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Evaluation of the external pressure exerted at the calf region using the boot-support-type leg-holder system in the lithotomy position

J. Mizuno (*), T. Takahashi (**)

Abstract : *Background***:** Well leg compartment syndrome (WLCS) is a devastating complication related to surgical procedures performed using a leg-holder system in the lithotomy position. We have reported that the external pressure at the calf region using the knee-crutch-type leg-holder system increases in men and is dependent on body size. In the present study, we investigated the relationship between the external pressure at the calf region using the boot-support-type leg-holder (BSLH) system and selected physical characteristics to investigate the risk factors for developing WLCS.

Methods : Thirty-one young, healthy volunteers, 15 men and 16 women, participated. The peak contact pressure (PCP) was measured as representative external pressure at the calf region in contact with the BSLH system using the pressure-distribution measurement system BIG-MAT®.

Results : No sex difference was found in PCPs. Significant positive correlations were not observed between the left PCPs and height, weight, body mass index (BMI), tibial length (TL), bimalleolar breadth (BB), maximum calf girth (MCG), or foot length (FL), and between the right PCPs and height, weight, BMI, BB, MCG, or FL.

Conclusion : The external pressure exerted at the calf region using the BSLH system in the lithotomy position is independent of sex, body, leg, and foot sizes.

Key words : well leg compartment syndrome ; peak contact pressure ; body size ; leg size ; foot size.

Introduction

Pain, redness, or swelling at the posterior aspect of the leg and well leg compartment syndrome (WLCS) are known complications related to colorectal surgical (1, 2), urological (3, 4), gynecological (5, 6), and orthopedic surgical procedures (7, 8) performed using a leg-holder system in the lithotomy position. WLCS after surgery in the lithotomy position is a potentially devastating complication that can cause neurological and motor dysfunctions and result in a life-threatening condition. Therefore, a high level of suspicion is required for the early recognition of WLCS caused by surgery in the lithotomy position. We must recognize the risks and perform necessary steps to prevent patients from developing WLCS.

WLCS occurs when intra-compartment pressure in the neuromuscular spaces pathologically increases, although each neurovascular structure is enclosed by strong, non-expansible fascial layers or bone in the four compartments of the calf region (3). One of the most important underlying factors for the onset of WLCS may be that intra-compartment pressure in the calf region increases because of decreased perfusion pressure due to elevation of the lower-extremity when using the leg-holder system and external compression to the leg. The two main theories regarding the cause of WLCS are hypo-perfusion theory by vascular insufficiency and direct external compression theory. The arterial pressure of the leg decreases proportionately with the height of the leg raised in the lithotomy position. The hydrostatic gradient between the level of the heart and ankle can be considered the most important factor associated with perfusion pressure in the leg (9). Elevation of the leg above the heart level in the lithotomy position will decrease the mean arterial pressure in the ankle (10) and perfusion pressure in the leg because of decreased hydrostatic pressure. Low perfusion pressure, achieved by elevating the leg in the lithotomy position, reduces the blood flow, which prevents nutrient and oxygen supply to the muscle cells in the calf region. Venous stasis, which may occur when using the leg-holder system during

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the lithotomy position, increases intra-compartment pressure in the calf region (11). The blood flow in the peripheral vessels stops when high external pressure compresses the skin and feeding vessels in the calf region, and the adjacent muscles and nerves are consequently exposed to local ischemia. Hypo-oxygenation may be a common pathway (12), and the combination of low perfusion pressure and high external pressure results in ischemia of the lower-extremity musculature and soft tissue. Ischemia may be followed by reperfusion with subsequent capillary leakage and tissue edema; subsequently, a vicious circle of tissue edema and further impairment of perfusion may lead to necrosis and ultimately to the onset of WLCS.

Using the knee-crutch-type leg-holder (KCLH) system to support the distal part of the posterior thigh, popliteal fossa, and calf regions (13) incidentally induces WLCS (7). Moreover, obesity may be a risk factor for the development of WLCS in the lithotomy position (4, 5, 8). We have reported that men and increases in height, weight, and body mass index (BMI) increase the external pressure at the calf region when using the KCLH system (14).

Recently, the boot-support-type leg-holder (BSLH) system to support the calf, ankle, heel, and plantar regions in a boot-like device (13) has been widely used in the lithotomy position during surgery. Using the BSLH system may be safer and more secure, although WLCS rarely occurs in the BSLH even as a complication (2,4). In the present study, we measured the external pressure at the calf region when using the BSLH system in the lithotomy position and evaluated the relationships between the external pressure and selected physical characteristics to investigate the risk factors for developing WLCS.

Methods

This study was approved by the ethics committee of Okayama Prefectural University (approval number 453) and was registered at UMIN-CTR (UMIN000030416). We recruited 31 young, healthy university students (age, 21.4 ± 0.6, 16 men and 15 women) as volunteers. Written informed consents for the publication of images and data were obtained from the participants before starting the study. Subjects with motor or sensory disturbances in the lower-extremities were excluded. Height, weight, BMI, tibial length (TL), bimalleolar breadth (BB), maximum calf girth (MCG), and foot length (FL) were measured, and the dominant leg of each subject was recorded.

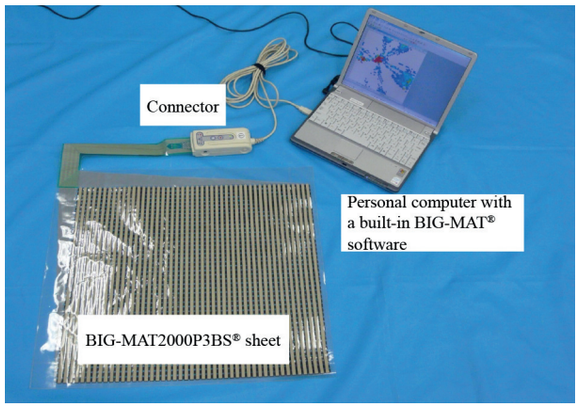

Fig. 1. — Pressure-distribution measurement system BIG-MAT®. The system comprises the BIG-MAT2000P3BS® sheet, sensor connector, and personal computer with the built-in BIG-MAT software.

The pressure-distribution measurement system, BIG-MAT® (Nitta Corp., Osaka, Japan), is a non-invasive method to measure the external pressure for industrial applications (15). The BIG-MAT® system comprises a pressure-distribution measurement sheet with 10-mm pitch with 2,112 (44 × 48) sensors BIG-MAT2000P3BS® (*L* 440 mm × *W* 480 mm × *D* 0.4 mm, Nitta Corp.), a sensor connector, and a personal computer with the built-in BIG-MAT® software (Fig. 1). The measurement using the BIG-MAT® system was described elsewhere, in our earlier reports (14,16-18). In our previous studies, the BIG-MAT® system has been used to measure the external pressure at the calf region, fibular head region, sacral region, and lateral region of the distal part of the fibula to investigate the cause of WLCS (14), common peroneal nerve paralysis (16, 17), decubitus ulcers using the KCLH system (18), and superficial peroneal nerve paralysis using the BSLH system (16), respectively, in the lithotomy position. The system was calibrated by careful placement of a 25-kg concrete block. Digital measurement values were converted to pressure information by the software, which displayed two-dimensional, visually understandable squares for each of the 2,112 sensor cells. Outputs from all sensor cells were also displayed as a number ranging from 0 to 255. Changes in pressure values were consecutively recorded, and chronological changes were saved as movie files on a personal computer. We recorded 100 pressure-distribution views for each participant, followed by measurement of the pressure distribution for the BIG-MAT2000P3BS® sheet.

In the present study, we measured the external pressure distribution at the calf region to investigate the cause of pain, redness, or swelling at the

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Fig. 2. — Lithotomy position using the boot-support-type leg-holder (BSLH) system Bel Flex®. The bilateral legs and feet were placed on the pressure-distribution measurement sheet BIG-MAT2000P3BS® sheet spread over the BSLH system Bel Flex®.

posterior aspect of the leg, and WLCS using the BSLH system in the lithotomy position using the BIG-MAT® system. The BSLH Bel Flex® (*L* 356 mm × *W* 200 mm; Takara Belmont Corp., Osaka, Japan), which supports the posterior aspect of the distal part of leg and foot, namely, the calf, ankle, heel, and plantar regions in the lithotomy position, was connected to a class IB® electric operating table (Takara Belmont Corp.; DR-3000-A). The BIG-MAT2000P3BS® sheet was spread over Bel Flex®. During the measurement, the subjects were asked to lie down in the lithotomy position on a mattress

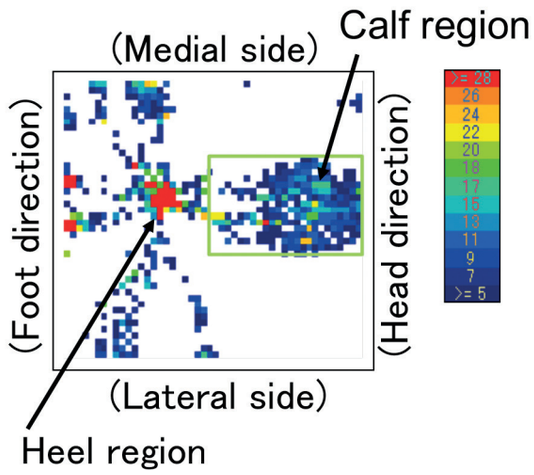

Fig. 3. — Representative pressure-distribution view measured by the pressure-distribution measurement system BIG-MAT® in the left calf, ankle, heel, and plantar regions in contact with the boot-support-type leg-holder (BSLH) system Bel Flex® in the lithotomy position. High- and low-pressure areas are shown in red and blue squares, respectively. The rectangle surrounded by the green box corresponds to the calf region. The red squares shown in the foot direction of the green box correspond to the heel region.

covering the class IB® (Fig. 2). The legs and feet were placed on the BIG-MAT2000P3BS® sheet spread over Bel Flex®. By using the angle gauge, the hip joints were flexed at 90º from the trunk, abducted at 45º, and minimally externally rotated from the midline, and the knee joints were flexed at 90º (19). After remaining in the lithotomy position for 5 minutes, the subjects remained in the same position for an additional minute while the measurements were being performed. The participants were kept awake throughout.

Figure 3 shows a representative view of the pressure distribution for contact of the calf, ankle, heel, and plantar in the left lower-extremity. We selected a square area of the display shown with the green box that corresponded to the calf region for analysis. The total force (TF), which represented the total loading value on the sensor cells within the green box, and two measures of the external pressure within the green box, namely, the contact pressure (CP) and peak contact pressure (PCP) were evaluated. CP represented the mean pressure on the loaded sensor cells inside the green box, which was equal to TF divided by the contact area covered by the loaded sensor cell. PCP represented the mean pressure on the loaded sensor cells within the 2×2 loaded sensor cells that corresponded with the highest pressure within the green box, which is the peak area, which was equal to TF in the four squares divided by the loaded sensor cell area within the peak area.

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Analyses were performed using Excel 2013® (Microsoft Corp., Redmond, WA, USA). BMI was calculated as the subject's weight (kg) divided by the square of their height (m). Values were expressed as mean ± standard deviation. Unpaired Student's *t*-tests were used for statistical comparisons between the men and women. Simple linear regression analyses were performed to determine correlations between TF, CP, or PCP, and subject-specific physical characteristics such as height, weight, BMI, TL, BB, MCG, and FL. A *P*-value of <0.05 was considered significant.

Table 1

Physical characteristics

	All subjects (n = 31)	Men (n = 16)	Women (n = 15)
Age (years)	21.4 ± 0.6	21.3 ± 0.7	21.5 ± 0.5
Height (cm)	164.0 ± 9.1	171.8 ± 5.6**	156.6 ± 4.5
Weight (kg)	55.2 ± 8.6	61.1 ± 8.0**	49.6 ± 4.3
BMI (kg/m²)	20.4 ± 2.1	20.7 ± 2.5	20.2 ± 1.6
Left TL (cm)	41.2 ± 2.6	43.1 ± 2.1**	39.5 ± 1.8
Right TL (cm)	41.1 ± 2.3	42.6 ± 1.9**	39.7 ± 1.6
Left BB (cm)	4.4 ± 0.7	4.6 ± 0.7	4.2 ± 0.7
Right BB (cm)	4.2 ± 0.7	4.2 ± 0.8	4.2 ± 0.7
Left MCG (cm)	34.9 ± 2.4	35.1 ± 2.6	34.7 ± 2.1
Right MCG (cm)	34.9 ± 2.4	35.1 ± 2.6	34.7 ± 2.1
Left FL (cm)	25.0 ± 1.8	26.6 ± 0.8**	23.4 ± 0.8
Right FL (cm)	25.0 ± 1.8	26.6 ± 0.8**	23.4 ± 0.8
Dominant leg (Left/Right)	1/30	1/15	0/15

** $P < 0.001$ versus women. Data are expressed as mean ± standard deviation. BMI, body mass index; TL, tibial length; BB, bimalleolar breadth; MCG, maximum calf girt; FL, foot length.

Results

Physical characteristics

Table 1 shows the physical characteristics of the 31 subjects, such as the body size, leg size, foot size, and dominant leg. The TLs and FLs in men were significantly longer than those in women.

TF, CP, and PCP

Table 2 shows TFs, contact areas, CPs and PCPs at the calf regions. No sex differences were found in TFs, CPs, and PCPs.

Significant positive correlations were not observed between the bilateral TFs and height, weight, BMI, TL, BB, MCG, or FL (Table 3). Furthermore, significant positive correlations were not observed between the bilateral CPs and height, weight, BMI, TL, BB, MCG, or FL. Moreover, significant positive correlations were not observed

Table 2

TFs, contact areas, CPs, and PCPs at the calf regions in contact with the boot-support-type leg-holder (BSLH) system Bel Flex® in the lithotomy position

	All subjects (n = 31)	Men (n = 16)	Women (n = 15)
Left TF (kg)	3.0 ± 0.9	2.8 ± 0.9	3.3 ± 0.9
Right TF (kg)	3.2 ± 1.0	2.9 ± 0.8	3.4 ± 1.2
Left contact area (cm²)	183.3 ± 37.7	166.5 ± 48.1*	199.0 ± 32.2
Right contact area (cm²)	186.4 ± 42.0	171.5 ± 44.3	200.3 ± 35.6
Left CP (mmHg)	12.1 ± 1.5	12.3 ± 1.4	11.9 ± 1.6
Right CP (mmHg)	12.2 ± 1.5	12.3 ± 0.8	12.1 ± 2.0
Left PCP (mmHg)	23.6 ± 6.8	22.7 ± 5.9	24.5 ± 7.6
Right PCP (mmHg)	24.3 ± 6.3	24.8 ± 5.9	23.8 ± 6.7

* $P < 0.05$ versus women. Data are expressed as mean ± standard deviation. TF, total force; CP, contact pressure; PCP, peak contact pressure.

Table 3

Physical characteristics and relationship between TFs, CPs, and PCPs at the calf regions in contact with the boot-support-type leg-holder (BSLH) system Bel Flex® in the lithotomy position

	TF				CP				PCP			
	Left		Right		Left		Right		Left		Right	
	r	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Height	-0.19	0.32	-0.07	0.70	0.15	0.42	0.22	0.25	0.02	0.90	0.27	0.15
Weight	-0.08	0.67	-0.05	0.80	0.18	0.34	0.17	0.38	0.06	0.74	0.32	0.09
BMI	0.09	0.64	0.002	0.99	0.11	0.55	0.00	0.98	0.06	0.73	0.15	0.43
TL	-0.13	0.48	0.09	0.62	0.15	0.47	0.31	0.10	0.05	0.77	0.36	0.05
BB	-0.08	0.69	-0.10	0.59	0.04	0.82	0.13	0.50	0.01	0.96	0.24	0.20
MCG	0.27	0.15	0.08	0.67	0.29	0.11	0.08	0.66	0.31	0.10	0.12	0.53
FL	-0.12	0.52	-0.10	0.59	0.21	0.26	0.18	0.34	0.03	0.87	0.30	0.11

TF, total force ; CP, contact pressure ; PCP, peak contact pressure ; BMI, body mass index ; TL, tibial length ; BB, bimalleolar breadth ; MCG, maximum calf girt ; FL, foot length ; *r*, correlation coefficient ; *P*, P value.

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between the left PCPs and height, weight, BMI, TL, BB, MCG, and FL, and between the right PCPs and height, weight, BMI, BB, MCG, or FL.

Discussion

The present study primarily found that PCPs at the calf regions in contact with the BSLH system in the lithotomy position did not have sex differences and did not increase with increasing height, weight, BMI, TL, BB, MCG, and FL.

External pressure

The combination of leg elevation and intra-operative direct external compression on the posterior compartment in the calf region using the BSLH system in the lithotomy position may lead to hypo-perfusion within the anterior and posterior compartments of the calf region (20). The lithotomy position immediately increases intra-compartment pressure in the calf region (10) and significantly decreases the diastolic blood pressure (dBP) in the ankle. The combined effect of increased intra-compartment pressure due to reduced perfusion pressure in the leg in the lithotomy position and the external compression from the calf support causes a significant reduction in the difference between dBP and intra-compartment pressure, which may have contributed to the development of WLCS (12).

The capillary blood pressure with micro-injection is 32 and 25 mmHg in the human skin (21) and canine muscle (22), respectively. Therefore, healthy capillary blood pressure ranging from 20 to 40 mmHg is generally accepted, with a mean of 32 mmHg (23). Capillary vessel occlusion will be induced if the external pressure exceeds 32 mmHg, resulting in ischemic injury. The external pressure loading to the skin surface below 32 mmHg and as low as possible has been recommended (24). In the present study, the mean PCP at the left and right calf regions at 23.6 and 24.3 mmHg, respectively, were significantly lower than the 32 mmHg threshold (P <0.001, paired Student's t-test). Therefore, the observed PCPs at the bilateral calf regions can not occlude the capillary vessels in the compartment. This means that the external compression to the calf region in contact with the BSLH system may suggest the low possibility for the development of WLCS.

BSLH type

The leg-holder type has been reported as one of the risk factors for the development of WLCS (14). We speculate that WLCS following surgery performed in the lithotomy position is related to the leg-holder system. For example, the use of Allen stirrups, i.e., the BSLH system, instead of the KCLH system is recommended to distribute pressure at the ankle and heel, rather than exclusively at the calf (25). Intra-compartment pressure in subjects positioned with the BSLH system increases compared with that in the supine position but does not differ from the subjects positioned with the KCLH system (26). Changing from the supine to the lithotomy position using the calf-supported leg-holder significantly increases intra-compartment pressure in the anterior and lateral compartments (27). Changing from the calf-supported leg-holder to the heel-supported leg-holder significantly reduces intra-compartment pressure in the anterior, lateral, and posterior compartments. The mean dBP in the ankle significantly decreases using the calf- and heel-supported leg-holders.

Increase in PCP in the lithotomy position with support near the calf may be one of the factors that contribute to the development of WLCS. In contrast, the lithotomy position with support near the ankle reduces intra-compartment pressure in the tibialis anterior muscle compartment to 8.7 mmHg compared with the 13.3 mmHg in the supine position (26). WLCS occurs in only some patients because the leg-holder system is too tight and causes vascular obstruction of the major leg vessels. Moreover, PCP at the left and right calf regions in contact with the BSLH system in the present study are significantly lower than the mean PCP with KCLH system at 53.7 and 63.0 mmHg in the previous study (14), respectively (P <0.001, paired Student's t-test). One of the important steps may be keeping lower external pressure at the calf region when using the BSLH system instead, indicating that the external pressure at the calf region using the BSLH system is lower compared with the KCLH system. The BSLH system may rarely cause WLCS compared with the KCLH system. Leaving lower external pressure at the calf region increases the difference between intra-compartment pressure and dBP (27). The BSLH system is recommended instead of the KCLH system to keep lower external pressure at the calf region and to prevent WLCS.

Sex, body size, leg size, and foot size

WLCS following surgery using the BSLH system more often occurs in men. In our previous study, the mean PCPs at the left and right calf regions in contact with the KCLH system were

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significantly higher in men at 82.4 and 65.3 mmHg than in women at 41.7 and 41.0 mmHg, respectively (14). However, in the present study, PCPs at the calf regions in contact with the BSLH system were not different between men and women. This finding indicates that the external pressure at the calf region using the BSLH system may be independent of sex.

Obesity is a general risk factor for WLCS (3,12). WLCS frequently occurs in patients with muscular and large bodies (4,5,8). Most documented cases of WLCS have occurred in young men with heavy body habitus. This suggests that increased muscle bulk in these patients is associated with a tighter and less compliant compartment (3). High BMI and muscular calf are associated with the development of WLCS (28). BMI > 25 kg/m^2 is a potential risk factor for the development of WLCS (3,5). Rhabdomyolysis in overweight patients with WLCS frequently occurs after surgical procedures in the lithotomy position (29). Therefore, we speculate that WLCS following surgery in the lithotomy position is related to body size. One reported cause of WLCS is the weight of the leg against a supportive leg holder. The external pressure depends on the muscular status of the leg. The patient's large muscle bulk and intraoperative hypotension while in the lithotomy position may also affect the elevation of the external pressure and decrease of perfusion pressure.

We speculate that PCP is the most important variable to estimate the occurrence of WLCS. Our previous study showed that PCPs at the calf regions in contact with the KCLH system increased with increasing height, weight, and BMI (14). However, in the present study, height, weight, and BMI did not correlate significantly with PCPs at the calf regions in contact with the BSLH system, indicating that the external pressure at the calf region using the BSLH system is independent of body, leg, and foot sizes.

Study limitations

This study has several limitations.

First, the subjects in this study were young, healthy university students with a relatively homogenous body habitus. In the future, the external pressure and variables measured in the volunteers should be applied to more patients with a wide age and weight range.

Second, we selected CP and PCP as representative variables using the BIG-MAT® system. We were unable to gather clear evidence on the correlation between the variables and the actual perfusion pressure and intra-compartment pressure. It may be ethically hard to defend, but measurement of invasive perfusion pressure and intra-compartment pressure in real patients would make this study even more conclusive. For example, the use of near infrared spectroscopy could have been incorporated along with CP and PCP; we might have had some data on perfusion of the calf region. Therefore, we need to obtain additional data on the correlations between CPs or PCPs and invasive pressure measurements such as perfusion pressure and intra-compartment pressure. This idea will be applied to future research.

Third, most patients who develop WLCS after surgery were under general anesthesia. The patients did not experience discomfort and were unable to control the lithotomy position during general anesthesia. Therefore, we need to measure CPs and PCPs in subjects with the use of sedation, analgesia, and a muscle relaxant.

Fourth, this study was not performed in the same conditions, such as in an operating room. It would have been better if the surgical settings were completely simulated: surgical drapes over the patient's legs and the nurse or the junior trainee in surgery leaning on the legs. We need to investigate CPs and PCPs in these more realistic settings.

Fifth, this study was performed for only a short period of time. Prolonged operative duration is a risk factor for the development of WLCS (28). The intra-compartment pressure shows minor elevations after initial lithotomy positioning and gradually increases, with levels rising to 30 mmHg over an average period of 5 hours (30). Canine skeletal muscle necrosis associated with impending WLCS occurs at a threshold intra-compartment pressure of 30 mmHg after 8 hours (31). Therefore, we need to continuously measure CPs and PCPs in subjects for a long period.

Sixth, this study did not compare WLCS incidence between BSLH and KCLH prospectively. The lower PCP may not necessarily mean lower incidence of WLCS. Direct comparison of the incidence of WLCS or external pressure between BSLH and KCLH systems would be clinically more relevant in a future study.

Seventh, the BIG-MAT® system should only be used in clinical studies with the approval of relevant ethics committees because it is not currently approved for clinical use as a medical instrument.

Conclusion

The CP and PCP exerted at the calf region in contact with the BSLH system in the lithotomy position is independent of sex, height, weight, BMI,

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TL, BB, MCG, and FL. Therefore, the sex, body size, leg size, and foot size are not factors to increase the external pressure at the calf region and may not contribute to the potential risks of inducing WLCS using the BSLH system in the lithotomy position during surgery.

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