20
Wahl et al., 2012 (1)	9			21 *	13 *
Wahl et al., 2012 (2)	9			31 *	23 *
Wahl et al., 2012 (3)	9			46 *	39 *
De Glanville et al., 2012	14	1.1	9.3	6 *	14.7*
Hamlin et al., 2012	22	1.1	9.3	8.6	13.4
Bovenschen et al., 2013	15			25-35	
Bovenschen et al., 2013	4			25-35	
Sperlich et al., 2013b (1)	12			13,5	
Sperlich et al., 2013b (2)	12			19.7	
Sperlich et al., 2013b (3)	12			39.5	
Driller et al., 2013	12			20.5	

*: in vivo measurement. n: number of subjects in the study. Measured: as measured in our laboratory. Publication: as reported in the original article.

at ankle and calf levels.

The range of pressures delivered was very wide, ranging from1.1 to 46 mmHg at the ankle, and from 8 to 39 mmHg at the calf, when *in vivo* measurements were included, and from 1.1 to 34.3 mmHg at the ankle and 8 to 27 mmHg at the calf when only *in vitro* pressures were included.When both values were available, the pressures measured in our laboratory were in agreement with *in vitro* pressures reported in the original articlesdifference (< 5 mmHg). On the other hand, *in vivo* pressures reported in 4 original articles were largely higher than the pressures measured in our laboratory (> 10 mmHg). Based on *in vitro* pressures, in seven studies (Bringard et al., 2006a; 2006b; de Glanville and Hamlin, 2012; Hamlin et al., 2012; Jakeman et al., 2010; Scanlan et al., 2008; Trenell et al., 2006), the compression garment presented a progressive pressure profile with a very low pressure at the ankle (1.1 and 5.2 mmHg) and a slightly higher pressure at the calf (9.3 mmHg). In two studies (Menetrier et al., 2011; 2012), the compression garment presented a progressive pressure with a low pressure at the ankle (10 mmHg) and a higher pressure at the calf (22 mmHg). In the other studies the pressure profile was degressive.

Comparison between the effects reported and the pressures delivered (Figures 1 and 2)

Compression worn during exercise only (Figure 1): An improvement in performance recovery was reported in 2 studies, no improvement was observed in 5 studies; a reduction of DOMS was reported in one study, and no reduction in 7 studies. For both effects, the pressure range used in studies with negative results largely overlapped with the pressure range used in studies with positive results. Thus, the results appear to be independent of the pressures exerted at the level of the ankle and calf. In all these studies, ankle pressure was higher than calf pressure (degressive pressure profile).

Compression worn during recovery only (Figure 2): An improvement in performance recovery was reported in the six studies in which this effect was investigated, with pressures ranging from 1.1 to 34.3 mmHg at the ankle, and from 9.3 to 20.5 mmHg at the calf. The pressure profile was degressive in 4 studies, and progressive in 2 studies.

A reduction in DOMS was reported in 4 studies, with pressures ranging from 1.1 to 34.3 mmHg at the ankle and 9.3 to 19.2 mmHg at the calf, whereas DOMS was not reduced in 2 studies with 1.1 mmHg at the ankle and 9.3 to 20.5mmHg at the calf (Driller and Halson, 2013), i.e. the same pressures that were shown to be efficient in another study (Jakeman et al., 2010). Among the 3 studies with positive results, 2 used a degressive pressure profile and 1 a progressive pressure profile.

The wear time effect during recovery

The length of time the compression garments were worn during recovery differed between studies. Indeed, the garment wear time ranged from 15 minutes (Menetrier et al., 2011) to 48 hours (Trenell et al., 2006). In 4 studies, the compression garments were worn for less than 2 hours, while in 4 studies they were worn for more than 12 hours.

DOMS were estimated in 6 protocols (3 short and 3 long), and the performance recovery was analyzed in 7 protocols (4 short and 3 long). DOMS were decreased during recovery in 5/6 studies. The study that did not report DOMS decrease implemented a long protocol (48 hours of wear time). Performance recovery was improved in 5/7 studies. The two studies that did not observe an improvement of performance recovery used a short protocol.

Two studies used the same pressure profile (1.1 mm Hg on the ankle and 9.3 mm Hg on the calf) and long wear times (12 hours and 48 hours); nevertheless, only one of the two studies observed a positive effect on DOMS (Jakeman et al., 2010) while the other did not (Trenell et al., 2006).

Discussion

From these 24 original articles, selected on the basis of their methodology and their relevance, two clear trends emerge.

Firstly, wearing compression garments on the lower limbs during exercise seem to have little effect, as most studies failed to demonstrate a beneficial effect on immediate performance, performance recovery, or on DOMS; regardless of the type of exercise performed (endurance or resistance).

Secondly, there is a trend towards a beneficial effect of compression garments worn during recovery, since performance recovery was found to be improved in the six studies in which it was investigated, and DOMS was reduced in 4/6 studies. In the 7 studies reporting an improvement in performance recovery, 3 used a resistance trial and 4 an endurance trial, and in the 4 studies reporting a reduction of DOMS, 3 used a resistance trial and 1 an endurance trial, so there is no obvious relation between the type of exercise and the efficacy of compression.

When the effects of wearing compression during recovery were compared with the pressures applied, no clear relation was observed. The improvement of performance recovery was obtained with very low progressive compression in 3 studies, but also with high degressive compression in 3 studies. Similarly, a reduction in DOMS was obtained both with low progressive compression (1 study), and with degressive (low and high) compression (3 studies). Both low progressive compression and high degressive compression were shown to be inefficient in other studies. Thus, a relation between the pressures applied and the effects cannot be demonstrated from these data. A possible explanation for this lack of relation is that the effect size was not quantified in our analysis. Because the various studies used different methods to evaluate the effects of compression, it was not possible to use a common quantification system, and the reported effects were only recorded as a binary, present-or-absent variable. This could mask the existence of varying degrees of effect size.

Evaluating the possible relation between the level of pressure and the effect within each study was also a failure. From the 6 publications(Ali et al., 2011, 2010; Miyamoto et al., 2011; Sperlich et al., 2013b, 2011; Wahl et al., 2012) reporting the evaluation of several compression levels with the same protocol in the same subjects, only one study found an impact of the pressure level (Ali et al., 2011), namely an improvement in performance recovery with low (15 mmHg at the ankle) and medium (21 mmHg) compression, worn during exercise, but unchanged with high pressure compression (32 mmHg). In the other four studies where compression was worn during exercise only, no effect of compression was observed, whatever the pressure level.

The existence of a pressure threshold above or below which the application of lower limb compression allows an improvement in venous hemodynamics is not clearly defined in the medical literature. Many parameters are used to evaluate the effects of compression, including the velocity of venous circulation, venous pump function, or the degree of decrease in edema. However, results are divergent. Some authors have reported that the application of low pressure (15 mm Hg) is as effective on these parameters as mild pressure (15 - 20 mmHg) (Lattimer et al. 2013; Struckmann et al., 1986; Weiss et al., 1999), while others indicate that mild (18.4 – 21.1 mm Hg) and moderate pressures (25.1 – 32.1 mm Hg) were most effective (Liu et al., 2008; Lattimer et al., 2014), and yet others report that strong compression also has a positive effect on these parameters (Lawrence et al. ,1980).

The effects of venous compression on lower limb hemodynamics thus depend on several factors, such as the pressure exerted (Liu et al., 2008), the pressure gradient (weak versus high, digressive versus progressive) (Struckmann et al., 1986) and the thickness of the device (difference between the interface pressure in the prone position and in an upright position) (Partsch et al., 2012). Unfortunately, no dedicated study has investigated the effects of compression in the context of physical activity reports using all these parameters.

Furthermore, the effect of garment wear time during recovery could not be evaluated in this analysis. Indeed, there was wide heterogeneity in garment wear time in the selected studies (15 minutes to 48 hours). We observed both positive and negative results for both short and long wear times during recovery.

With the exception of one study (Moehrle et al., 2007) that included 37 subjects, the number of subjects investigated in each experiment was between 6 and 22, and most often less than 15. This rather small number may have precluded the detection of significant effects and the demonstration of any dose-response relation. Demonstrating the existence of a dose-response relation would require a much larger number of subjects involved in a single study, using uniform conditions of exercise and measurements.

Conclusion

Finally, wearing compression garments during recovery from exercise seems to be beneficial for performance recovery and DOMS, but the factors affecting this efficacy remain to be elucidated. Neither the type of exercise performed (endurance or resistance), nor the mechanical characteristics of the compression garment (value and spatial pattern of the pressure applied) were shown to influence the results. Furthermore, the mechanisms involved are largely hypothetical. The main hypotheses advanced to explain the effects of compression garments worn during physical exercise are the decrease in vibrations, the decrease in muscular micro traumatisms and reduced edema. The effects of compression garments during recovery are purportedly mediated by an improvement in venous return and in blood waste clearance.

Consequently, the use of compression garments in sports practice remains empirical. In order to progress towards an evidence-based choice of optimal pressures, further studies are necessary, with some basic methodological requirements. Firstly, for every tested compression garment, the authors should specify the pressure exerted, the pressure gradient and the thickness. Secondly, athletes participating in such studies should all have a similar level of practice, in order to avoid variation in the response. Thirdly, age, sex, muscle mass, hydratation, and potential venous disease are all factors that could affect the variability in tissue compressibility between subjects. Fourthly, the type of exercise chosen for the evaluation should induce reproducible effects. Fifthly, efficacy should be evaluated by means of objective and preferably quantified criteria (e.g. muscular soreness measured with an algometer, biological data, measure of muscular oscillations). Lastly, a dose-response assay with different pressure levels, including a placebo stocking, is highly desirable.

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Key points

- We observed no relationship between the effects of compression and the pressures applied.
- The pressure applied at the level of the lower limb by compression garments destined for use by athletes varies widely between products.
- There are conflict results regarding the effects of wearing compression garments during exercise.
- There is a trend towards a beneficial effect of compression garments worn during recovery.

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