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Original Article

Grip Exercise of Non-Paretic Hand Can Improve Venous Return in the Paretic Arm in Stroke Patients: An Experimental Study in the Supine and Sitting Positions

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Objective: This study aims to determine the effect of grip exercise by the non-paretic hand on venous return in the paretic arm in stroke in sitting and supine positions.
Methods: The study population included 21 stroke patients (mean age, 59.5 years). The diameter (mm) and time-averaged mean velocity (TAMV) (cm/s) of the axillary vein on the paretic side were measured by ultrasound during three distinct conditions: resting, rhythmic non-resistive grip exercise, and resistive exercise (30% of maximum grip strength) in supine and sitting positions. The venous flow volume (ml/min) was calculated using the obtained data.
Results: In the supine and sitting positions, the venous flow volume during rhythmic non-resistive and resistive exercises was increased in comparison to resting, which resulted in more increased venous flow volume by rhythmic resistive grip exercise than by non-resistive grip exercise (both, p=0.01).
Conclusion: Grip exercise by the non-paretic hand was found to be effective for increasing the venous flow volume in the paretic hand, and resistive grip exercise caused the greatest increase. Our results suggest that rhythmic handgrip exercise may be clinically useful for reducing the incidence of hand edema in stroke patients.

Keywords: paretic hand, resistive exercise, stroke, venous return

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Introduction

Dependent edema is common in the paretic upper extremities after stroke. Poststroke hand edema has been found in 37% of patients with chronic stroke and 33% of patients with acute stroke.[1)] Edema can lead to a decreased upper extremity function, resulting in reduced capacity to complete activities of daily living, thereby affecting quality of life.[2)] Accordingly, the health professional should pay attention to the management of edema. Although rehabilitation is carried out to alleviate poststroke hand edema, drawing any firm conclusions about its clinical significance in the management of poststroke hand edema is not yet possible.[3)] As there is little evidence to guide clinical decision-making,[1)] it has become apparent that novel, more effective interventions are required to address poststroke hand edema. It has been suggested that the etiology of poststroke hand edema is impaired functioning of venous return due to immobility.[2,3)] In a review article, Geurts et al.[4)] reported that immobility of the paretic upper extremity, repeated minor trauma, elevated filtration pressure, and altered capillary permeability due to autonomic vasomotor dysregulation may be associated with the development of hand edema. Although the etiology of poststroke hand edema remains unclear, the most widely accepted hypothesis regarding poststroke upper extremity edema is that the decreased venous return is related to the loss of the muscle-pumping function in the paretic extremity.[5)] Thus, the promotion of venous return of the paretic hand would be important for addressing poststroke hand edema.

Previously, a pilot study in a small sample of individuals with stroke was carried out to examine whether resistive rhythmic grip exercise by the non-paretic hand of stroke patients could increase venous return in the paretic arm.[6)] The study revealed that resistive rhythmic grip exercise with the non-paretic hand increased venous return in the paretic arm of stroke patients. However, the pilot study was associated with some limitations. First, the only form of exercise performed by the subjects was resistive exercise, which raised the following question: Could exercise without resistance increase venous return in the paretic arm? If so, patients could easily and repeatedly perform the exercise by themselves. Second, venous return was only measured in the supine position. However, because it is critical for promoting an active sitting or standing position in stroke patients,[7] the status of venous return associated with exercise of the non-paretic hand should be assessed in the sitting position. Thus, this study aims to determine the effect of resistive and non-resistive grip exercises by the non-paretic hand on venous return in the paretic arm in stroke patients in both sitting and supine positions.

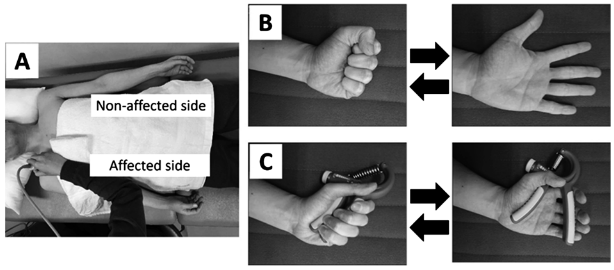

Fig. 1 Hemodynamic measurement and rhythmic handgrip exercise. (**A**) Hemodynamic measurement in the axillary vein on the paretic side. (**B**) Rhythmic handgrip exercise with non-resistance. (**C**) Rhythmic handgrip exercise with resistance. Both non-paretic hand exercises were carried out at a pace of 1 second/cycle.

Methods

Design and Subjects

The present experimental study, with its within-subject design, was approved by the research ethics committee of Seijoh University (Approval No.: 2016C0022), Gifu Central Hospital (Approval No.: 133), and Tokai Memorial Hospital (Approval No.: 28-3). The study was conducted in accord with the Helsinki Declaration guidelines.

The study population included 21 patients (mean age, 59.5 years; range, 44–83 years) within 6 months after stroke onset. Subjects were limited to men in the present study, as the subject's upper body needed to be naked for assessment. According to the Brunnstrom recovery stages,[8] patients had severe to moderate upper extremity paresis: stage II (n=7), III (n=8), and IV (n=6). Among the 21 patients, 9 had hemorrhagic stroke and 12 had ischemic stroke, of which 6 had hypertension, 6 had diabetes, and 1 had arrhythmia as comorbidity. The mean body mass index was 21.5 (range, 15.0–26.2) kg/cm^2. All patients were admitted to the post-acute rehabilitation unit of Gifu Central Hospital or Tokai Memorial Hospital for intensive rehabilitation. Patients with severe cognitive impairment and severe higher brain dysfunction were excluded from the study. Written informed consent was obtained from each participant before each procedure.

Procedure

The temperature was maintained at 24°C–26°C during experiments. A digital handgrip dynamometer (Takei Scientific Instruments, Niigata, Japan) was used to measure the grip strength (kg) of the non-paretic hand of each patient for calculating the 30% maximum voluntary contraction (MVC) of grip strength, which was recorded as the average of two trials. Following the grip strength measurement, subjects were permitted 10 min of supine rest before the second measurement. The mean 30% MVC of grip strength was 8.9 (range, 4.2–14.8) kg.

After resting in a supine position, the diameter (mm) and time-averaged mean velocity (TAMV) (cm/second) in the axillary vein on the paretic side were measured using a Xario ultrasound device (Toshiba Medical Systems, Tokyo, Japan) with a 7.5-MHz linear probe as described in a previous study.[6] The diameter and TAMV were examined with the arm in the neutral position and during three distinct conditions—resting, non-resistive rhythmic grip exercise, and resistive rhythmic grip exercise (30% MVC of grip strength) with a hand grip strengthener adjustable resistance—in the supine position (**Fig. 1**). Accurate identification of the vein was confirmed by applying a positive compressive pressure test and by assessing venous flow via color Doppler imaging. The vessel was viewed in the longitudinal plane, and the maximal diameter of the axillary vein was assessed using B-mode images while moving the probe in parallel. TAMV was also assessed using pulse-wave Doppler imaging. Doppler spectra were acquired in a longitudinal plane at the same site with the angle of insonation maintained at $<60°$ to calculate the TAMV (cm/s). After the rest period, the diameter and TAMV were measured as data on resting. Following the resting data measurements, the same parameters were measured during non-resistive rhythmic grip exercise and with resistive of non-paretic hand in the supine position. Non-resistive rhythmic grip exercise and resistive grip exercise were carried out for 20 seconds at a pace of 1 second/cycle. During grip exercises, subjects were instructed to sustain normal breathing. Each ultrasound measurement lasted 15 seconds. After these measurements in the supine position, the participants were permitted 10 min of sitting rest on a wheelchair. The same measurements were made using the same procedure but with the patient in the sitting position.

Using the obtained data, we calculated the venous flow volume (ml/min) as the venous return in the axillary vein on the paretic side using the following equation:

Venous flow volume (ml/min)
= radius (half of the diameter of the axillary vein) (mm)^2
× π (circular constant) × TAMV (cm/s) × 60/100

The systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR) were measured on the non-paretic side at resting and immediately after the grip exercise condition using an automatic sphygmomanometer (HEM-780; Omron, Kyoto, Japan) in both supine and sitting positions.

Statistical Analyses

The diameter, TAMV, and venous flow volume in the axillary vein; the blood pressure; and the HR at resting and during non-resistive rhythmic grip exercise and resistive rhythmic grip exercise (30% MVC) in the sitting and supine positions were compared using one-way analysis of variance with a Bonferroni correction to analyze the differences in measurements between resting and non-resistive rhythmic grip exercise, resting and rhythmic resistive grip exercise, and rhythmic non-resistive and resistive grip exercises in both positions. Statistical analyses were conducted using EZR, a graphical interface for the R Commander software package for Windows (version 1.37),[9] which is commonly used in biostatistics. Unless noted otherwise, p values of <0.05 showed statistical significance. The effect size was calculated with Cohen's "d" method using the HAD software program (version 16).[10]

Results

Supine Position

The characteristics of the hemodynamic measurements at resting and during both exercises in the supine position and the results of the statistical analyses are presented in **Table 1**.

Bonferroni tests demonstrated that the venous diameters were not increased significantly from resting by rhythmic non-resistive or rhythmic resistive exercises ($p=0.10$ and $p=0.37$, respectively). Furthermore, venous diameters during resistive grip exercise were not significantly increased in comparison to during non-resistive grip exercise ($p>0.99$). In comparison to the resting value, the TAMV was not significantly increased during non-resistive grip exercise ($p=0.08$) but was significantly increased during resistive grip exercise ($p=0.02$). The TAMV during rhythmic resistive grip exercise was not significantly increased in comparison to that during non-resistive grip exercise ($p=0.14$). In comparison to the resting value, the venous flow volumes were significantly increased during non-resistive and resistive grip exercises ($p<0.01$ and $p<0.01$, respectively). The venous flow vol-

Table 1 Hemodynamic measurements in the supine position at resting and when performing non-resistance and resistance exercises

Measurements	Resting		Non-resistance exercise		Resistance exercise		Resting vs. non-resistance		Resting vs. resistance		Non-resistance vs. resistance	
	Mean	SE	Mean	SE	Mean	SE	p	d	p	d	p	d
Diameters (mm)	6.8	0.4	7.2	0.4	7.3	0.5	0.10	−0.20	0.37	−0.22	>0.99	−0.02
TAMV (cm/s)	3.2	0.3	3.8	0.4	4.5	0.5	0.08	−0.41	0.02	−0.69	0.14	−0.34
Volume (ml/min)	67.1	8.0	96.1	12.9	106.8	12.7	0.01	−0.58	<0.01	−0.80	0.01	−0.18
SBP (mmHg)	128.4	3.4	130.2	3.8	134.7	3.9	>0.99	−0.11	0.20	−0.37	0.11	−0.25
DBP (mmHg)	79.3	2.1	78.6	2.3	79.7	2.2	>0.99	0.07	>0.99	−0.03	>0.99	−0.10
HR (beats/min)	67.1	3.0	67.0	2.7	68.2	2.5	>0.99	0.01	0.96	−0.09	0.15	−0.10

TAMV: time-averaged mean velocity; Volume: venous flow volume; SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate

Table 2 Hemodynamic measurements in the sitting position at resting and when performing non-resistance and resistance exercises

Measurements	Resting		Non-resistance exercise		Resistance exercise		Resting vs. non-resistance		Resting vs. resistance		Non-resistance vs. resistance	
	Mean	SE	Mean	SE	Mean	SE	p	d	p	d	p	d
Diameters (mm)	4.7	0.3	5.0	0.4	5.1	0.33	0.13	−0.23	0.11	−0.32	>0.99	−0.06
TAMV (cm/s)	3.5	0.5	4.9	1.1	6.5	1.2	0.12	−0.37	<0.01	−0.78	<0.01	−0.36
Volume (ml/min)	30.5	3.3	47.9	8.4	73.7	10.3	0.04	−0.58	<0.01	−1.21	0.01	−0.59
SBP (mmHg)	130.7	3.4	129.5	3.6	130.5	3.5	>0.99	0.07	>0.99	0.01	>0.99	−0.06
DBP (mmHg)	81.3	2.5	80.5	2.1	80.0	2.9	>0.99	0.08	>0.99	0.111	>0.99	0.04
HR (beats/min)	70.1	2.7	68.8	2.8	70.9	2.8	0.83	0.10	>0.99	−0.06	< 0.01	−0.15

TAMV: time-averaged mean velocity; Volume: venous flow volume; SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate ume was more significantly increased during resistive grip exercise than non-resistive grip exercise ($p=0.01$).

There were no significant increases in the SBP, DBP, or HR values after either exercise.

Sitting Position

The characteristics of the hemodynamic measurements at resting and during both exercises in the sitting position and the results of the statistical analyses are presented in **Table 2**.

Bonferroni tests demonstrated that, during non-resistive and resistive grip exercise, the venous diameters were not significantly increased in comparison to resting ($p=0.13$ and $p=0.11$, respectively). The venous diameters were not significantly increased by either non-resistive or resistive grip exercise ($p>0.99$). In comparison to resting, the TAMV was not significantly increased during non-resistive grip exercise ($p<0.12$) but was significantly increased during resistive grip exercise ($p<0.01$). The increase in the TAMV during resistive grip exercise was significantly greater than that during non-resistive grip exercise ($p<0.01$). In comparison to resting, the venous flow volume was significantly increased during non-resistive and resistive grip exercises ($p=0.04$ and $p<0.01$, respectively). The venous flow volume during resistive exercise was also significantly increased in comparison to that during non-resistive grip exercise ($p<0.01$). The venous flow volume in sitting position was approximately half of that in the supine position.

The SBP and DBP did not increase to a statistically significant extent (in comparison to resting) after either of the exercises. The HR after resistive grip exercise was significantly increased in comparison to that after non-resistive grip exercise ($p<0.01$).

Discussion

We examined the effect of resistive and non-resistive grip exercises performed by the non-paretic hand on the venous return in the paretic arm in stroke patients in both sitting and supine positions. It was found that the venous flow volume was significantly increased in comparison to resting by handgrip exercises in both supine and sitting positions. The increase in venous return (in comparison to resting) induced by resistive grip exercise was greater than that induced by non-resistive grip exercise. Although non-resistive grip exercise significantly increased venous return in the paretic arm, resistive grip exercise seemed to increase venous return more than non-resistive grip exercise.

The grip exercise conditions did not significantly influence the venous diameters on paretic side in this study, whereas significant differences were observed in the venous flow volume under the three conditions, suggesting that the increased venous flow volume primarily resulted from the increased TAMV. It is known that the rhythmic contraction of the skeletal muscles results in the compression of the intramuscle veins and facilitates venous return to the heart.[11] However, because the rhythmic grip exercise was implemented by the non-paretic hand, the venous diameters in the paretic side could not change in the paretic side.

Although the mechanism is unclear, a previous study[12] reported that the deoxygenated hemoglobin of non-contracting arm muscles decreases during voluntary single-arm cranking exercise, which may indicate that changes in the venous return at the non-contracting arm be induced by single-arm exercise. Kiss at al.[13] reported that exercises of the lower extremity of non-paretic side significantly increase the venous blood flow velocity in the extremity of paretic side due to consensual effect. However, their regiment of exercise included breathing effect and a little contraction of paretic side. In present study, we hypothesized that the venous flow volume in the paretic arm might increase due to the pressure distribution in the superior vena cava during the rhythmic exercise cycle—from the deep venous systems of the arm (i.e., from the wrist up to the axillary vein, brachiocephalic vein, and superior vena cava). When the rhythmic venous flow of both right and left sides reaches the superior vena cava, pressure is then distributed between the muscle contraction and relaxation phases. We suggest that the rhythmic venous return of the non-paretic side reaches the superior vena cava earlier than the venous return of the paretic side, causing pressure distribution, with the venous return of the paretic side possibly drawn up to the superior vena cava.

Gravity causes venous pooling in vessels.[14] Hydrostatic pressure occurs in the vascular system because of the weight of blood in the vessels,[15] and postural changes alter hydrostatic pressure patterns according to the body's alignment due to gravity.[16] When the hand is lower than the heart, the intravascular pressure is increased.[17] Hence, in the sitting position, venous return in the paretic hand is decreased. However, the present study showed that grip exercise of the non-paretic hand was associated with increased venous return in both positions. Even in a setting with reduced venous return due to gravity, grip exercise by the non-paretic hand could promote venous return in the paretic arm.

The SBP and DBP did not differ from the resting values after grip exercise. The only significant difference in HR was observed between non-resistive and resistive exercises; however, the effect size (d) was small because the difference in HR was relatively small. Notarius et al.[18] reported that the mean arterial pressure and HR do not show significant increases during the first minute of isotonic grip at 30% MVC in either heart failure patients or normal subjects. Thus, because handgrip exercises in the present study were only carried out for 20 seconds, they did not influence the SBP, DBP, or HR.

Various treatments, including neuromuscular stimulation-induced muscle contraction and continuous passive motion, have been advocated for poststroke hand edema; however, there is yet to be a consensus on a preferred treatment strategy.[19] We believe that the results of the present study are potentially useful for decreasing poststroke hand edema. In this study, venous return in the paretic arm was increased by grip exercise using the non-paretic hand. It is generally easy for patients with hemiplegia to move the non-paretic hand. Our results suggest that rhythmic grip exercise by the non-paretic hand may be a novel technique for reducing upper arm edema in stroke patients. In the acute and subacute stage, resistive and rhythmic exercises may be required to reduce hand edema.

The present study was associated with several limitations. A previous study indicated that the loss of autonomic vasomotor tone contributed to reductions in venous vascular function.[20] However, the autonomic nervous system was not measured in the present study. Although venous return in the paretic arm was increased by grip exercise using the non-paretic hand in this study, the precise mechanism remains unclear. Additionally, to measure the diameter of vein, measuring the short plane may also be required. However, we measured the diameter and TAMV of axillary vein on the longitudinal plane as described in previous studies.[21,22] It was adequate to continually obtain the data of diameter and TAMV by keeping the probe on the longitudinal plane without moving and converting to the short plane.

Conclusion

Based on the results of this study, we drew the following conclusions: (1) Grip exercise by the non-paretic hand effectively increases the venous flow volume in the paretic hand in the supine and sitting positions. (2) Resistive grip exercise is more effective than non-resistive grip exercise. (3) Grip exercise by the non-paretic hand may be useful for decreasing poststroke hand edema on the paretic side. Nevertheless, further research is needed to determine the efficacy of grip exercise for reducing hand edema in stroke patients.

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Disclosure Statement

The authors declare no conflicts of interest in association with the present study.

Author Contributions

Study conception: HH, MA
Data collection: HH, MA
Analysis: HH, MA
Writing: HH, MA
Funding acquisition: HH
Critical review and revision: all authors
Final approval of the article: all authors
Accountability for all aspects of the work: all authors

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