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Change in Contralateral Muscle Blood Volume During Passive Unilateral Muscle Stretching Before and After Surgery

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Objective: Passive muscle stretching is a common physical therapy for critically ill patients in the intensive care units. This study aimed to evaluate the effects of unilateral passive stretching of the gastrocnemius muscle (GM) before and after surgery on blood volume (BV) in the contralateral (non-stretched) GM in patients who are sedated after surgery.
Methods: We enrolled eight patients with esophageal cancer. The patients completed two sessions of passive cyclical stretching (20-s hold, 10-s release, 10 cycles) of the right GM: one before surgery (awake) and one after (under sedation). We used near-infrared spectroscopy to measure the BV in the stretched and contralateral GM. BV kinetics were compared between the ipsilateral and contralateral GM.
Results: In seven of the eight patients, BV in the stretched GM decreased during stretching and increased during the stretch-relaxation phase, both before and after surgery. Both before and after surgery, the change in the BV in the contralateral GM was inversely synchronized to the stretching cycle.
Conclusions: Unilateral passive stretching of the GM influenced the microcirculation of the contralateral GM. The mechanism underlying the synchronous change in the BV in the contralateral GM remains to be clarified.

Key words: gastrocnemius muscle, passive stretching, near-infrared spectroscopy, muscle blood volume, non-stretched muscle

INTRODUCTION

Physical therapy for critically ill patients admitted to the intensive care unit (ICU) has been recommended to prevent muscle weakness, maintain joint range of motion, and prevent venous thrombosis [1]. Patients in ICUs often have restricted movement because of disease severity or the invasiveness of treatment. The resulting immobilization causes muscle weakness and joint contracture, which can negatively affect performance in activities of daily living [2]. Passive limb exercise, which includes passive muscle stretching, is a common physical therapy intervention for critically ill patients requiring mechanical ventilation in the ICU [3].

The effects of muscle stretching on central and peripheral hemodynamics have been investigated in young healthy individuals [4–6], in whom a 5-s passive dorsiflexion stretch can induce a transient and significant increase in muscle sympathetic nerve activity, heart rate (HR), and mean blood pressure (BP) [4]. Another study showed that a 4-min passive dorsiflexion stretch induced a transient increase in HR but with no associated increase in BP [5]. The onset of the cardiovascular response to a dorsiflexion stretch, known as the exercise pressor reflex, may be induced by stimulation of mechanoreceptors of the stretched muscle. Despite the absence of central hemodynamic changes, blood flow to the passively stretched limb muscle is altered by changes in muscle length [7–9].

Changes in the microvascular blood volume (BV) of the stretched muscle have been investigated using near-infrared spectroscopy (NIRS) [5, 10–12]. This technique uses the absorption of near-infrared light at specific wavelengths and allows for a qualitative and non-invasive in vivo assessment of changes in the oxygenated and deoxygenated hemoglobin and myoglobin (Hb/Mb) at the level of the small arterioles and venules, capillaries, and intracellular sites [13], where the total Hb/Mb (oxygenated Hb/Mb + deoxygenated Hb/Mb) level is indicative of the BV in the observed region. Static [10, 11] and intermittent passive stretching [12] of the GM have been reported to produce a decrease in the BV in the GM during stretching, with an increase in BV during release. However, Kruse *et al*. [5] reported an increase in muscle BV during stretching. Moreover, although the effects of stretching on the peripheral hemodynamics and microcirculation

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have been investigated in stretched muscles, the effects of stretching on circulation in muscles of the contralateral limb have not been thoroughly investigated. Accordingly, the effects of active or passive exercise on blood flow to the non-exercising limbs remain controversial [14, 15]. A recent study in healthy individuals reported that BV in the non-contracting muscle increased at the start of voluntary (active) unilateral leg exercise but did not increase with passive exercise [15].

The effect of active and passive lower limb exercise on ipsilateral and contralateral blood flow is important for rehabilitation in general and ICU patients specifically because acute vascular changes induced by stretching may result in improved vascular function [16]. Most patients requiring mechanical ventilation in the ICU are sedated and receive daily bilateral passive lower limb stretching. Additionally, postoperative patients sometimes receive an epidural block, using opioids, for pain control. Therefore, BV kinetics in stretched and non-stretched muscles may be very different in these patients compared to that in healthy individuals as the sensory input from the peripheral muscle to the spine may be partially blocked by anesthesia. There is scarce information regarding the influence of passive stretching on BV in both the stretched and non-stretched muscles of sedated and mechanically ventilated patients. Thelandersson *et al.* [17] did not identify a change in blood flow velocity during passive range of motion exercise (ankle, knee, and hip joint) among comatose and/or sedated critically ill patients. Therefore, our aim was to evaluate the effects of a unilateral passive ankle dorsiflexion stretch on the BV in the GM using NIRS among patients, measured bilaterally (stretched and non-stretched GM), before and after surgery. Patients were awake before surgery but were sedated and received epidural analgesia after surgery. We previously reported a change in the BV in the stretched GM in five patients with esophageal cancer after surgery [18]. In this study, we aimed to extend these findings by further investigating the effects of stretching on the BV in the contralateral (non-stretched) GM and comparing both ipsilateral and contralateral effects before and after surgery.

PATIENTS AND METHODS

This observational case-control study was conducted between May and November 2011, approved by the Institutional Review Board for Clinical Research at Tokai University (no. 11R-011), and conforms with the principles outlined in the Declaration of Helsinki. Written and informed consent was obtained from each patient.

Participants

We enrolled eight patients with esophageal cancer who were scheduled to undergo cancer surgery and to be mechanically ventilated under sedation for 1 or 2 days after surgery and who could walk independently before admission. Individuals with neuromuscular diseases, vascular disorders of the lower limbs, severe heart failure, and renal failure were excluded. In addition, computed tomography (CT) was used to confirm the absence of any brain lesion. Patients included in the study did not use vasopressors and did not present with lower limb edema or varicose veins.

Study protocol

Patients underwent two sessions of passive stretching of the right GM. The first (pre-surgery; patient awake) session was performed in the surgical ward on the day before the scheduled surgery, with the second (post-surgery; patient sedated) session performed in the ICU several hours after surgery. Both sessions were performed with patients in the supine position on the bed, and all patients wore compression stockings (Cardinal Health Japan, T.E.D.™ anti-embolism stockings®). Each session consisted of repetitive passive dorsiflexion stretching, performed only on the right side, for a period of 5 min. The oxygenation state of the GM was measured bilaterally at rest, during passive stretching, and during the recovery phase from stretching, using NIRS (Hamamatsu Photonics Co., NIRO-200™).

Stretching

The maximal dorsiflexion range without evoking pain was measured using a goniometer before the pre-surgery stretching session. For the stretch, the knee was placed in an extended position and the foot was passively dorsiflexed from its resting position to the maximal dorsiflexion range, measured before the pre-surgery session, by applying manual pressure. The GM stretch was held for 20 s, followed by a 10-s stretch-relaxation phase, and the stretch-relaxation cycle was repeated 10 times for a total treatment period of 5 min. One investigator performed the stretching protocol for all patients.

Demographic data

The following data were obtained from patients' medical records for analysis: age, diagnosis, medical history, height and weight, duration of surgery, volume of bleeding due to surgery, and pre- and post-surgery hemoglobin levels.

Vital signs (blood pressure [BP], pulse rate [PR], and level of consciousness), lower thigh circumference, and skinfold thickness of the right lower thigh were measured. The level of consciousness during the post-surgical period was measured using the Richmond Agitation and Sedation Scale (RASS) score. The circumference was measured at the proximal one-third of the lower thigh using a tape measure and skinfold thickness was measured on the medial site of the proximal one-third of the lower thigh using a caliper (Yagami, MK-60®). Using an air-packed type contact surface pressure-measuring system (AMI Techno Co. Ltd., A0905-SA®), the pressure induced by the stocking was measured at the proximal one-third of the lateral lower thigh before starting the stretching protocol. An air-packed 20-mm bag was placed between the skin and the compression stocking, and the air pressure generated inside the air bag was measured. Arterial oxygen saturation (SpO_2) was continuously monitored using pulse oximetry (Teijin-Pharma, Pulsox-300®-Me).

Muscle BV

The oxygenation state of the GM was continuously measured, simultaneously from the right and left GM, using NIRS (NIRO-200™), operating at three wavelengths (775 nm, 810 nm, and 850 nm). The optodes were placed on the proximal one-third of the medial head of the GM, oriented along the longitudinal direc-

Table 1 Characteristics of the enrolled participants before surgery

		(n = 8)		
Age	(years)	63.1	±	3.4
Height	(cm)	165.5	±	5.6
Weight	(kg)	63.0	±	12.6
BMI	(kg/m^2)	22.9	±	3.8
Circumference of the lower thigh	(cm)	35.6	±	4.0
Skinfold thickness of the lower thigh	(mm)	4.2	±	1.1
BP (systolic)	(mmHg)	126.8	±	18.5
BP (diastolic)	(mmHg)	75.8	±	8.3
PR	(bpm)	63.6	±	10.4
SpO_2 (RA)	(%)	98.9	±	0.6
Angle of dorsiflexion	(°)	49.4	±	3.2
Compression pressure	(mmHg)	20.3	±	3.6

BMI: body mass index, BP: blood pressure, PR: pulse rate, SpO_2: oxygen saturation, RA: room air

tion of the muscle fibers, with an inter-optode distance of 3 cm. We adopted the total Hb/Mb as a measure of muscle BV. Relative changes in the total Hb/Mb were obtained every 0.5 s because the NIRS procedure used in this study could not determine the absolute Hb/Mb concentration. Amplitudes of changes in the total Hb/Mb in every stretch cycle were measured in the pre- and post-surgery sessions, and the ratio of the amplitude for the non-stretched GM to that for the stretched GM (amplitude ratio) was calculated.

Statistical analysis

All data are presented as mean ± standard deviation (SD). Hemodynamic data were compared before and after surgery using an paired t-test (Microsoft Excel 2010®, Microsoft), with a p-value < 0.05 considered statistically significant.

RESULTS

Profiles of participants

All eight patients included in our study were men, with a mean (± SD) age of 63.1 ± 3.4 years. Patients' relevant physical characteristics before surgery are summarized in Table 1. The skinfold thickness of the lower thigh was 4.2 ± 1.1 mm, the BP was relatively high in some patients, SpO_2 was within normal range, and the ankle dorsiflexion range was 49.4 ± 3.2°. There was no reported incidence of muscle pain or any other stretch-related complaints either during or after the first stretching session. The second session was performed on average of 132.9 ± 72.5 min after surgery. At that point, all patients were mechanically ventilated and sedated, with a RASS score of -5 (no response to voice or physical stimulation). Fentanyl citrate (Fentanyl®) and ropivacaine hydrochloride hydrate (Anapeine®) were continuously infused for analgesia via an epidural catheter inserted between thoracic (Th) levels 6–7 or 7–8. Hemoglobin concentration significantly decreased after surgery, from 12.5 ± 1.0 g/dl to 10.6 ± 1.2 g/dl. There was no difference in the compression pressure of the stockings between the first (pre-surgery, 20.3 ± 3.6 mmHg) and second (post-surgery, 19.4 ± 4.5 mmHg) stretching session.

BV in the stretched GM

The NIRS recordings from three of the eight patients in the study group are presented in Fig. 1–3. A decrease in total Hb/Mb was identified during stretching, with a recovery during the stretch-relaxation phase both before and after surgery in seven of the eight patients in the study group (Fig. 1A and 2A as examples before surgery, and Fig. 1B and 2B as examples after surgery). One patient showed an opposite pattern, with an increase in total Hb/Mb during stretching and a decrease during the stretch-relaxation phase both before (Fig. 3A) and after (Fig. 3B) surgery.

BV in the non-stretched GM

The total pre- and post-surgery Hb/Mb of the contralateral GM for the representative recordings are shown in Fig. 1C, 2C, and 3C and in Fig. 1D, 2D, and 3D, respectively. Both before and after surgery, the total Hb/Mb for all patients increased slightly during stretching and decreased during the stretch-relaxation phase. The amplitude ratio was smaller after surgery than before surgery in six of the eight patients (Fig. 1, 2, and 3). In two patients, the increase in total Hb/Mb during stretching was observed until the fourth stretch-relaxation cycle, reaching a plateau thereafter (Fig. 2C and 3C).

DISCUSSION

We investigated the bilateral change in BV in the GM muscle in patients with esophageal cancer undergoing unilateral dorsiflexion stretches before and after surgery. BV in the stretched GM decreased with stretching and recovered with relaxation in seven of the eight patients in our study group. The contralateral (non-stretched) GM showed rhythmic changes in BV that were synchronized to the stretch-relaxation cycle. The mechanism of these rhythmic changes remains to be elucidated.

BV in the stretched GM

We observed a decrease in the total Hb/Mb of the stretched muscle during stretching, with a subsequent increase during the stretch-relaxation phase in seven of eight patients, both before and after surgery. This finding is consistent with those of previous studies that have used NIRS to measure the effects of a muscle stretch on local hemodynamics [10–12, 14, 18, 19]. These hemodynamic effects are likely caused by the distention of the stretched muscle fibers, which reduce the diameter of individual capillaries, leading to reduced arterial inflow and a decrease in muscle BV [11, 19].

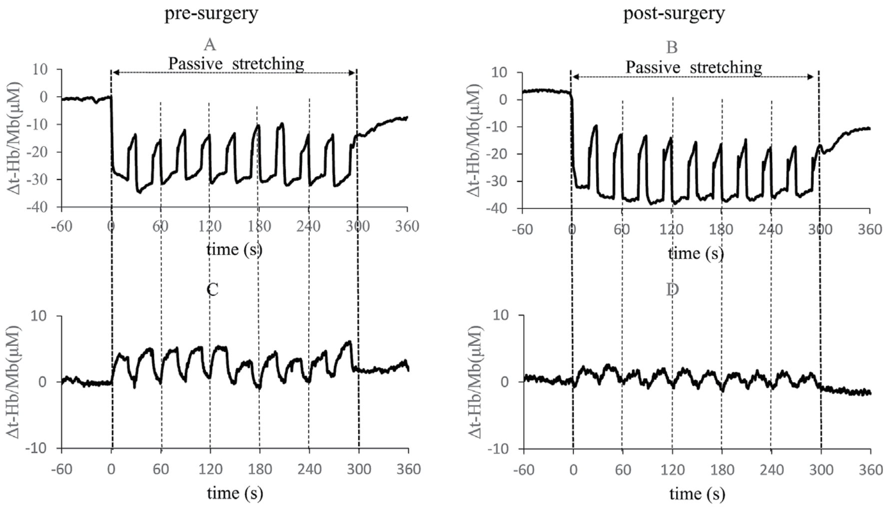

Fig. 1 Change in total hemoglobin-to-myoglobin (t-Hb/Mb) during passive repetitive stretching of the right gastrocnemius muscle (GM) in a 64-year-old patient. (A) Stretched GM before surgery, (B) Stretched GM after surgery, (C) Non-stretched GM before surgery, and (D) Non-stretched GM after surgery. Total Hb/Mb in the stretched GM decreased during stretching and increased during the stretch-relaxation phase both before (A) and after surgery (B). In the contra-lateral non-stretched GM, changes in the total Hb/Mb showed just synchronized alternate response (C and D).

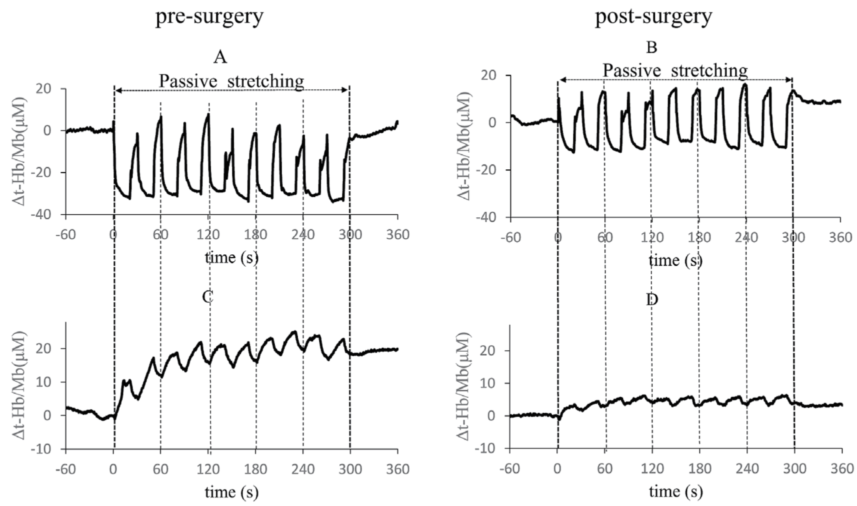

Fig. 2 Change in total hemoglobin-to-myoglobin (t-Hb/Mb) during passive repetitive stretching of the right gastrocnemius muscle (GM) in a 65-year-old patient. (A) Stretched GM before surgery, (B) Stretched GM after surgery, (C) Non-stretched GM before surgery, and (D) Non-stretched GM after surgery. Changes in total Hb/Mb in the stretched GM were same as the patients shown in Fig. 1. Total Hb/Mb in the contra-lateral non-stretched GM before surgery increased until the fourth stretch-relaxation cycle and reached a plateau with the same synchronized response (C).

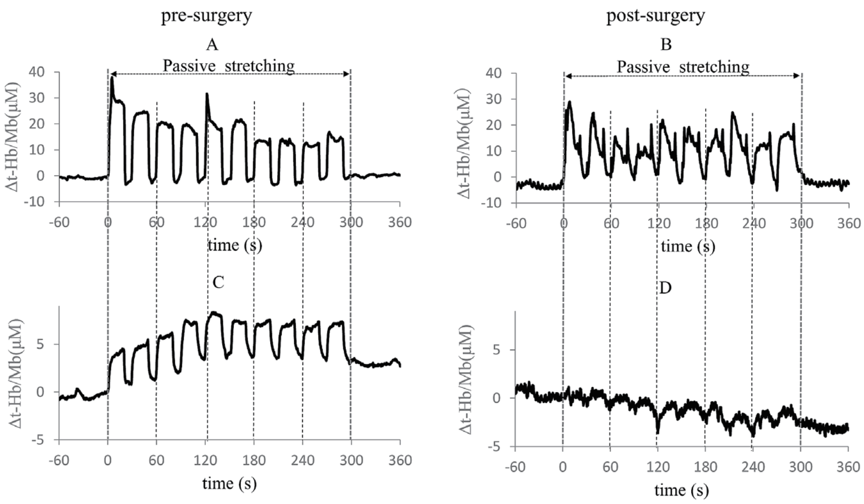

Fig. 3 Change in total hemoglobin-to-myoglobin (t-Hb/Mb) during passive repetitive stretching of the right gastrocnemius muscle (GM) in a 61-year-old patient. (A) Stretched GM before surgery, (B) Stretched GM after surgery, (C) Non-stretched GM before surgery, and (D) Non-stretched GM after surgery. Total Hb/Mb in the stretched GM increased during stretching and decreased during the stretch-relaxation phase both before (A) and after surgery (B).

One patient demonstrated opposite changes in total Hb/Mb of the stretched GM in both the pre- and post-surgery sessions. First, this result may be explained by insufficient stretching of the GM muscle fibers because of an insufficient dorsiflexion angle [20]. However, the dorsiflexion angle obtained in the patient showing an opposite response was 50°, which was not different from the dorsiflexion angle used in other patients. Second, the area recorded by the NIRS may include the soleus muscle. During a passive dorsiflexion stretch, the total Hb/Mb decreased in the GM but increased in the soleus muscle, probably because of a discrepancy in the elongation rate between these two muscles [19, 20].

BV in the contralateral (non-stretched) GM

The total Hb/Mb in the contralateral GM also changed rhythmically in sync with the stretch-relaxation cycle, increasing slightly during stretching and decreasing during subsequent relaxation. To the best of our knowledge, no previous study has reported on the alternative and synchronized BV change in the contralateral muscle in response to cyclical passive stretching of the GM. Rhythmic BV changes synchronized with the stretch-relaxation cycle may result from vasodilation or an increase in blood flow, which may relate to autonomic nerve activity. Wray *et al.* [6] reported that one-leg passive dynamic knee extension slightly increased femoral blood flow in the non-exercising limb, and Callister *et al.* [21] suggested that reflex sympathetic withdrawal that could reduce systemic vascular resistance in the resting limb was a possible mechanism for this. Our preliminary study showed that similar rhythmic BV changes were observed in the bilateral forearm muscles during one-side repetitive GM stretching in healthy subjects (data not shown). This may have involved the central nervous system; however, the precise mechanism remains unclear.

In contrast, Ishii *et al.* [15, 22] reported an initial increase in the BV in the non-exercising vastus lateralis muscle during voluntary one-leg cycling and motor imagery, but not during passive cycling. The authors concluded that central command may have played a role in this phenomenon. In our study, as patients were sedated for the second (post-surgery) stretching session, motor imagery did not contribute to the synchronous changes in BV observed in the contralateral (non-exercised) GM.

The epidural analgesia may influence the muscle blood change during stretching. Venturelli *et al.* [23] examined the effect of repetitive unilateral knee extension on the blood flow of the lower limbs in patients with spinal cord injury, reporting an effect in the moving limb but not in the contralateral (non-exercised) limb. Considering that neural afferent feedback from mechanoreceptors is not available due to spinal cord injury, the absence of an effect on the contralateral lower limb indicates that local mechanical stimuli may be important to stimulating the hyperemia response. We do note that patients in our study received epidural analgesia, at the level of Th 7–8 or 8–9. Six of the eight patients showed attenuation of changes in the BV in the contralateral GM during the post-surgery session. Although afferent sensory input from the GM occurs at the L4–5 level, the epidural analgesia may have had some influence on the hyperemia response.

For two patients, the total Hb/Mb of the non-stretched GM increased until the fifth stretch, plateauing thereafter. Therefore, there may not be a unique mechanism underlying the synchronized change in total Hb/Mb; however, our study was not designed to address this issue.

Study limitations

In our study, we did not continuously measure BP or HR; therefore, we could not confirm changes in systemic circular or sympathetic activity during stretching. A previous study showed that in healthy individuals, passive repetitive GM stretching induced an initial transient increase in muscle sympathetic nerve activity and HR, with a subsequent increase in BP [4]. Studies investigating the relationship between rhythmic changes in muscle BV and sympathetic activity in the contralateral (non-stretched) limb are warranted to clarify the underlying mechanism.

In conclusion, this study documented that unilateral intermittent passive stretching of the GM induced a decrease in the BV in the stretched GM and an increase in that of the contralateral non-stretched GM both before and after surgery. Although the underlying mechanism remains to be clarified, our findings do indicate that unilateral passive GM stretching can influence the microcirculation of the contralateral muscle under sedation and/or epidural analgesia. Stretching continued for the long term may have therapeutic effects on muscle and/or vascular function.

CONFLICT OF INTEREST

None of the authors has any conflict of interest to disclose for this study.

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