

Research Advancements in Humanoid Compression Garments in Sports

Regular Paper

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Abstract The utilization of sport-related compression garments has attracted a great deal of attention from among Sports Science scholars. The function of the garments, such as to maintain muscle functions, reduce sports injuries and improve athletic performance, has been an issue of debate since the beginning of the new century. In this study, a number of methods including a literature review, logical analysis and mathematical statistics, are used to analyse earlier compression garments research, which can be found by searching hardcopy journals and online databases. Among the existing studies, most have tested and confirmed the functions of the garments; however, only a few have mentioned the underlying mechanism. Thus, by using more advanced and appropriate compression materials, future studies into compression garments will be focused on the vibration characteristics of muscles (soft tissues), and especially on their proprioceptive sensation, neuromuscular control, injury prevention and performance enhancement.

Keywords Compression Garments, Sports Science, Medical Engineering, Research Advancements

1. Introduction

High-tech sports-related equipment play a crucial role in both athletics and fitness in general, with the progress of

time and the development of technology. Compression garments (Figure 1), as just one type of high-tech equipment using unique techniques and having specific functions, are also becoming increasingly popular among professional and amateur sports participants [1-3]. From the “Siamese compression clothes”, which appeared in track and field competitions in the 1990s, to the new compression swimming suit “fast-skin”, which made big echo in the 2008 Beijing Olympic Games, compression garments are attracting increasing attention from researchers for their effects upon maintaining muscle functions, reducing sports injuries and enhancing sports performance [4,5].

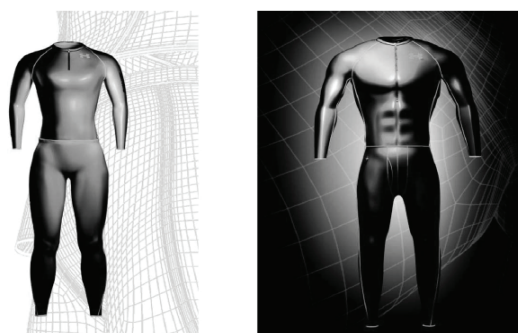


Figure 1. Recharge® compression garments produced by Under Armour.

Compression garments are normally made with an elastic fabric that conforms to the body's contour. This elastic element provides a degree of compression, which is evenly applied to the limbs, the trunk and other specific body areas, depending upon the different materials and designs. In recent years, compression garments - as commercial products - have been proposed as playing a positive role in improving the strength, endurance and recovery of athletes [1,5]. This paper reviews the advancements of compression garments research in the field of sports from around the world and is intended to serve as a valuable reference for further study of sports equipment in Sports Engineering and Sports Biomechanics.

2. Properties and major functions of compression garments

Generally, compression garments are made of a series of elastic textiles which can exert compression (pressure) on human limbs and the trunk through their own elasticity [6]. The material used in producing garments can be divided into two kinds [7]: one is a synthetic fibre which contains polyurethane (most sports-related compression garments use this material); another is an elastic fabric which consists of polyamide and elastodiene (this material is mainly used to produce clinical-related compression garments). Good compression garments should provide compression, a comfort feeling, ensure a proper fit and stretch, absorb humidity and optimize skin contact - they should also be light and enduring [6,8,9]. With regard to these features, compression garments are called as "the second level of human skin" by researchers.

With the broad use and study of compression garments in sports, the explanations for the performance enhancing function of the garments can be summarized as follows: 1) they can accelerate blood circulation; 2) they can alter kinematics parameters; 3) they can enhance proprioception and the related functions of human muscles; 4) they can reduce soft tissue vibrations [10-13]. Despite the functions stated above, more work is needed as these four explanations are a mere summary of all the previous research, among which, however, no similar or supportive results are given from among the mass of research. This is probably because: 1) different movements were tested in different studies; 2) the material or compressive level of the tested compression garments were not the same [14]. Moreover, no data has been found to explain the effect of compression on muscle responses, which restricts us from further understanding the compression apparel's underlying mechanism.

3. A current review of the research on compression garments

We searched: 1) electronic databases (Pubmed, SPORTDiscus and China National Knowledge

Infrastructure); 2) journals (Journal of Sports Engineering, International Journal of Sports Science and Engineering, Journal of Applied Biomechanics, Sports Biomechanics); and 3) conference papers (International Society of Biomechanics, 2005 to 2009; International Society of Biomechanics in Sports, 2005 to 2009; Chinese Society of Biomechanics, 2005 to 2009; Chinese Society of Biomechanics in Sports, 2005 to 2009; Chinese Conference on Sports Science and Sports Engineering) using the following subject terms and keywords: compression garment (clothing, short, sock, stockings and tights).

Up until 2010, 123 relevant papers were found. From the - time curve, we can see that the number of papers regarding compression garments has been increasing decade by decade (Figure 2). The number of studies into compression garments has also been exponentially increased during the last 10 years (Figure 3). In particular, over the last two years, the research conducted from various perspectives - including Physiology and Biochemistry, Biomechanics, Sports Medicine, Materials Science, and Design and Structure - has focused on compression garments (Table 1). The miscellaneous research will surely create a prosperous future for the development of compression garments.

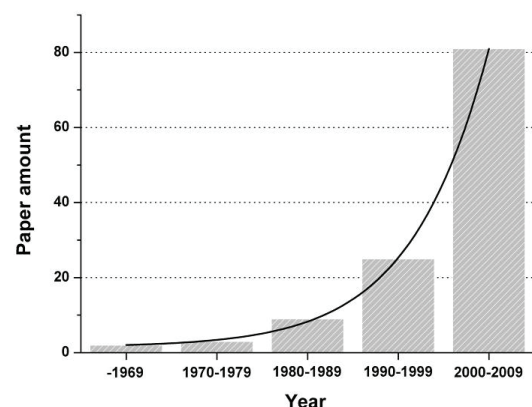


Figure 2. The amount of compression garments papers over the past 40 to 50 years.

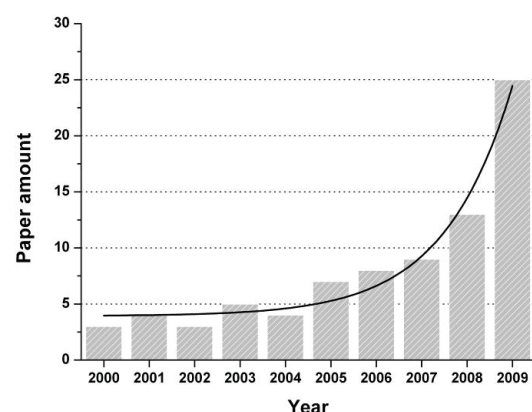


Figure 3. The amount of compression garments papers during 2000-2009.

Fields	Quantity	Percentage (%)
Physiology & Biochemistry	52	42.3
Biomechanics	30	24.4
Sports Medicine	18	14.6
Materials Science	13	10.6
Design and Structure	11	8.9
Others	7	5.7

Table 1. The application field of compression garments.

4. Popular topics in compression garments research

According to the research topics, we noticed that the initial stage of compression garments research can be classified in terms of those concerning Medical Physiology and others concerning Pathology. For example, wearing a compression garment was used as a treatment for postural hypotension and hemorrhagic shock as early as 1956 [15]. Later on, there were studies using medical compression apparel to avoid posture-caused low blood pressure and using compression stockings to prevent the so-called 'varicose symptom complex' among postoperative patients [16]. In the 1980s, however, compression garments were then applied into the sports field due to the invention of new elastic materials [17] and the emerging of Ergonomics [18]. Afterwards, sports-related compression garments were introduced to the field and were believed to have positive effects on sports performance. In the following thirty years, the research focused on Biomechanics, Sports Medicine and others, gradually dividing into three topics: 1) the effect of compression garments on athletes' strength; 2) the mechanism of fatigue; 3) the relationship between compression and muscle functions.

4.1 Compression garments and strength performance

For nearly two decades, up until the present, Sports Science and Sports Training experts have been using external sports performance to evaluate the function of compression garments when studying the relationship between compression and output strength.

As early as the beginning of the 1990s, Harman and co-workers found that by tightening the bandages on weightlifting athletes' knees, the vertical force output at the athletes' feet were significantly increased (amount: 11.4 ± 2.7 kg), while sports performance also indicated that wearing the bandage added 1RM for the athletes' squat thrust exercises [19].

From 1996 until 2001 [11,20-23], systematic research on various types of compression shorts with Lycra elastic fibres was conducted (Table 2). According to the results, it was found that compression shorts did not have a special effect on the single maximum ground reaction force or maximum power compared with normal sports shorts. However, during long-endurance exercise and during fatigue periods, compression garments did have a positive effect on strength output.

Year	Subject	Types	Protocols	Major results
1996	18 male and 18 female varsity volleyball players.	1) Compression shorts of normal fit. 2) Undersized compression shorts. 3) loose fitting gym shorts as the control garment.	10 consecutive maximal counter movement jumps with hands held at waist level were evaluated.	No effect on maximal force or power of the highest jump. The mean force and power production of wearing the compression shorts were significantly ($p \sim 0.05$) higher than CT for both men and women.
1998	20 healthy young adults (10 male, 10 female).	1) Compression shorts (CS). 2) Control (no compression) shorts (CT).	1) 3 sets of 50 maximal isokinetic knee extension/flexion movements at $180^\circ/\text{s}$. 2) The maximal number of reps at 70% 1-RM using a Tru Squat exercise machine.	No Significant differences were found between the CS and CT in peak torque or total work performed in the isokinetic knee extension/flexion exercise or in the max number of reps.
1998	10 healthy college age males and 10 healthy college age females.	1) Compressive shorts with 16%, 25% and 35% Lycra elastic fibre. 2) Control shorts.	1) 10 consecutive maximal counter movement jumps with arms held at waist level. 2) Joint position sense test. 3) Muscle vibration test. 4) 10 maximal isokinetic knee extension movements.	No effect on the maximal power of the highest jump in either men or women. Significantly enhanced mean power output in the jump test both before and after different fatigue tasks. Significantly reduced the vertical velocity of muscle movement upon landing.
2000	12 healthy females participated in this study.	1) 4 types of GCS. 2) Control shorts.	A total of 8 h of standing on hard floors. Experimental tests included determination of lower leg venous cross-sectional area, blood pressure, variation in the centre of pressure, vertical jump performance, etc.	GCS was effective in mediating a reduction in oedema in the ankles and legs while reducing the amount of venous pooling and discomfort in the lower body. May mediate these overall effects via different physiological mechanisms related to fluid shifts and muscle tissue damage.
2001	20 non-impaired non-strength-trained females participated in the study.	1) A testing compression sleeve group. 2) Control group.	Subjects performed 2 sets of 50 passive arm curls with the dominant arm on an isokinetic dynamometer with a velocity of $60^\circ/\text{s}$ and MVC.	Creatine kinase was significantly elevated from the baseline value in both groups. Compression sleeve use prevented the loss of elbow motion, decreased the perceived soreness, reduced swelling and promoted the recovery of force production.

Table 2. A 6 year systematic study of compression shorts conducted by Dr. Kraemer, W.J., and his group.

Meanwhile, in a recent study about compression garments and strength performance [24], subjects were shown to achieve a 5-second maximum isometric contraction and a continuous 25-time maximum isokinetic concentric contraction with a velocity of 60°/s and 300°/s. The result indicated that there were no significant differences in relative peak moment, relative peak power, the first five average power and the total work among three different compression conditions. This conclusion also supported Dr. Kraemer's finding in 1998 [25] that in a continuous 50-time maximum knee extensor isokinetic contraction, no differences were found in peak moment or total work between the compression garments group and the control group. Similarly, athletes' oxygen uptake, pH index, muscle soreness and fatigue sensation volumes showed no significant difference between two groups during the sub-maximal and maximal oxygen consumption treadmill exercise in another study [26].

Thus, despite the previous studies which stated that sports equipment with a particular compression could improve strength output, the possible mechanism - such as the compression effect - may change the kinematics parameters in motion or else increase muscle proprioception and balance [27,28] still needs to be confirmed.

4.2 Compression garments and sports fatigue

The first sports-related study concerning compression equipment was performed by Berry and MacMurray in 1987. They found that the lower limbs' blood's lactic acid decreased after high intensity exercise while wearing compression garments, which contributed to fatigue recovery [29]. Since then, scientists have begun to study the relationship between sports compression garments and fatigue. By observing the variations of the human body, they found that compression garments could affect fatigue. Some physiological research can explain this phenomenon: one showed that compression garments shortened the time that the muscle needed to reach its optimized temperature (38.5°C) [30]; at the mean time, they prevent the human thermal regulation system from getting over-heated and over-wet [31]. In addition, some studies on post-match recovery proved that compression garments can facilitate the elimination of muscle oxygenation and CK [32], alleviate DOMS [33], decrease the accumulation of the blood's lactic acid [34,35] and, finally, accelerate the recovery process after high intensity exercise [36].

Apart from the physiological research, there were also a number of studies which were conducted by Biomechanics experts. In a repeated vertical jump movement study, the power output turned out to be better under compression conditions; the compression shorts also asserted a positive effect on fatigue

elimination [22]. Meanwhile, Fu et al. [37] found that the normalized declination of knee extension torque was much slower under high compression conditions, which illustrated that wearing compression garments can enforce the anti-fatigue ability of muscles.

4.3 Compression garments and muscle functions

Recently, studies of compression garments have not been limited to their effects on human external performance; more attention has been paid to exploring the relationship between the additional load - which is added by compression garments - and the feedback of the human internal musculoskeletal system. New methods and new measurements have contributed to this progress. For example, through using electromyography (EMG) and mechanomyography (MMG), it is possible to investigate the electrical and mechanic characteristics of muscle and soft tissue vibrations and excitation-contraction coupling, which is helpful in understanding the motor control strategies of the neuromuscular system [38,39]. Using EMG and MMG RMS amplitude, Xiong et al. [40] observed muscle activity under different compression conditions. The results indicated that in both low and high speed isokinetic concentric contractions, additional elastic bandage could affect muscle activities as well as the recruitment of the nerve muscle fibres during the long-duration contraction of the *rectus femoris*. This finding supported those found by Miyamoto et al. [41].

On the other hand, since part of the muscles' activities (muscle tuning) were proven to reduce soft tissue resonance, it is proposed that the soft tissue vibration was crucial for the energetics of running [42,43]. Meanwhile, there are more published papers supporting the statement that compression equipment could reduce muscle vibrations during human locomotion [17]. Thus, it is reasonable to assume that external devices like compression garments can be used to reduce soft tissue vibrations, prevent unnecessary muscle tuning activities and decrease energy consumption. The hypothesis was then tested by Coza and Nigg, and the results showed that the damping coefficient of soft tissue vibration in the compression shorts group increases by $8\% \pm 2.1\%$ ($p < 0.05$) within 200 ms after touchdown and that the EMG amplitude in the compression shorts group was much smaller within 100 ms before and after touchdown [13].

Coincidentally, an earlier study has already been conducted to examine the relationship between compression garments and muscle vibration [30]. Subjects were asked to perform vertical jumps wearing compression shorts. The results indicated that the vibration amplitude of the wrapped lower extremity muscles significantly decreased by 0.32 cm in the vertical direction and 0.40 cm in the anteroposterior direction in

both women and men. This supported the hypothesis made by Kraemer in 1998 [25]. One possible mechanism that the author considered was that the decrease of muscle vibration displacement could optimize neurotransmission, and these mechanical changes may exist at the molecular level.

5. Conclusion

Along with the development of technology and globalization, high-tech sports equipment is playing an increasingly crucial role in competitive sports and daily life. It has already created tremendous economic value. According to the data issued by WFSGI and SGMA [44], the global scale of the sports devices market has exceeded a hundred billion dollars each year. With the prospects of a broad market, compression garments will surely become an important issue in sportswear studies.

Currently, international sports elites are choosing commercial compression garments as their training and competition apparel. For instance, in 2007, Nike launched the Nike pro series compression garments; in 2008, Adidas produced their POWERWEB compression apparel; in 2009, Speedo developed a new generation LZR Racer compression swimsuit, while the American professional sports equipment company, Under Armour, also exploited the Recharge® series of compression tights. However, the mechanism as to how compression garments promote sports performance remains uncertain and supportive results are still lacking [14].

To sum up, with the discovery of more advanced compression materials, future studies of compression garments will continue to be focused on muscle (soft tissue) vibration characteristics, and especially on proprioceptive sensation, neuromuscular control, injury prevention and performance enhancement.

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