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Compression suits with and without films and their effects on EMG during isokinetic exercise

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Abstract

This study aimed to determine the differences in the EMG of thigh among film-welded compression suits (WCS), film-free compression suit (CS) and a loose sportswear during knee joint exercise. To differentiate the effect of clothing variable accurately, two types of compression suits were made elaborately using the same material and 3D pattern. Difference in two compression suits is only whether film was welded or not. EMG was observed during isokinetic exercise of flexion and extension, comprising four sets of maximum contraction of thigh at the angular velocity of 60, 180 and 240°/s using Cybex 660. When the WCS was worn, the mean muscle activities of the anterior thigh was generally higher during extension, especially in the left rectus femoris (RF) and right vastus oblique medialis (VMO) throughout the exercise. Wearing WCS enhanced mean muscle activities and decreased muscle fatigue of VL and VMO at each angular velocity, however, it did not support the mean muscle activity nor the fatigue of the hamstrings in almost all conditions of exercise. Muscle-specific EMG implies that film-welded compression suit designed in this study is beneficial to VMO, inducing high muscle activity with less fatigue during knee extension.

Keywords: Compression suits, Film-welded, EMG, Isokinetic exercise, Muscle activity, Fatigue of thigh

Introduction

Compression garments are widely used among athletes, and studies have been conducted to determine the compression effect on the wearers' physiology and performance in sports activities. There are reports that compression garments not only provide a beneficial effect on vein blood circulation and muscle oxygenation (MacRae et al. 2012) but also reduce oscillations or vibrations, which consequently reduce energy loss and fatigue (Doan et al. 2003; Higgins et al. 2007; Duffield and Portus 2007). In a recent work, compression pants facilitated angular velocity during drop landing (Lee et al. 2017), however, controversy regarding the effectiveness of compression garments on the biomechanics or performance still exists depending on various sports activities and experimental conditions, such as participant conditions or compression items (Hsu et al. 2017; Jimenez et al. 2016). Especially, no detailed reports have revealed the effect of different compression suit types on the physiological and biomechanical performance. As the necessity of developing more sophisticated compression garments has emerged, various commercial products applying the kinesio taping - like films on base compression garments have been developed. However, to date, there has been very little research on the performance of muscles depending on the design elements of the compression suits such as a reinforcing film welded on the compression suit, which is analogous to kinesio taping on skin.

Kinesio taping itself has been widely used in the treatment of neuromuscular disorders. The main advantage of taping is that it is a non-invasive but easily applicable tool in various sports without any adverse effects. Taping prevents sports injury recurrence and improves sports performance, such as muscle strength (Han 2015; Slupik et al. 2007; Thelen et al. 2008). Ha et al. (2008) proposed taping as an effective method for improving muscle performance by exerting relief to the tensed muscles, helping to contract the weak muscles. Further, muscle strength is increased by stabilizing the muscles when taping is applied during exercise and increasing coordination functions, maintaining the balance of the cooperative and antagonistic muscles (Lee et al. 2002). However, there are negative opinions regarding the effectiveness of taping (Parreira et al. 2014) in muscle activity; taping did not affect the electromyographic (EMG) activity neither in the trapezius and serratus anterior (Cools et al. 2002) nor the knee and thigh (Fu et al. 2008). According to the recent meta-analysis, strength-enhancing effects of Kinesio taping were negligible (Reneker et al. 2018; Csapo and Alegre 2015). Although, taping on the skin was not effective in improving the isokinetic strength of healthy individuals (Kang et al. 2012; Wong et al. 2012), questions regarding the effect of Kinesio taping on those who are not healthy or old still remain. In addition, authors stated that there is still potential for Kinesio taping to enhance sports performance psychologically (Reneker et al. 2018).

As mentioned above, there have been many studies on the effects of Kinesio taping, however, the effects of various types of compression garments on human reaction have not been studied thoroughly, yet. So far, commercially available compression items were compared with those products without any compression in many prior researches on compression suits (Jimenez et al. 2016; Kerherve et al. 2017). In recent years, interest to design more functional compression suits has been evolved from a simple viewpoint of whether a compression suit is put on. As a result, research efforts to analyze the effects of compression suits accurately are increasing. However, comparing the types of compression garments in the market could not tell the accurate effect of design elements such as welded film. It is not easy to find a pair of pressure suits which have the same design characteristics and materials and differ only by the film in the commercial market. As such, it is difficult to determine the separate effect of the reinforcing film on the wearer.

Although the goal of wearing a functional compression suit is to improve performance in a total system, the first thing to consider is to focus on a variable in question step by step, controlling other variables that cause errors. From this point of view, studies using Cybex are desirable at an early stage of study. Cybex is an isokinetic exercise device that allows flexion and extension of a specific body part only (Kannus 1994). EMG measurement on the specific muscles while performing Cybex exercise will be helpful to understand the relationship between the design elements of compression garments and related specific muscle. Therefore, we designed two types of 3D compression suits of a film-welded compression suit (WCS) and a film-free compression suit (CS) to be identical except for the welded film and analyzed electromyogram of the groups of thigh muscles while performing knee exercise using Cybex. Ultimately, the effect of WCS on the muscle activity and fatigue was investigated to provide information on the design of functional compression suit which is beneficial to the specific muscle of thigh.

Methods

Questions

As such, this study was conducted to determine the following questions

1. Do compression garments with welded films (WCS) have a better effect on thigh muscle activities than film-free compression garments (CS) during isokinetic exercise of knee joint?
2. If compression garments are effective for muscle activity and fatigue delay, does this effect appear equally in the anterior and posterior thigh muscles?
3. Is there any difference in the muscle performance depending on the mode of exercise such as flexion/extension, angular velocity of knee movement or duration of exercise?

Subjects and experimental garment

Experiments were conducted on seven male college students attending the physical education department who were familiar with the Cybex exercise (age: 21.4 ± 1.7 years, height: 175.8 ± 5.9 cm, weight: 72.0 ± 9.0 kg, body mass index: 23.2 ± 1.5 kg/m^2). Those who agreed to participate after fully understanding the purpose and procedure of the study and providing a signed informed consent underwent the pre-test. All procedures were approved by the ethics committee (201612-SR-064-01). Physical examination and pre-test were conducted to evaluate whether there was an abnormality in the knee and thigh. The subjects were instructed to abstain from drinking and exercising extensively for 24 h prior to the experiment and provided a simple meal 3 h before the experiment.

The experimental garments consisted of short-sleeved t-shirts and shorts as a control (BS), compression suit (CS), and power film-welded suit on the CS (WCS) (Fig. 1). The material composition of two compression suits was Cation Dyed Polyester (CDP)77/Polyurethane (PU) 23 and thickness was .55 mm. Polyurethane film was welded onto the compression garment, and the lines of film was selected and connected to one another to provide stable pressure to the waist, hip, and part of thigh, while avoiding places where the skin is stretched in the upper leg (Choi and Hong 2015). In order to prevent slipping of hem during knee exercise, taping film wrapped the legs along the circumferential direction below the patella. We developed a three-dimensional pattern suitable for the subject and made a compression suit, CS. For WCS, the same three-dimensional pattern panel was fabricated by welding PU film on each panel firstly and sewing panels with welded film. The garment pressure range of CS on human body was about .7–3.5 kPa and that of WCS was 1–5.3 kPa. The maximum value was observed at the measurement point just above the skeleton, iliac crest. Clothing pressure of two types of suits was

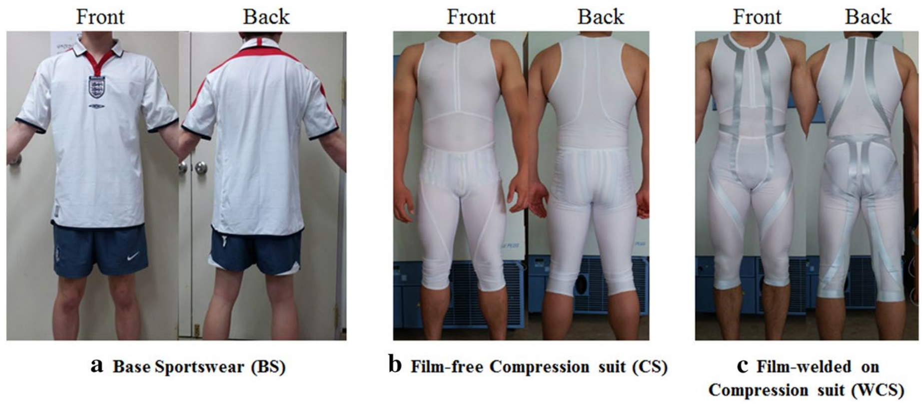

Fig. 1 Experimental garments used in this study

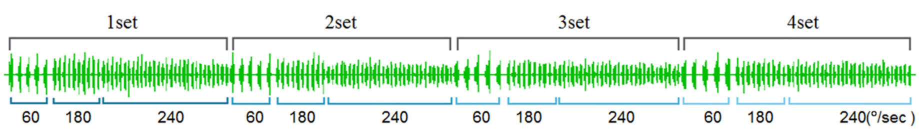

Fig. 2 Exercise protocol of the knee joint flexion and extension exercise using Cybex

generally less than 2 kPa, and clothing pressure of WCS was about 0.3 kPa greater than that of CS on average.

Exercise protocol

Cybex 660 (Cybex Inc., USA) was used to perform isokinetic knee exercises at the angular speeds of 60°/s, 180°/s, and 240°/s. The range of motion limited the angle between the knee and ankle from 0° to 100°. The exercise protocol comprised a set of five trials at an angular velocity of 60°/s, 10 trials at 180°/s, and 30 trials at 240°/s (Fig. 2). The subjects were seated in the chair and stabilized with straps across the pelvis and torso, familiarized with the protocol in the pre-test and verbally encouraged to perform maximum contraction during knee exercise. They were allowed to rest for 1 min between each angular velocity and 2 min between each isokinetic exercise set. Since they could not continue the isokinetic exercise beyond more than four sets owing to muscle fatigue, the exercise protocol was limited to four sets. To avoid a carry-over effect of the previous exercise, the following exercise was performed 1 week later.

Measurements

The electromyography (EMG) electrodes were attached on three points on the anterior thigh (rectus femoris, vastus lateralis, and vastus medialis oblique), and two on the posterior thigh (semi tendinosus, and biceps femoris), using the Noraxon EMG system (Telemyo 2400T G2, Noraxon, USA). To determine the mean muscle activity, maximum muscle activity, and fatigue, the mean RMS (root mean square), peak RMS, and mean MDF (median frequency) from the EMG were extracted. The data were measured using the wi-fi communication, and the sampling rate was set at 1000 Hz. The EMG data were analyzed using a bandpass filter to analyze the signal of the frequency band corresponding to 20–500 Hz. Repeated measures (ANOVA), split plot analysis and Tukey post hoc analysis were employed using IBM SPSS Ver.21.0.

Results and discussion

Mean muscle activities during total exercise sets

When all data across the exercise protocol were analyzed during total exercise sets, mean muscle activities of the three anterior muscles with WCS (rectus femoris, vastus lateralis, and vastus medialis oblique) were generally higher than those with CS or BS during knee extension (Table 1). Especially, mean muscle activity of the left rectus femoris (RF) was significantly higher with the WCS (121.74 µV) than with the CS (88.76 µV) ($p < .05$, Table 1) and that of the right vastus medialis oblique (VMO) with the WCS (192.0 µV) was significantly higher than that with the BS (141.5 µV) ($p < .05$) during knee extension. The result of this experiment was supported by the previous study in that taping on compression pants resulted in higher mean muscle activity of thigh than kinesio taping directly on the skin (Choi et al. 2016). Such insufficient effect of direct taping on skin was found in other work, in that taping did not support the EMG activity of the vastus lateralis (VL) and VMO oblique (Janwantanakul and Gaogasigam 2005). In the recent research, however, Kinesio taping did alter EMG responses, notably enhancing VMO activation during cycling (Losier et al. 2019). VMO was noted as a dynamic stabilizer of patella, aligning the patellar within the patella-femoral joint trochlea. In fact, the film welded on WCS traversed the VMO in this study, wrapping below the patella of knee, which likely stimulate VMO and stabilize patella.

On the other hand, WCS showed different effects on the groups of thigh muscles during extension and flexion of knee joint. There were no significant WCS effects in the mean muscle strength of the posterior thigh muscle either during extension or flexion even when semi tendinous and biceps femoris led to larger muscle contraction power of the posterior thigh.

Table 1 Mean muscle activity of five muscles during knee extension using Cybex (unit: µV)

Muscles	Right/left leg	Base sportswear		Film-free compression suit		Film-welded compression suit		F	*p*
		M	(SD)	M	(SD)	M	(SD)		
Rectus femoris (RF)	Right	99.06	(28.18)	113.10	(45.41)	110.92	(46.11)	.549	.598
	Left	111.38	(19.11)^{AB}	88.76	(16.17)^{A}	121.74	(27.43)^{B}	5.940	.031*
Vastus lateralis (VL)	Right	136.52	(40.60)	159.96	(48.70)	176.64	(38.34)	2.787	.121
	Left	123.48	(24.56)	139.98	(28.75)	156.98	(32.88)	3.607	.084
Vastus medialis oblique (VMO)	Right	141.46	(32.52)^{A}	157.08	(27.85)^{AB}	191.98	(40.64)^{B}	4.638	.046*
	Left	147.00	(26.21)	145.56	(43.18)	176.20	(23.87)	1.311	.328
Semi tendinosus (SF)	Right	14.54	(2.40)	12.98	(4.40)	22.10	(26.75)	.502	.623
	Left	17.60	(11.54)	11.72	(3.10)	11.96	(3.67)	.551	.599
Biceps femoris (BF)	Right	19.62	(7.67)	16.34	(8.47)	17.30	(5.28)	.857	.460
	Left	22.55	(5.26)	21.86	(7.85)	25.44	(8.39)	1.414	.305

$^{A–B}$ Different alphabet indicates significant difference by Tukey

*$p < .05$

Mean muscle activities at each angular velocity

Regarding the effect of mode of exercise, the mean muscle activities depending on experimental clothing at different angular velocities were investigated at each 60,180, 240°/s. For the statistical analysis, split plot analysis was used in SPSS, in that data of the garment type were allocated as the subplots and the set number of exercise repetitions as the main plot to maximize the effect of the compression suit type.

At the angular velocity of 60°/s

During knee extension, the anterior muscles of thigh were contracted, so that the mean muscle activities of the anterior thigh were larger than those of posterior muscles as shown in the left graph in Fig. 3. Among the three anterior muscles of thigh, the mean muscle activities of the left rectus femoris were significantly higher with the WCS than with the film-free CS and the BS during knee extension at 60°/s. In the cases of the left vastus lateralis, mean muscle activities were significantly higher with the WCS than with the BS. The film-welded WCS did not show significantly higher mean muscle activity in other muscles of thigh. During the knee joint flexion (right in Fig. 3), the relative magnitude of muscle activity of the anterior and posterior thigh muscles with the WCS were reversed. The mean muscle activities of two posterior muscles, semi tendinosus and biceps femoris, were higher than that of anterior thigh in case of knee flexion. No difference in muscle activities was found depending on the types of experimental garments. The tendency of the peak EMG for the maximum muscle activity was similar to that of mean muscle activity both during extension and flexion.

In the case of subjects' dominant leg, which is subjects' right leg, significant positive effects of the film-welded WCS on the anterior thigh were found in muscles of vastus lateralis (VL) and vastus medialis oblique (VMO) ($p < .05$), not in rectus femoris (RF) during extension (left of Fig. 4). During knee flexion, film welded compression suit was not favorable to the posterior muscles of thigh, CS was slightly better than WCS, which

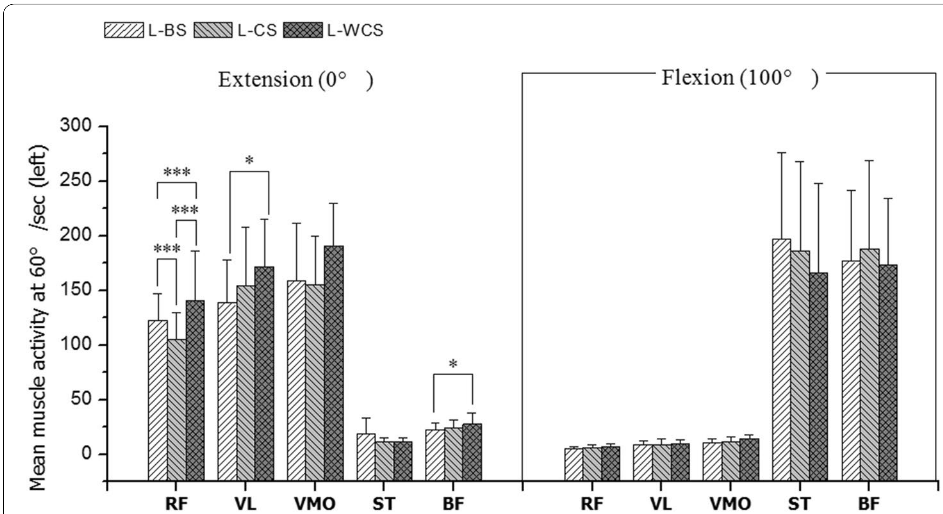

Fig. 3 Mean muscle activities of the left legs at the angular velocity of 60°/s: left (during knee extension); right (during knee flexion)

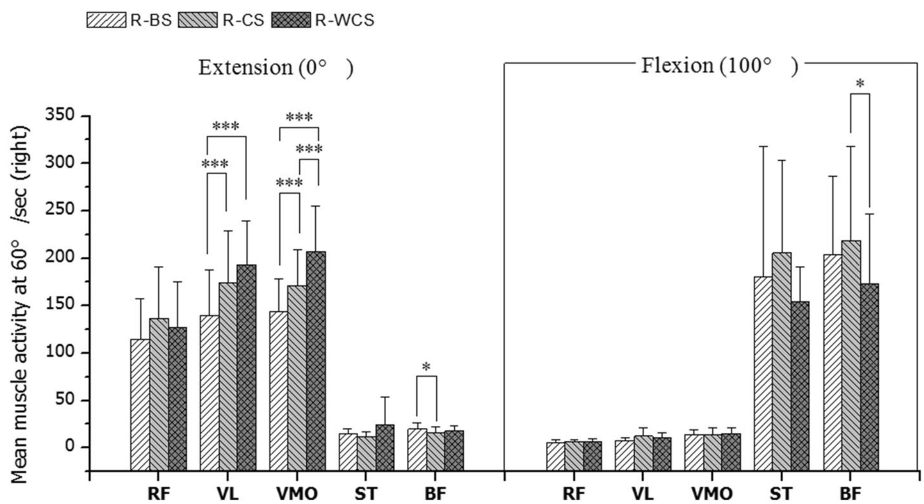

Fig. 4 Mean muscle activities of the dominant right legs at the angular velocity of 60°/s: left (during knee extension); right (during knee flexion)

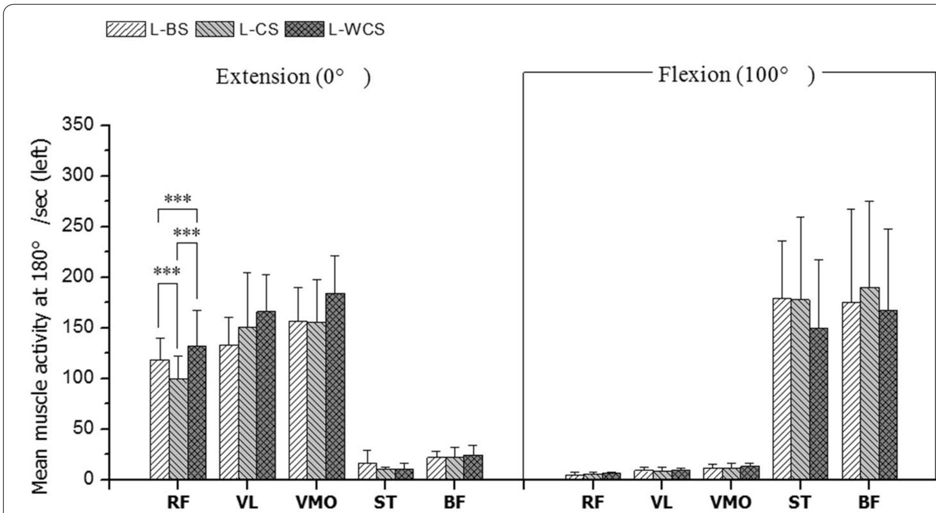

Fig. 5 Mean muscle activities of the left legs at the angular velocity of 180°/s: left (during knee extension); right (during knee flexion)

was also detected in the case of maximum muscle activity. Different reaction of posterior muscles of hamstring was also found in the previous work of Lumbroso et al. (2014) where they found that the hamstring reacted differently when kinesio taping was applied. They could not observe an increased peak force in the hamstring right after kinesio taping. It was detected only after 2 days. Considering the Lumbroso et al.'s result, it is necessary to investigate the effect of WCS for extended periods in future to find the different effect of film-welded WCS on the muscle activity.

At the angular velocity of 180°/s

In the case of the left rectus femoris, the mean muscle activities were again significantly higher with the WCS than with the BS or CS (Fig. 5, left) at the medium angular velocity (180°/s). As in the case of the previous slow angular velocity of 60°/s, WCS did not increase the mean muscle activities of other muscles during knee flexion.

In Fig. 6, the mean muscle activity of dominant right leg at 180°/s showed the similar result very much as in the case of 60°/s angular velocity. Wearing WCS resulted in the highest values in vastus lateralis (VL) and vastus medialis oblique (VMO) during extension. During flexion, wearing film-free CS was beneficial to produce higher mean and maximum muscle activities of SF than the case of WCS.

At the angular velocity of 240°/s

During knee extension, the mean muscle activity of the left RF was higher with the WCS than with the CS and BS (Fig. 7). In addition, at the 240°/s, the mean muscle activities of the VL and VMO with the WCS were significantly higher than with the CS and BS. No difference was found among the experimental garments during knee flexion. Further research is needed to find whether the reactions of posterior muscles, BF and ST, by the compression suit are slow and time dependent, since the effect of kinesio taping on the hamstring was time dependent and not immediate (Beck et al. 2012).

In the case of the dominant right leg, the WCS was favorable to the mean muscle activity of VL and VMO as in the case of 60°/s and 180°/s (Fig. 8).

Fatigue (MDF: median frequency)

There was no significant difference in the mean fatigue of the five muscles when data collected from the entire exercise sets were dumped together, so that MDF at each exercise set and angular velocity was further investigated.

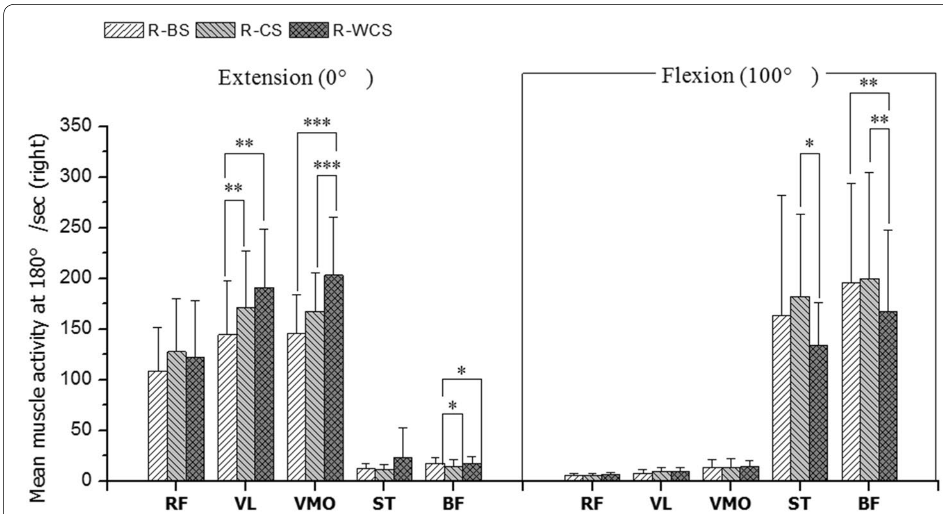

Fig. 6 Mean muscle activities of the right legs at the angular velocity of 180°/s: left (during knee extension); right (during knee flexion)

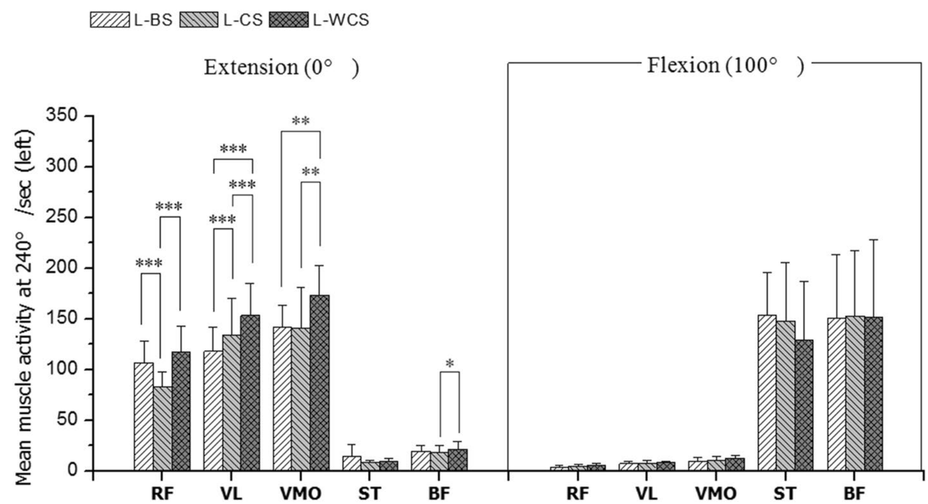

Fig. 7 Mean muscle activities of the left legs at the angular velocity of 240°/s: left (during knee extension); right (during knee flexion)

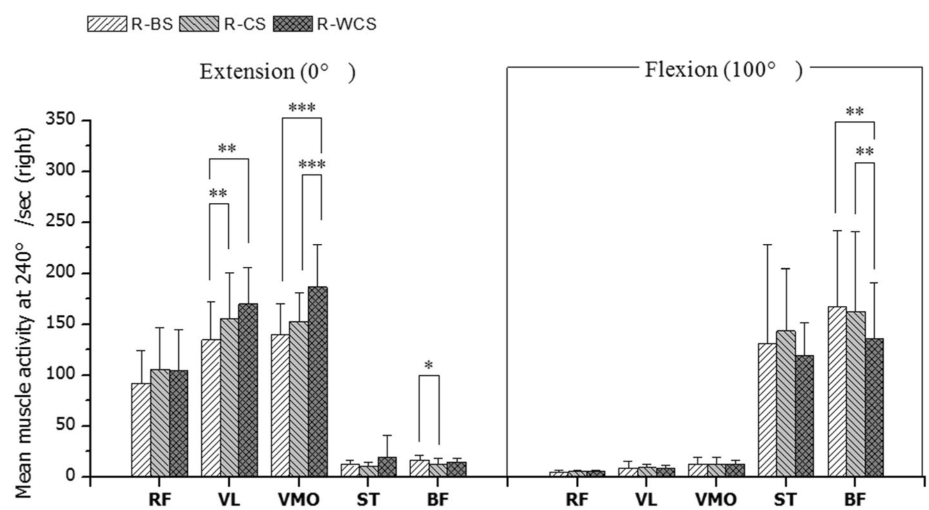

Fig. 8 Mean muscle activities of the right legs at the angular velocity of 240°/s: left (during knee extension); right (during knee flexion)

MDF at each exercise set

At certain exercise sets, partial differences in fatigue measured as MDF were found, where a higher MDF indicates a lesser muscle fatigue (Phinyomark et al. 2012). In this study, the WCS showed higher MDFs than the CS and BS in the left VMO in the third and fourth sets, indicating that when the subjects wore the 3D WCS, they had lesser muscle fatigue in the left VMO at the later stage of the exercise protocol (Table 2). The VMO was reported to exert its influence as a stabilizer of the patella during knee extension (Hubbard and Opersteny 2002). It is possible that the diagonal film securing the VMO supported the muscle (Lee et al. 2002), which should be verified further.

Table 2 MDF for muscles at each exercise set (data presented only if there were significant differences by type of clothing) (unit: Hz)

Muscle	Set	Base sportswear		Film-free compression suit		Film-welded compression suit		F	p
		M	(SD)	M	(SD)	M	(SD)		
Vastus medialis oblique (VMO) (Left)	3	51.6	(4.6)^A	53.5	(6.6)^A	60.5	(8.2)^B	9.382	.010*
	4	51.8	(5.0)	52.6	(5.4)	60.6	(9.8)	5.101	.043*

A–B Different alphabet indicates significant difference by Tukey

*p < .05

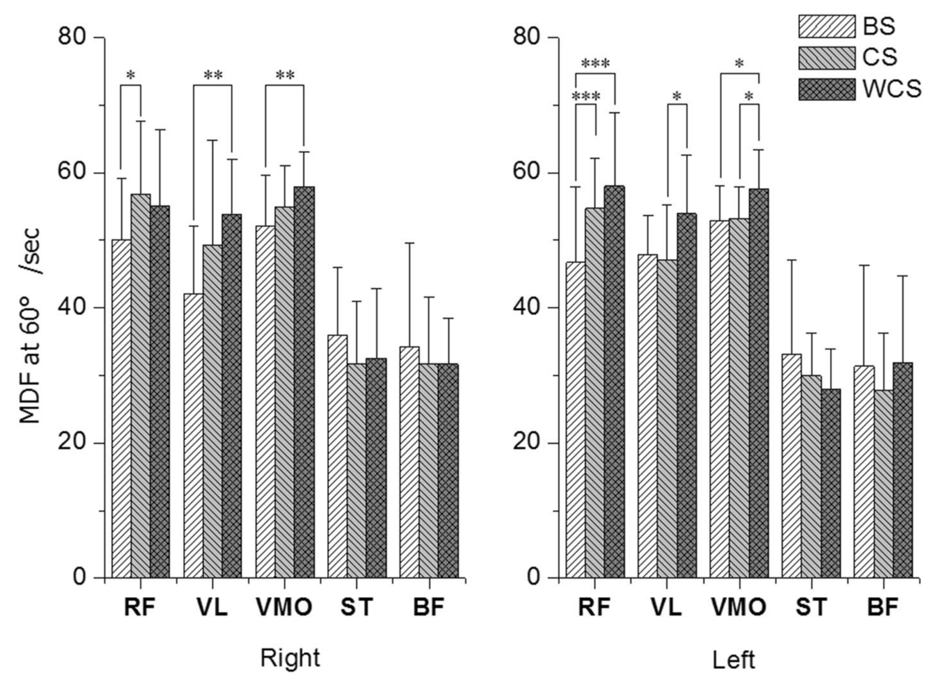

Fig. 9 MDF at the angular velocity of 60°/s: left is for the left leg; right is for the right leg

MDF across the groups of thighs at 60°/s

To determine the effect of the experimental garments on the groups of muscle fatigue depending on the angular velocity of exercise, the MDF was analyzed at each angular velocity. There was a significant difference in the MDF among the experimental garments in all anterior muscles (RF, VL, VMO) at 60°/s (Fig. 9). The MDF with the WCS was highest on the all anterior muscles of both the left and right thigh, meaning that the WCS was effective in relieving fatigue of the anterior thigh at the low angular velocity, however, the effect of the WCS did not present at the posterior thigh (ST and BF).

MDF at 180°/s

Wearing WCS was also beneficial to the fatigue of RF, VF of the left thigh, and VL and VMO of the right thigh (Fig. 10). The similar result was reported previously, where the fatigue in rectus femoris decreased during isokinetic muscle contraction (Fu et al. 2012; Wang et al. 2016).

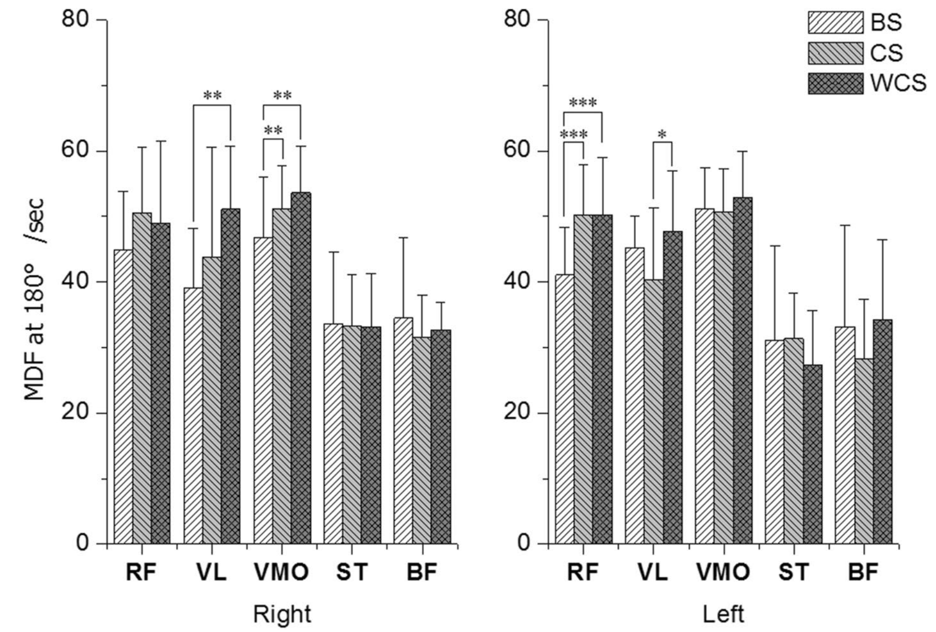

Fig. 10 MDF at the angular velocity of 180°/s: left is for the data of left leg; right is for the right leg

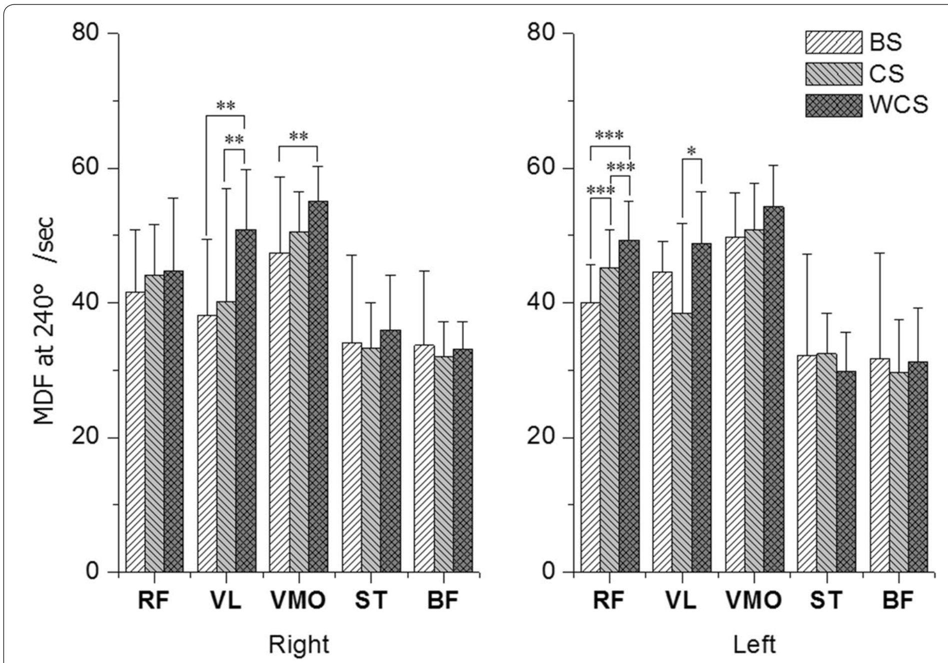

Fig. 11 MDF at the angular velocity of 240°/s: left is for the data of left leg; right is for the right leg

MDF at 240°/s

The WCS showed a higher MDF in the left RF and VL than the CS and BS (Fig. 11). The MDF of the right VL and VMO was higher with the WCS than with the BS.

If we plot the fatigue generation as the number of repetitions increased, we could find that MDF of WCS was apparently higher for right and left VL and VMO, meaning wearing WCS generated less fatigue at VL and VMO of the anterior leg (Fig. 12c–f), which was not found in the posterior thigh. It is also noted that, wearing compression suit would delay muscle fatigue slightly at the beginning of exercise as shown in the case of BF (Fig. 12g, h).

Conclusion

In this study, the effect of a film-welded compression suit (WCS) on the muscle activity and fatigue was investigated, compared with that of film-free compression suit (CS) and loose-fit basic sportswear (BS) during isokinetic knee joint exercise. Findings showed that muscle strength-enhancing patterns with WCS were not apparent in all thigh muscles throughout all conditions of exercise. WCS increased the rectus femoris (RF) activity of the non-dominant leg, left RF, but did not increase the RF activity of the dominant leg. As a further study, it is necessary to confirm that the compression suit is more advantageous for relatively weak muscles.

It was noted that the muscle activity of the right vastus medialis oblique (VMO) muscles enhanced significantly and MDF of the VMO was higher when wearing the WCS, meaning when subjects wear such WCS, they could have benefit of the high muscle activity for a longer time with less fatigue. This result is presumed to be due to the film attached to the WCS supporting the VMO and stabilizing the patella in this study. VL also had benefits in muscle activity and muscle fatigue at each angular velocity when WCS was worn, however, as for the posterior thigh muscles, WCS did neither support

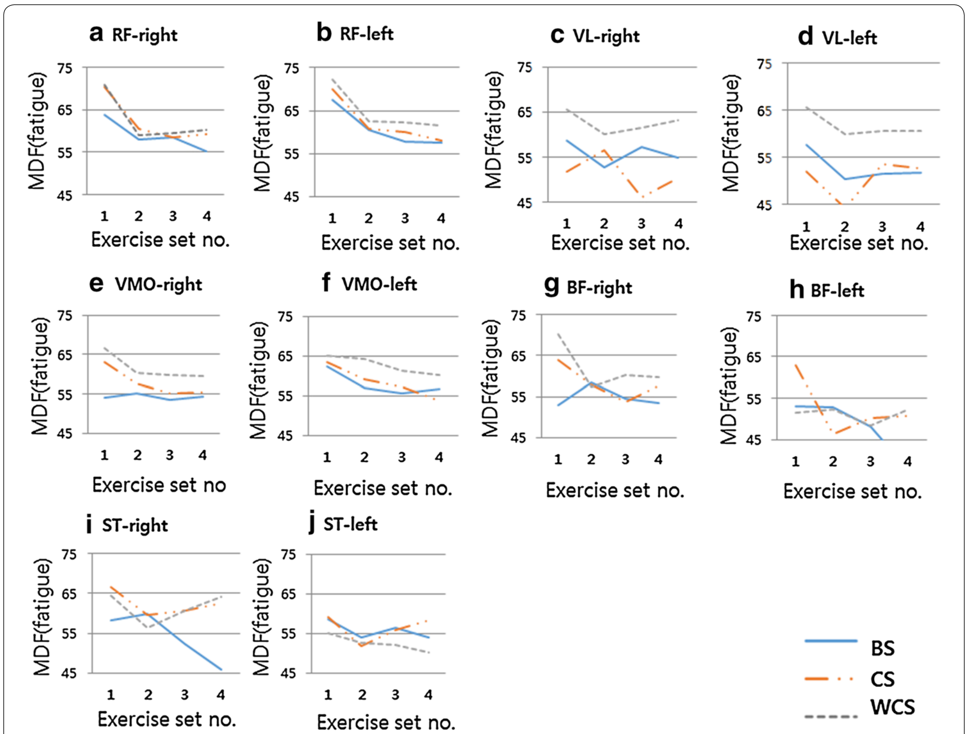

Fig. 12 MDF across the entire exercise protocol for each muscle

the mean muscle activity nor the fatigue of the hamstrings (SF and BF) during both extension and flexion throughout most of the exercise. Further investigation on the muscle performance with detailed structure of welded film on the suit is necessary in the next step.

Authors' contributions
JC collected and analyzed data. KH discussed the result with JC. Both authors read and approved the final manuscript.

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Competing interests
The authors declare that they have no competing interests.

Availability of data and materials
The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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