KJSB

Korean Journal of Sport Biomechanics 2016; 26(4): 421-426
http://dx.doi.org/10.5103/KJSB.2016.26.4.421
http://e-kjsb.org eISSN 2093-9752

ORIGINAL

Differences in Rectus Femoris Activation Among Skaters Wearing Fabric Speed Skating Suits with Different Levels of Compression

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Received : 18 November 2016
Revised : 13 December 2016
Accepted : 17 December 2016

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Objective: The purpose of this study was to investigate how different levels of compression exerted on the femoral region (known as the power zone) by coated fabric influences the activation and anaerobic capacity of the rectus femoris.

Method: Three different levels of compression on the rectus femoris of the participants, namely 0% (normal condition), 9% (downsize), and 18% (downsize), were tested. The material of the fabric used in this study was nonfunctional polyurethane. Surface electromyography test was used to investigate the activation of the rectus femoris, while the isokinetic test (Cybex, 60°/sec) and Wingate test were used to investigate the maximum anaerobic power.

Results: The different compression levels (0%, 9%, and 18%) did not improve the strength and anaerobic capacity of the knee extensor. However, knee flexor interfered with activation of the biceps femoris, which is an agonist for flexion, during 18% compression.

Conclusion: Compression garments might improve the stretch shortening cycle effect at the time of eccentric contraction and during transition from eccentric to concentric contraction. Therefore, future studies are required to further investigate these findings.

Keywords: Speed skating suit, Compression, Rectus femoris, Muscle activation

INTRODUCTION

In a speed skating simulation study, Saetran (2008) reported that different race suits could produce a difference of 3 seconds in a 1,500-m race. Given that the difference between the first and second place in the 1,500-m final at the 2014 Sochi Winter Olympics was only 0.003 seconds (Lee et al., 2014), the small effect of the suit and apparatus can have a major impact on the outcome of a race. Thus, the importance of sportswear is receiving increasing attention (Brownlie et al., 2004). As scientific and differentiated equipment reduces friction, improves motor efficiency, and has a positive impact on athletic ability, active athletes consider their personal equipment and clothing to be important, and are quick to adopt innovative, proven equipment if it could help them achieve even slightly better results. Recently, race suits for athletes have focused on the development of functional clothing that reduces muscle fatigue by limiting the size of large muscle movements during exercise. Compression clothing improves athletic performance, and alleviates post-exercise muscle pain and tissue damage. Kraemer et al. (2010) and Doan et al. (2003) reported that even simple compression stockings contribute to reducing fatigue (Berry & McMurray, 1987) and improving muscle power (Done et al., 2003). Takarada (2002) implemented blood flow restriction training in the lower limb and reported a 15% improvement in muscle strength and a 10% increase in cross-sectional muscle area. Based on the observation that compression reduces edema, and improves venous and lymphatic return, Chatham and Thomas (2013) suggested that compression improved muscle strength by increasing blood circulation. However, Ebersole (2006) found no significant differences in peak torque, total work, or peak power at different levels of compression. Thus, opinions vary on the effectiveness of compression clothing. Moreover, it has not been clearly demonstrated that compression is effective in improving athletic performance. Nevertheless, compression clothing is receiving attention worldwide from elite athletes, both in intense competitions and leisure sports (Fu et al., 2012). Efforts have been made to develop samples or products that can improve athletic performance through compression clothing. Therefore, based on a functional coated fabric applied to the femoral region of speed skating suits (developed as part of a nationally funded project to develop textiles, led by the Korea Evaluation Institute of Industrial Technology), the present study analyzed how different levels of compression affected the maximum power and activation of the rectus femoris, which produces the most power during racing, with the aim of assisting the future manufacture of speed skating suits.

METHODS

1. Participants

The participants in this study were 6 male and 4 female students currently enrolled in a physical exercise-related major who had experience in using isokinetic machine and Wingate equipment, and had no musculoskeletal disorders. The mean physical characteristics of the male participants were as follows: age, 20 ± 0.89 years; height, 172 ± 4.9 cm; and body weight, 66.7 ± 10.9 kg. The mean physical characteristics of the female participants were as follows: age, 20.75 ± 0.5 years; height, 165.2 ± 2.4 cm; and body weight, 56.75 ± 5.7 kg.

2. Data processing

Prior to the experiment, the study aims and procedures were explained to all the participants, and only the participants who gave their willful consent to participate were instructed to sign the consent form. In addition, the participants were instructed that they could withdraw their consent to participate in the study at any time, at their own will. The coated fabric used in this study is applied to the femoral area during manufacture of speed skating suits. It is a non-functional polyurethane material consisting of a 0.2-mm film layer and a 0.12-mm adhesive layer. The linear mass density of the main structure that contacts the skin is 300 g/y and is composed of 20% spandex and 80% nylon. Photographs of the material are shown in Figure 1.

Figure 1. Property of the coating fabric and attachment location

Three compression conditions were used for the coated fabric (0%: fitted perfectly when the rectus femoris was neither flexed nor extended; 9%: a compression of 9% relative to the 0% condition; and 18%: a compression of 18% relative to the 0% condition). To minimize errors during the experiment at each of the 3 compression conditions, the study used a random-assignment, crossover design (with 2 days of rest). The crank, seat, and shoulder straps were adjusted to fit each participant's body, and the femoral region and ankle were fixed with knee-pads and straps. To produce the maximum torque, before making any measurements, the participants were instructed on the objectives and order of the measurements, and the operating principles of the equipment. The participants were also given ample practice time to warm up appropriately and to practice the positions for the proper posture during the measurements. During the measurement with the isokinetic machine, the knee joint was fixed as shown in Figure 2. To measure the peak muscle strength of the rectus femoris, 3 measurements were taken each on the right and left sides, at 60˚/sec. For the Wingate test, the saddle height was set as shown in Figure 2 to enable the participants to completely extend the leg (120~150˚). The participants were given 2 minutes to thoroughly loosen up and adapt to their position. Relative resistances of 0.08 and 0.077 kp/kg of body weight were applied for the male and female participants, respectively. After a 5-second countdown, the participants were shown a "Start" signal, after which they pedaled at a maximum speed for 30 seconds. In addition, the participants were provided at least 3 minutes of rest between actions. One measurement was made for each compression condition. After completing all the experimental procedures, the participants only left after performing cooldown exercises for their own safety.

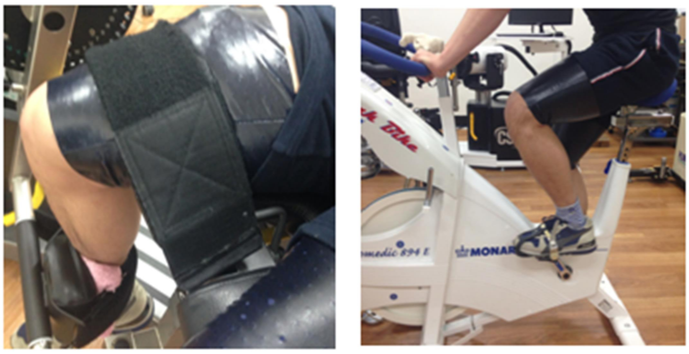

Figure 2. (Left) The Cybex test and (Right) Wingate test

3. Measurements

Electromyography (EMG) was performed bilaterally on the rectus femoris, which produces the largest forces during speed skating (Kim et al., 2005, Jung & Kim, 2012). After removing superficial hairs from the skin and cleaning the area with an alcohol-soaked swab to obtain a better signal, 22-mm-diameter Ag/AgCl surface electrodes (Noraxon, Scottsdale, AZ, USA) were attached to the cleaned surface to measure signals from the muscle (Hermens et al., 1999). A Butterworth fourth-order high-pass filter with a cutoff frequency of 20 Hz was applied to the EMG signal to eliminate movement artifacts and noise around the zero point (De Luca et al., 2010). Full-wave rectification was then performed to obtain the root mean square, after which a Butterworth fourth-order low-pass filter with a cutoff frequency of 15 Hz was applied to make a linear envelope (Laughlin et al., 2011). This signal processing was applied identically to all maximal voluntary contractions (MVC) and EMG measurements included in this study (Kim et al., 2000). The MVC values measured in the 60˚ isometric test were divided by body weight to normalize the data. For the % MVC of the rectus femoris, the mean values of the three measurements were calculated for each side. An isokinetic dynamometer (CSMI Solutions, USA) was used to measure the isokinetic muscle strength of the right and left knees at 60°/sec. Maximum muscle strength was measured three times on each knee before taking the mean for each side and normalizing the body weight provided by the Cybex. Anaerobic power was measured three times for each compression condition using the Wingate test with a bicycle ergometer (Monark, Sweden). A resistance of body weight × 0.075 kp was calculated and applied to each participant before having the participant pedal at full capacity for 30 seconds (Lamb, 1978). As soon as the pedals reached maximum speed, the weight dropped and was recorded as 0 seconds. Anaerobic power was measured for 30 seconds after that, and changes in rectus femoris activation were analyzed bilaterally in the intervals of 0~5, 6~10, 11~15, 16~20, 21~25, and 26~30 seconds (Rana, 2006).

4. Statistical analysis

In accordance with the aims of this study, differences in activation and maximum power of the rectus femoris were measured and analyzed under different levels of compression by a fabric used in the development of speed skating suits. The mean and standard deviation (mean ± SD) were calculated for each measured variable, and SPSS 18.0 (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis. As the number of participants in this study was too small to show meaningful group characteristics, the distribution of the study population was not considered and nonparametric tests were used to draw conclusions based only on the possibility of the acquired data from the sample. A repeated-measures one-way analysis of variance (ANOVA) was used to analyze changes in the rectus femoris under the three compression conditions (0%, 9%, and 18%) by the fabric. A statistical significance level of $p < 0.05$ was used. As the ANOVA revealed a significant difference, paired t tests were performed as a post hoc analysis to verify the relationships between pairs of compression conditions (0% and 9%, 9% and 18%, and 0% and 18%). To account for type 1 errors, a Bonferroni test was performed using a statistical significance level of $p = 0.017$.

RESULTS

1. Isokinetic muscle strength

Table 1 shows the results of analyzing muscle strength using an isokinetic machine. No statistically significant difference in peak torque was observed with increasing compression. The mean power at 0% compression was 188.7 ± 38.11 W for right extension, 180.3 ± 32.30 W for left extension, 121.7 ± 22.30 W for right flexion, and 116.0 ± 20.85 W for left flexion. At 9% compression, the mean power values were 192.8 ± 30.37, 181.5 ± 22.04, 120.6 ± 24.79, and 110.7 ± 32.83 W, respectively. At 18% compression, the mean power values were 182.6 ± 29.46, 179.3 ± 33.55, 112.5 ± 26.26, and 114.5 ± 20.21 W, respectively. Statistical analysis revealed that the mean power of flexion was significantly lower at 18% compression than at 0% compression ($p < .017$).

Therefore, power was greater at 0% compression than at 18% compression.

2. Anaerobic power (Wingate test)

Table 2 shows the results of the analysis of anaerobic power with the Wingate test. The peak power (mean power during the first 5 seconds) was 12.23 ± 3.008 W at 0% compression, 12.13 ± 2.913 W at 9% compression, and 12.12 ± 2.584 W at 18% compression. No statistically significant differences in anaerobic power were observed with increasing compression.

3. Rectus femoris activity during isokinetic and anaerobic power testing

Table 3 shows the results of the EMG analysis of the rectus femoris

Table 1. Results of the isokinetic muscle strength test

Variables			Compression garment 0%	9%	18%	Post hoc
Peak torque (Nm)	Extension	R	266.8 ± 68.11	279.7 ± 57.51	265.0 ± 64.81	
		L	267.0 ± 65.96	269.7 ± 45.84	259.4 ± 60.46	
	Flexion	R	151.4 ± 28.73	150.2 ± 33.23	143.3 ± 27.98	
		L	146.3 ± 30.01	145.4 ± 25.32	145.1 ± 27.05	
Mean power (Watt)	Extension	R	188.7 ± 38.11	192.8 ± 30.37	182.6 ± 29.46	
		L	180.3 ± 32.30	181.5 ± 22.04	179.3 ± 33.55	
	Flexion	R	121.7 ± 22.30	120.6 ± 24.79	112.5 ± 26.26	0% > 18%
		L	116.0 ± 20.85	110.7 ± 32.83	114.5 ± 20.21	

Note: $p < .017$

Table 2. Result of the anaerobic power test (unit: W)

Variables	Peak power (1 sec)	Post hoc
0%	12.23 ± 3.008	
9%	12.13 ± 2.913	
18%	12.12 ± 2.584	

Note: p < .017

during the isokinetic and anaerobic power testing under different compression conditions. The MVC measured before the Wingate test was 49.59% ± 14.62% on the right side and 48.89% ± 4.993% on the left side at 0% compression, 51.19% ± 5.404% on the right and 54.98% ± 10.31% on the left at 9% compression, and 47.36% ± 13.45% on the right and 51.37% ± 20.99% on the left at 18% compression. Although no statistically significant differences were found at different levels of compression, measurements were slightly higher at 9% compression. During anaerobic power testing, from 0 to 5 seconds, the MVC was 6.003% ± 4.769% on the right and 4.826% ± 3.498% on the left at 0% compression, 2.741% ± 1.590% on the right and 4.149% ± 2.884% on the left at 9% compression, and 3.095% ± 1.774% on the right and 3.934% ± 2.147% on the left at 18% compression. Post hoc testing revealed that the rectus femoris activity was significantly higher at 0% compression than at 9% compression during the anaerobic power testing (p < 0.017). From 6 to 10 seconds, the MVC was 5.578% ± 1.929% on the right side and 4.649% ± 1.428% on the left at 0% compression, 3.369% ± 1.180% on the right side and 4.411% ± 2.151% on the left at 9% compression, and 4.082% ± 2.067% on the right side and 4.891% ± 2.757% on the left at 18% compression, showing a similar pattern to the 0- to 5-second interval. However, after 10 seconds, no statistically significant difference in rectus femoris activity was found according to compression level.

DISCUSSION

This is a basic study to support the development of a high-functioning speed skating suit with popular appeal, in preparation for the 2018 Pyeongchang Winter Olympics. To this end, we tested how the level of compression affected the strengthening of the rectus femoris using a fabric developed for use in the manufacture of speed skating suits. Smith (1987) studied the relationship between anaerobic power and isokinetic torque, and reported a positive correlation between maximum power in a Wingate test and peak isokinetic torque. Based on this finding, we measured isokinetic power and anaerobic power to verify the muscle strengthening effects of compression by the fabric. In the analysis of isokinetic muscle strength (Table 1), the compression level had no significant effect on the mean power during knee extension. However, during knee flexion, power was significantly lower at 18% compression. Compared with the results of the study by Ebersole (2006), who reported that the level of compression had no significant effect on peak torque, maximum power, or total work, our results were similar when the rectus femoris was the agonist, but were different during knee flexion when the rectus femoris was acting as an antagonist.

Table 3. Results of the rectus femoris muscle activation during anaerobic power measurement

Trial and phase			Compression garment			Post hoc
			0%	9%	18%	
Isokinetic test (%)	MVC	R	49.59 ± 14.62	51.19 ± 5.404	47.36 ± 13.45	
		L	48.89 ± 4.993	54.98 ± 10.31	51.37 ± 20.99	
Wingate test (%)	0~5 sec	R	6.003 ± 4.769	2.741 ± 1.590	3.095 ± 1.774	0% > 9%
		L	4.826 ± 3.498	4.149 ± 2.884	3.934 ± 2.147	
	6~10 sec	R	5.578 ± 1.929	3.369 ± 1.180	4.082 ± 2.067	0% > 9%
		L	4.649 ± 1.428	4.411 ± 2.151	4.891 ± 2.757	
	11~15 sec	R	5.433 ± 2.493	3.972 ± 1.297	4.819 ± 2.623	
		L	5.045 ± 2.254	4.300 ± 1.723	5.190 ± 2.256	
	16~20 sec	R	5.528 ± 2.459	4.565 ± 2.397	5.678 ± 3.712	
		L	5.142 ± 2.416	4.478 ± 1.518	5.271 ± 3.265	
	21~25 sec	R	6.500 ± 2.538	5.774 ± 2.767	6.772 ± 4.000	
		L	6.632 ± 3.059	5.349 ± 2.545	5.925 ± 3.903	
	25~30 sec	R	7.395 ± 2.631	6.989 ± 3.724	7.374 ± 4.684	
		L	6.999 ± 2.798	5.663 ± 2.703	7.300 ± 4.294	

Note: p < .017

During flexion, the rectus femoris acts as the antagonist muscle and opposes the action of the agonist muscle, the biceps femoris. At 18% compression, it showed less activation than at 0% and 9% compressions. We suggest the following reasons for these results. First, at 18% compression, the fabric had a negative effect on the ability of the rectus femoris to exert an antagonistic force. Second, when the rectus femoris acted as an antagonist, the fabric was stretched and tried to return to its original state. This elastic effect causes a decrease in the antagonistic force that needs to be produced by the rectus femoris. Doan (2003) reported an improvement of up to 2.4 cm in counter-movement jump when wearing compression clothing as compared with the control. By contrast, Fu (2012) argued that compression clothing makes it easier to adopt a squat position in preparation for a jump and that a deep squat before the jump increases the height of the jump. Combining this information, the result of Doan can be considered from a different perspective. As compression clothing is inherently highly elastic, it has the potential to increase the effect of the stretch shortening cycle, in which extension is followed immediately by contraction. EMG results were analyzed during isokinetic muscle strength measurements on the Cybex and during anaerobic power measurements in the Wingate test. While no significant differences were found during the isokinetic measurements, during the Wingate test, muscle activity was significantly lower at 9% compression than at 0% compression during both the 0- to 5-second interval and 6- to 10-second interval. Miyamoto (2011) reported differences in EMG activation according to compression level, while Crenshaw (2000) reported that fatigue and EMG activation decreased when wearing compression clothing. Based on these studies, the decrease in EMG activation when wearing compression clothing in the present study is thought to demonstrate the possibility of a more-efficient exercise performance. On the other hand, these results could also be explained by a decrease in muscle vibration and improved blood circulation, which have been proposed as the major functions of compression clothing (Duffield, Cannon & King, 2010); therefore, this possibility should not be overlooked.

CONCLUSION

This is a basic study to support the development of a high-functioning speed skating suit with popular appeal, in preparation for the 2018 Pyeongchang Winter Olympics. We tested how compression level affected the strengthening of the rectus femoris using a fabric developed for use in the manufacture of speed skating suits. Isokinetic measurements were performed using a Cybex machine, and anaerobic power was measured using the Wingate test. The results of this study showed that the compression level had no significant effect on the mean power during isokinetic knee extension under most conditions. However, at 18% compression, the mean power of flexion was significantly lower. Two possible explanations can be considered for these results. The first possibility is that at 18% compression, the fabric had a negative effect of suppressing the force that could be exerted by the rectus femoris. The second possibility is that during knee flexion, the extension of the antagonist muscle rectus femoris caused the fabric to stretch, at which point the elasticity of the fabric had the positive effect of reducing the force required from the rectus femoris to complete the movement. The latter positive effect is thought to be more prominent, but future research is required.

EMG analysis was also performed during the measurements of isokinetic muscle strength on the Cybex machine and anaerobic power in the Wingate test. EMG activation was found to be lower at 9% compression than at 0% compression. This decrease in EMG activation is thought to demonstrate the possibility of a more efficient exercise performance.

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