
BJHMedical
YOUR TRUSTED
Lifetime Partner
Life Care Solution :
- Rehabilitation
- Neurological Technogy & Innovation
- Physical Therapy
- Cardiac Science AED
natus.
magstim
chattanooga
EMS
ARGON
HOLOGIC
CARDIAC science
EMCOOLS
HITACHI
Inspire the Next
ALOKA
BJH MEDICAL | WWW.BJHMEDICAL.COM | Nanchaya Tel. 02-367-1111 Ext.2454
BJHMedical

วารสารวิทยาศาสตร์และเทคโนโลยีการกีฬา ปีที่ 16 ฉบับที่ 2, ธันวาคม 2559
Journal of Sports Science and Technology Volume 16, No. 2, December 2016

นิพนธ์ต้นฉบับ (Original article)
สรีรวิทยาการออกกำลังกายและกีฬา (Sports and Exercise Physiology)

# ผลของแรงกดของถุงน่องแบบผ้ายืดที่มีต่อการทำงานของกล้ามเนื้อขาท่อนล่างขณะออกกำลังกายด้วยการเดิน

พงษ์ศักดิ์ เชิงขุนทด[1]*, วารี วิดจายา[2], เมตตา ปิ่นทอง[2]
[1]คณะวิทยาศาสตร์การกีฬา, มหาวิทยาลัยเกษมบัณฑิต, มีนบุรี, กรุงเทพมหานคร 10510
[2]วิทยาลัยวิทยาศาสตร์และเทคโนโลยีการกีฬา, มหาวิทยาลัยมหิดล, ศาลายา, นครปฐม 73170

**บทคัดย่อ**

การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาผลของการใส่และไม่ใส่ถุงน่องแบบผ้ายืดด้วยแรงกดที่แตกต่างกันของถุงน่อง ที่มีต่อการทำงานของกล้ามเนื้อ ขณะออกกำลังกายด้วยการเดิน อาสาสมัครเป็นชายที่มีสุขภาพดีทั้งหมด 30 คน อายุระหว่าง 21-22 ปี ทำการออกกำลังกายด้วยการเดินบนลู่วิ่งไฟฟ้าเป็นเวลา 45 นาที (ที่ความเร็ว 3.5 ไมล์ต่อชั่วโมง, ความชัน 10%, โดยอบอุ่นร่างกายด้วยการเดินที่ความเร็ว 2 ไมล์ต่อชั่วโมง เป็นเวลา 3 นาที) พร้อมกับการใส่ถุงน่องแบบผ้ายืด ที่มีแรงกดของถุงน่องที่บริเวณน่อง ประมาณ 4 มิลลิเมตรปรอท (P4; n=17) หรือ 10 มิลลิเมตรปรอท (P10; n=13) ขณะออกกำลังกาย และอาสาสมัครจะทำการทดสอบทั้งหมด 2 ครั้ง คือ การทดสอบขณะทำการใส่และไม่ใส่ถุงน่อง โดยการทดสอบในแต่ละครั้งจะมีระยะเวลาห่างกัน 7 วัน ค่าแรงบิดสูงสุด และค่า root mean square (RMS) ที่ได้จากคลื่นไฟฟ้ากล้ามเนื้อ โดยวัดที่กล้ามเนื้อ tibialis anterior (TA) และกล้ามเนื้อ medial gastrocnemius (MG) ของขาข้างขวา ซึ่งจะถูกวัดค่าขณะที่มีการทดสอบการหดตัวสูงสุดของกล้ามเนื้อ ด้วยการทำ isokinetic dorsi-plantar flexion จำนวน 5 ครั้งทั้งก่อนและหลังจากหยุดออกกำลังกายทันที และนำข้อมูลมาคำนวณค่าเปอร์เซนต์ของค่าแรงบิดสูงสุดและค่า RMS

จากการศึกษาพบว่า การใส่ถุงน่องส่งผลให้เปอร์เซนต์ของค่าแรงบิดสูงสุดของกล้ามเนื้อ MG ก่อนการออกกำลังกายมีค่าต่ำกว่าเมื่อเทียบกับการไม่ใส่ถุงน่อง แต่ภายหลังการออกกำลังกายไม่พบว่ามีความแตกต่างของค่าแรงบิดสูงสุดระหว่างการใส่และไม่ใส่ถุงน่อง นอกจากนี้พบว่าภายหลังจากการออกกำลังกาย การใส่ถุงน่องสามารถรักษาค่าแรงบิดสูงสุดเมื่อเทียบกับตอนเริ่มต้นก่อนการออกกำลังกายได้ การใส่ถุงน่องแบบผ้ายืดอาจช่วยให้การทำงานของ muscle pump ดีขึ้น และลดการล้าของกล้ามเนื้อได้ อย่างไรก็ตามการใช้ถุงน่องแบบผ้ายืดในการศึกษานี้อาจจำกัดการเคลื่อนไหวและทำให้ความยาวของกล้ามเนื้อ MG ลดลง จึงทำให้แรงบิดสูงสุดของกล้ามเนื้อมีค่าลดลง

(Journal of Sports Science and Technology 2016; 16(2) : 67-77)

**คำสำคัญ**: ถุงน่องแบบผ้ายืด, แรงบิดสูงสุด, ไอโซไคเนติก, มัธยฐานของความถี่, การบันทึกคลื่นไฟฟ้ากล้ามเนื้อ

***ผู้นิพนธ์หลัก**: พงษ์ศักดิ์ เชิงขุนทด
คณะวิทยาศาสตร์การกีฬา, มหาวิทยาลัยเกษมบัณฑิต,
มีนบุรี, กรุงเทพมหานคร 10510
E-mail: bird.pongsak@gmail.com

วารสารวิทยาศาสตร์และเทคโนโลยีการกีฬา ปีที่ 16 ฉบับที่ 2, ธันวาคม 2559

Journal of Sports Science and Technology Volume 16, No. 2, December 2016

นิพนธ์ต้นฉบับ (Original article)

สรีรวิทยาการออกกำลังกายและกีฬา (Sports and Exercise Physiology)

# EFFECTS OF ELASTIC COMPRESSION STOCKING ON LOWER LEG MUSCLE ACTIVITY DURING WALKING

Pongsak CHERNGKHUNTHOD[1]*, Waree WIDJAJA[2], Metta PINTHONG[2]

[1]*Faculty of Sports Science, Kasem Bundit University, Minburi, Bangkok, Thailand 10510*

[2]*College of Sports Science and Technology, Mahidol University, Salaya, Nakhon Pathom, Thailand 73170*

## ABSTRACT

The aim of the present study was to investigate the changes of muscle activity with and without the elastic compression stocking (ECS) with two different compression pressures during walking. Thirty healthy male subjects (age range of 21-22 years) participated in this study. Subjects performed walking on the treadmill for 45 minutes (at speed 3.5 mph, inclination 10%, including warm up at speed 2 mph for 3 min) and wore either the ECS with compression pressure approximately 4 mmHg (P4; n=17) or 10 mmHg (P10; n=13) at the calf during exercise. Each group performed two trials, 7 days apart, with and without elastic compression stocking in a randomized manner. Before and immediately after the walking, isokinetic peak torque and the root mean square (RMS) from surface electromyography (EMG) signal of right tibialis anterior (TA) and right medial gastrocnemius (MG) muscles were recorded during isokinetic dorsi-plantar flexion for five times of maximal repetitive contractions.

The results showed that the percentage peak torque of MG muscle was significantly lower when wearing the ECS compared to not wearing the ECS at pre-exercise, whereas those with and without the ECS at post-exercise were not different. Additionally, the peak torque following walking with ECS could be maintained at the baseline because of the enhancement of the muscle pump and reduction of muscle fatigue. However, using ECS in the present may compromise peak torque at pre-exercise especially in the MG muscle because the stiffness of the ECS might restrict joint movement and decrease muscle length.

(Journal of Sports Science and Technology 2016; 16(2) : 67-77)

**KEY WORDS:** Elastic compression stocking, Peak torque, Isokinetic, Median frequency, Electromyography

***Corresponding author:** Pongsak CHERNGKHUNTHOD

Faculty of Sports Science, Kasem Bundit University,

Minburi, Bangkok, Thailand 10510

E-mail: bird.pongsak@gmail.com

## INTRODUCTION

The ECS can be used effectively not only for medical treatment but also for enhancement of sport performance in a diversity of sports[1]. Mechanism of the ECS is that pressure exerted by the stocking will increase intra-compartmental pressure. As a result, it will increase either intramuscular pressure[2] or cutaneous pressure[3]. The stocking exerted a compression pressure at the ankle was higher than at the calf producing a "degressive" pressure profile on the leg[4]. Thus, the ECS can reduce a cross-section of vein[5] and its venous blood flow is expedited[6]. In addition, it has been reported that the ECS improves venous return[7] and reduces blood pooling[8] as well as reduces blood lactate accumulation in the lower limb during exercise[9]. The recommendation for optimal pressure of the ECS was 20-40 mmHg for enhancement physical performance such as vertical jump, running time, and fatigue[10].

Lawrence and Kakkar (1980) investigated that ECS exerted external compression on blood circulation responses include for low pressure range of 10, 8, and 4 mmHg and for high pressure range of 30, 24, and 14 mmHg at the ankle, calf, and knee, respectively. The authors reported that the high pressure range was decreased deep venous velocity in some subjects and subcutaneous tissue flow, whereas the low pressure range was increased muscle blood flow and subcutaneous tissue flow[11]. Liu and coworker (2008) suggested that the ECS with light (10-14 mmHg), and mild (18.4-21.2 mmHg) compression profiles influenced reduction in venous cross-sectional area, venous pooling, and improved venous return of the lower extremities[7]. In other study reported that about the effects of ECS on subjective sensation, which that they investigated the proximal external compression force at the ankle (0, 15, 21 and 30 mmHg for control, low, medium and high-grade of ECS, respectively). It was found that ECS gave more comfortable sensation in the low and the control groups than the medium and the high groups[12]. Moreover, compressive pressure of ECS approximately 15-20 mmHg at the ankle was claimed to be difficult to put on and removal the stocking[13]. Therefore, the present study used the ECS with low compression pressure, which consisted of 4 and 10 mmHg external compression at the calf for investigation of the effect of the ECS on physiological responses.

On the other hand, studies of compression stocking garment are mostly related to peripheral blood circulation[7,8,9], whereas few studies assessed the effects of the ECS on muscle fatigue by using surface electromyogram (EMG) and torque generated capacity of the muscle contractions. Human muscle fatigue has been investigated by using several assessment methods, exercise profile, and procedures. In isokinetic contraction, one of the choices assessed muscle fatigues is maximal power output as well as peak torque value. In addition, muscle fatigue can be investigated by using the EMG. The EMG signal produces power spectral estimation, whose frequency contents tends to decrease when fatigue occurs. In the EMG analysis, a root mean square (RMS) of the EMG signal indicates muscle fatigue which arises from impaired muscle fiber velocity (MFV) and increased motor unit (MU) recruitment during muscle contraction[14]. The purpose of this study was to investigate changes of muscle activity in the conditions of without and with two different pressures of the ECS during walking.

## MEDTHODS

### Subjects

Thirty healthy males, voluntarily participated in this study. Subject characteristics are given in Table 1. They did not participate in any physical activity for more than 2 times a week. Each subject provided written informed consent before the start of the test. This study was approved by the Mahidol University Institutional Review Board (2012/098.3105).

**Table 1.** Characteristics of subjects

| Variables | | P4 (n=17) | P10 (n=13) |
|---|---|---|---|
| Anthropometric variables: | | | |
| | Age (yrs) | 22.1 ± 0.57 | 21.0 ± 0.2 |
| | Body weight (kg) | 65.74 ± 2.05 | 73.17 ± 3.91 |
| | Height (cm) | 171.47 ± 1.42 | 175.54 ± 1.62 |
| | BMI (kg·$m^2$) | 22.32 ± 0.54 | 23.62 ± 1.0 |
| | Range of motion (ROM) of the ankle (deg) | | |
| | *Dorsi flexion* | 21.29 ± 1.40 | 22.85 ± 2.43 |
| | *Plantar flexion* | 48.41 ± 2.42 | 52.7 ± 2.75 |
| Lower leg circumference (cm): | | | |
| Right | *Leg length* | 34.47 ± 0.46 | 35.65 ± 0.48 |
| | *Ankle* | 22.58 ± 0.27 | 23.18 ± 0.44 |
| | *Calf* | 36.91 ± 0.58 | 37.68 ± 0.96 |
| | *Below the knee* | 32.60 ± 0.44 | 34.41 ± 0.81* |
| Left | *Leg length* | 34.47 ± 0.46 | 35.65 ± 0.46 |
| | *Ankle* | 22.60 ± 0.26 | 23.27 ± 0.50 |
| | *Calf* | 36.78 ± 0.60 | 36.95 ± 0.83 |
| | *Below the knee* | 32.71 ± 0.43 | 34.52 ± 0.80 |
| Baseline isokinetic characteristic: | | | |
| | Peak torque ($N \cdot m$) | | |
| | *Dorsi flexors* | 28.06 ± 1.67 | 27.54 ± 1.40 |
| | *Plantar flexors* | 50.47 ± 4.43 | 65.92 ± 5.08** |

* Significantly different between groups ($p$<0.05). ** Significantly different between groups ($p$<0.01).
P4: group of the ECS with compression pressure 4 mmHg,
P10: group of the ECS with compression pressure 10 mmHg.

**Elastic compression stocking**

In this study, the manufactured ECS was fabricated (Thai Parfun, Japan). The sizes (circumferences and lower leg length) of ECS were adjusted relatively to each subject's morphology i.e. the circumference of the ankle, calf, and below the knee were 60%, 65%, and 70%, respectively, regardless of the texture of stocking garment. Circumferences of the lower leg were measured at four points during standing position according to the following approach; *Ankle:* The minimum circumference of the ankle was taken at the narrowest point lateral malleolus, *Calf:* At the maximal circumference of the calf, *Below the knee:* measured at the tip patella, and *Lower leg length:* measured between lateral malleolus and below of the knee point along the line of lower leg[28]. In addition, the pressure exerted by the ECS was assessed by using a special device on both legs, measured at the calf level on each lower leg. The pressures exerted by ECS on the right and left leg of P10 were 9.54 ± 0.85 and 9.77 ± 0.44 mmHg, while those of P4 were 4.41 ± 0.35 and 4.41 ± 0.33 mmHg, respectively.

**EMG recording**

The surface EMG was recorded concurrently from two muscles (Tibialis anterior; TA and Medial Gastrocnemius; MG) of the right leg. Before the measurement, the hair at the choosen skin area was shaved, and rubbing cleaned the outermost epidermal layer. Oil and dust from the skin were removed with a 70% alcohol cotton. The recordings were obtained by using bipolar surface electrodes, placed with an inter-electrode distance of 20 mm on the target muscle[15]. The electrodes were placed at one-third of the length of TA muscle through the line running between the tip of the fibula and the tip of medial malleolus. Additionally, the electrodes were placed at one-third of the length of MG muscle through the line running between head of tibia and heel. The EMG signal was amplified by using an analog differential amplifier with a band-pass filtering between 8-500 Hz and then recorded on a personal computer with a sampling frequency of 1,000 Hz (Megawin software V2.3.3, Mega electronic, Ltd.).

**Isokinetic muscle test**

Isokinetic concentric/ concentric performances, of the right TA and the right MG, were measured by using the isokinetic dynamometer (LIDO multijoint II, USA). *Ankle dorsi-plantar flexion test:* Subject was seated on the dynamometer chair with the feet hanging off the front of the seat cushion. The thigh was stabilized with a strap just above the right knee joint which was in a flexed position. The foot was fit to the ankle plate. Then, the ankle joint ROM was determined using goniometer and the ankle joint was adapted to the neutral position before beginning the dorsi-plantar flexion test. Next, the subjects performed five maximum repetitive contractions for the measurement of the peak torque for each muscle. The angular velocity of the test was set at 60 degree/sec[16].

**Experimental procedure**

On the experimental session, the subject came to the laboratory and took a rest for 10 min. In accordance with randomized test, subjects were asked to wear or not to wear the ECS for each compression pressure groups (P4 & P10). Then, the subjects performed the isokinetic ankle test (dorsi-plantar flexion) for five times of maximal repetitive contractions pre-exercise and EMG was recorded during this test. During the exercise test, the subjects were asked to walk on a treadmill, which consisted of 3 min warming up with a speed set at 2 mph. Then, speed was increased and kept constantly at 3.5 mph, inclination 10% for 45 min. After the end of exercise, subjects were instructed to immediately perform the second isokinetic ankle dorsi-plantar flexion test to evaluate the changes of peak torque following the exercise. The EMG during this test was also recorded.

**Data analysis**

The raw data of the EMG of the right TA and right MG muscles were analyzed using a software program (Megawin software V2.3.3, Mega electronic, Ltd.). The average peak torque value of the isokinetic test and RMS of the EMG signal during dorsi flexion of the right TA and plantar flexion of the right MG muscle were calculated from five maximal isokinetic contractions. Percentage changes of peak torque when wearing the ECS were calculated as the followings:

$$\frac{\text{peak torque (with ECS; pre-exercise)}}{\text{peak torque (without ECS; pre-exercise)}} \times 100 \quad \text{for pre-exercise, and}$$

$$\frac{\text{peak torque (with ECS; post-exercise)}}{\text{peak torque (without ECS; post-exercise)}} \times 100 \quad \text{for post-exercise.}$$

Percentage changes of RMS when wearing the ECS were calculated using similar equation as previously indicated for percentage changes of peak torque.

**Statistical analysis**

Normal distribution test was tested by using Kolmogorov-Smirnov test. Data was expressed as mean and standard error of mean (SEM) or otherwise indicated. Two way mixed model ANOVAs (within × between; application of ECS × groups) were used to analyze the main effect of wearing ECS (with and without ECS), main effect of ECS pressures (P4 and P10), and main effect of time (pre- and post-exercise) on percentage peak torque and percentage RMS from the isokinetic ankle test.

## RESULTS

The percentage peak torque of right TA muscle during with the ECS at pre and post-exercise were 104.02 ± 3.48 and 105.55 ± 4.11 for P4, 100.63 ± 4.79 and 101.75 ± 5.36 % of baseline for P10, respectively, while that right MG muscle were 93.85 ± 6.86 and 91.29 ± 7.27 for P4, 81.76 ± 6.04 and 85.12 ± 7.07 % of baseline for P10, respectively. The percentage of isokinetic peak torque among without (baseline), with the

ECS during pre and post-exercise were no significant difference for the right TA muscle (Fig 1 A). However, there was significant difference between without (baseline) and with the ECS during pre-exercise of P4 and P10 [F (2, 56) = 4.56, *p*<0.05], while the percentage of isokinetic peak torque with the ECS during pre-exercise was lower than without (baseline) the ECS for right MG muscle (Fig 1 B). The percentage RMS of right TA muscle during with the ECS at pre and post-exercise were 103.67 ± .4.41 and 101.75 ± 4.24 for P4, 96.81 ± 7.75 and 99.44 ± 8.0 % of baseline for P10, respectively, while that right MG muscle were 97.0 ± 5.33 and 91.80 ± 5.31 for P4, 91.22 ± 6.91 and 93.56 ± 8.0 % of baseline for P10, respectively. The percentage of RMS from EMG signal recorded during isokinetic ankle test among without (baseline), with the ECS at pre and with the ECS at post-exercise were no significant difference for the right TA muscle (Fig 2 A), as well as the percentage RMS of medial gastrocnemius there was no significant difference among three conditions (Fig 2 B).

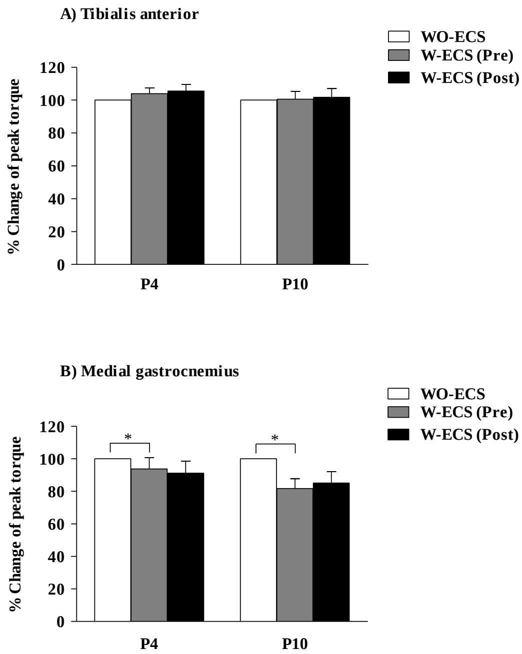


**Fig 1** The percentage change of peak torque during isokinetic ankle test of the right leg with the ECS during pre and with the ECS during post-exercise relative to without ECS in the right TA (A) and the right MG (B) muscle on different pressures of P4 and P10. *Significant different between without (baseline) and with the ECS during pre-exercise (*p*<0.05).

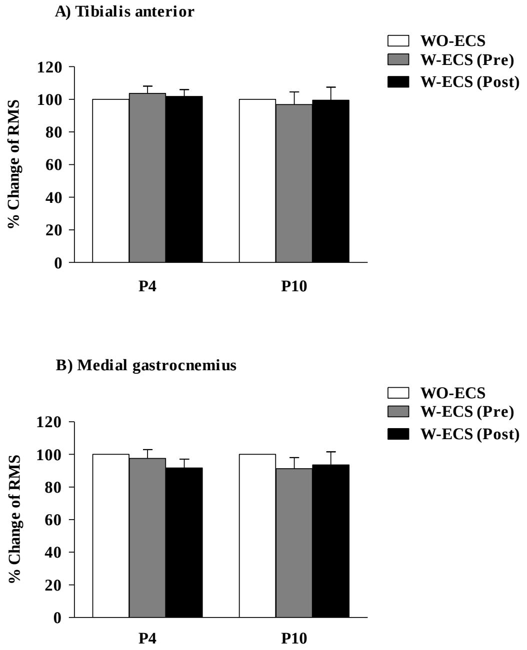


**Fig 2** Mean ± SEM of the percentage change of RMS from EMG signal recorded during isokinetic ankle test of the right leg with the ECS at pre and with the ECS at post-exercise relative to without ECS in the right TA (A) and right MG (B) muscle on different pressures.

## DISCUSSION

The higher peak torque of P10 compared to P4 was in parallel with the greater circumference of the right lower leg at below the knee (Table 1.). In fact, the calf muscle was mainly made up of medial and lateral gastrocnemius muscle[17]. It is well established that the muscle size is associated to muscle strength. Bamman and co-worker (2000) suggested that the anthropometric technique (e.g. limb circumference measurement) can be used to estimate the muscle strength, since muscle strength was related to the muscle size. Additionally, the correlations between the calf circumference or muscle size and maximum voluntary isometric strength was reported (r=0.6-0.8)[18,19]. The subjects who had greater lower extremity circumference; therefore they had greater isokinetic ankle plantar flexion torque[16].

The decrement of percentage change of peak torque at pre-exercise during wearing the ECS was observed when compared with baseline (without wearing ECS) values. Similarly, to the previous mention, the compressive pressures of the ECS may impede the ankle movement as well as the mobility range of motion. Partsch (2005) investigated the effect of different compression materials on the stiffness of the elastic, inelastic stocking, short, and long-stretch materials[20]. The study reported that the short-stretch material and inelastic stocking had higher stiffness index than the long-stretch and elastic stocking. The stiffness index values were greater than 10 mmHg for inelastic, short-stretch material and less than 10 mmHg for elastic, long-stretch material[20]. The stiffness is defined as the increase in pressure per 1 cm increase in leg circumference, and this determines the exerted compressive pressure of the compression device[21]. Although stiffness index was not measured in the present study, it may be speculated that stiffness of the ECS used in the present study may possibly be responsible for the decrement of peak torque compared to without wearing the ECS[22]. Because the force of muscle was affected by the variation of angles of ankle movement, and associated with the force-length of muscle relationship[23].

On the other hand, when compared between without the ECS (baseline) and with the ECS at post-exercise, no significant different was observed. Our result showed that the percentage change of peak torque in MG muscle after exercise could be maintained to the baseline values during wearing the ECS. During walking, the muscle activation was improved. The calf muscle pump is the primary mechanism to propel blood from the lower limbs to the heart resulting increase venous return[24]. Previous study showed that the higher stiffness of stocking on the calf could increase muscle pump, although a possible reduction of ankle movement may be found[25]. The stiffness of compression stocking could restrict the ankle movement, but improved the ejection fraction due to an increase of muscle pump[26].

In this study, wearing the ECS can maintain the peak torque after exercise resulting from the concomitant increase the muscle pump during exercise. Liu and co-worker (2008) examined the effect of graduated compression stocking and gradient distribution profile on the venous function of lower extremities. They found that the graduated compression stocking with low compression pressure reduced venous dilation and venous pooling, as well as improved venous return in the lower extremities[7]. Similarly, the recent study reported that wearing graduated compression stocking with optimizing compression was increased venous return greater than not wearing stocking[27].

## REFERENCES

1. De Glanville KM, Hamlin MJ. Positive effect of lower body compression garments on subsequent 40-kM cycling time trial performance. The Journal of Strength & Conditioning Research. 2012;26(2):480-6
2. Maton B, Thiney G, Ouchene A, Flaud P, Barthelemy P. Intramuscular pressure and surface EMG in voluntary ankle dorsal flexion: Influence of elastic compressive stockings. Journal of Electromyography and Kinesiology. 2006;16(3):291-302
3. Liu R, Kwok YL, Li Y, Lao TT, Zhang X. The effects of graduated compression stockings on cutaneous surface pressure along the path of main superficial veins of lower limbs. Wounds. 2006

4. Benigni J-P, Branchoux S, Bacle I, Taieb C. Difficulty associated with donning medical compression stockings: results from a survey comparing two different compression stockings. Women's Health. 2013;9(3):291-300
5. Benkö T, Kalik I, Chetty M. The physiological effect of graded compression stockings on blood flow in the lower limb: an assessment with colour Doppler ultrasound. Phlebology. 1999;14(1):17-20
6. Maton B, Thiney G, Dang S, Tra S, Bassez S, Wicart P, et al. Human muscle fatigue and elastic compressive stockings. European journal of applied physiology. 2006;97(4):432-42
7. Liu R, Lao TT, Kwok YL, Li Y, Ying MT-C. Effects of graduated compression stockings with different pressure profiles on lower-limb venous structures and haemodynamics. Advances in therapy. 2008;25(5):465-78
8. Ibegbuna V, Delis KT, Nicolaides AN, Aina O. Effect of elastic compression stockings on venous hemodynamics during walking. Journal of vascular surgery. 2003;37(2):420-5
9. Berry MJ, McMurray RG. Effects of graduated compression stockings on blood lactate following an exhaustive bout of exercise. American Journal of Physical Medicine & Rehabilitation. 1987;66(3):121-32
10. Wallace L, Slattery K, Coutts A. Compression garments: do they influence athletic performance and recovery. Sports Coach. 2006;28(4):38-9
11. Lawrence D, Kakkar V. Graduated, static, external compression of the lower limb: a physiological assessment. British Journal of Surgery. 1980;67(2):119-21
12. Ali A, Creasy RH, Edge JA. The effect of graduated compression stockings on running performance. The Journal of Strength & Conditioning Research. 2011;25(5):1385-92
13. Carpentier P, Becker F, Thiney G, Poensin D, Satger B. Acceptability and practicability of elastic compression stockings in the elderly: a randomized controlled evaluation. Phlebology. 2011;26(3):107-13
14. Rogers DR, MacIsaac DT. EMG-based muscle fatigue assessment during dynamic contractions using principal component analysis. Journal of Electromyography and Kinesiology. 2011;21(5):811-8
15. Kamen G, Gabriel D. Essentials of electromyography: Human kinetics; 2010
16. Fugl-Meyer AR. Maximum isokinetic ankle plantar and dorsal flexion torques in trained subjects. European journal of applied physiology and occupational physiology. 1981;47(4):393-404
17. Andrew Franklyn-Miller EF PM, Peter Brukner. Clinical sports anatomy. Australia: McGraw-Hill; 2011

18. Bamman MM, Newcomer BR, Larson-Meyer DE, Weinsier RL, Hunter GR. Evaluation of the strength-size relationship in vivo using various muscle size indices. Medicine and science in sports and exercise. 2000;32(7):1307-13

19. Trappe S, Trappe T, Lee G, Costill D. Calf muscle strength in humans. International journal of sports medicine. 2001;22(03):186-91

20. Partsch H. The static stiffness index: a simple method to assess the elastic property of compression material in vivo. Dermatologic surgery. 2005;31(6):625-30

21. Van der Velden S, Neumann H. The post-thrombotic syndrome and compression therapy. Phlebology. 2014;29(1 suppl):83-9

22. Miyamoto N, Hirata K, Mitsukawa N, Yanai T, Kawakami Y. Effect of pressure intensity of graduated elastic compression stocking on muscle fatigue following calf-raise exercise. Journal of Electromyography and Kinesiology. 2011;21(2):249-54

23. Maganaris CN. Force–length characteristics of in vivo human skeletal muscle. Acta Physiologica Scandinavica. 2001;172(4):279-85

24. O'Brien JA, Edwards HE, Finlayson KJ, Kerr GK. Understanding the relationships between the calf muscle pump, ankle range of motion and healing for adults with venous leg ulcers: a review of the literature. Wound Practice and Research. 2012;20(2):80-5

25. Mosti G. Response to'Re. Improvement of venous pumping function by double progressive compression stockings: higher pressure over the calf is more important than a graduated pressure profile'. European journal of vascular and endovascular surgery: the official journal of the European Society for Vascular Surgery. 2014;48(1):107

26. Mosti G, Partsch H. Improvement of venous pumping function by double progressive compression stockings: higher pressure over the calf is more important than a graduated pressure profile. European Journal of Vascular and Endovascular Surgery. 2014;47(5):545-9

27. Lattimer C, Kalodiki E, Kafeza M, Azzam M, Geroulakos G. Quantifying the degree graduated elastic compression stockings enhance venous emptying. European Journal of Vascular and Endovascular Surgery. 2014;47(1):75-80

28. Norton K, Olds T. Anthropometrica: a textbook of body measurement for sports and health courses: UNSW press; 1996