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Original Article

Effects of high-intensity pulse irradiation with linear polarized near-infrared rays and stretching on muscle tone in patients with cerebrovascular disease: a randomized controlled trial

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Abstract. [Purpose] The purpose of this study was to clarify the influence of high-intensity pulse irradiation with linear polarized near-infrared rays (HI-LPNR) and stretching on hypertonia in cerebrovascular disease patients. [Subjects and Methods] The subjects were 40 cerebrovascular disease patients with hypertonia of the ankle joint plantar flexor muscle. The subjects were randomly allocated to groups undergoing treatment with HI-LPNR irradiation (HI-LPNR group), stretching (stretching group), HI-LPNR irradiation followed by stretching (combination group), and control group (10 subjects each). In all groups, the passive range of motion of ankle dorsiflexion and passive resistive joint torque of ankle dorsiflexion were measured before and after the specified intervention. [Results] The changes in passive range of motion, significant increase in the stretching and combination groups compared with that in the control group. The changes in passive resistive joint torque, significant decrease in HI-LPNR, stretching, and combination groups compared with that in the control group. [Conclusion] HI-LPNR irradiation and stretching has effect of decrease muscle tone. However, combination of HI-LPNR irradiation and stretching has no multiplier effect.

Key words: Muscle tone, Linear polarized near-infrared ray, Stretching

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INTRODUCTION

Linear polarized near infrared rays (LPNR) emitted by therapeutic equipment deeply penetrate the body because infrared rays within the wavelength range (600–1,600 nm) are not readily absorbed by hemoglobin and water in the blood[1)]. Irradiation reaches deeper as the output rises, but a high intensity increases the risk of burn. Previous phototherapy mainly used low-output laser therapeutic equipment with an output of several ten to several hundred mW or LPNR therapeutic equipment with a maximum output of approximately 2,000 mW[2, 3)]. High-intensity pulse irradiation with LPNR (HI-LPNR) equipment with a maximum output of 10 W and pulse irradiation laser therapeutic equipment have recently been applied in clinical use[4, 5)]. These systems reduce the burn risk by applying pulse irradiation in several ten-millisecond intervals while securing deep penetration by high-intensity output. In previous studies on intense phototherapy equipment, pain relief and sympathetic ganglion irradiation were mainly investigated[4, 5)]. Based on this, we previously reported that HI-LPNR irradiation might

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Table 1. Subject characteristics

	Total	Group (10 subjects each)			
	(n=40)	HI-LPNR	Stretching	Combination	Control
Age [yrs]	79.1 ± 8.0	77.7 ± 8.5	83.2 ± 8.4	77.7 ± 5.6	77.6 ± 8.8
Gender (male/female)	24/16	4/6	6/4	7/3	7/3
Diagnosis					
Cerebral infarction	34	8	9	9	8
Cerebral hemorrhage	6	2	1	1	2
Paretic side (right/left)	23/17	4/6	7/3	7/3	5/5
Duration of illness [d]	1,434.8 ± 2,878.0	3,127.8 ± 4,481.6	1,187.3 ± 3,095.9	478.2 ± 670.5	945.9 ± 1,113.2
Base line PROM [°]	−1.18 ± 6.13	0.00 ± 4.00	−2.20 ± 9.67	−2.80 ± 5.47	0.30 ± 3.92
Base line PRJT [N·m]	5.85 ± 1.04	5.45 ± 1.09	5.97 ± 0.83	5.76 ± 0.83	6.21 ± 1.32
Base line APTS (0/1/2/3/4)					
SR	16/13/7/2/2	3/4/3/0/0	5/3/1/0/1	3/3/2/1/1	5/3/1/1/0
MR	7/20/12/1/0/	2/6/2/0/0	0/6/4/0/0	2/4/4/0/0	3/4/2/1/0
FR	0/13/26/1/0	0/5/5/0/0	0/0/10/0/0	0/2/8/0/0	0/6/3/1/0

Values are either n or mean ± standard deviation.
No significant differences were noted in the all index among the groups.
APTS: Ankle Plantar Flexors Tone Scale; SR: stretch reflex; MR: middle range resistance; FR: final range resistance; Ext: knee extended position; Flex: knee flexed position; PROM: passive range of motion; PRJT: passive resistive joint torque

suppress muscle tone in cerebrovascular disease (CVD) patients[6].

On the other hand, stretching is widely performed as a physical therapeutic approach to hypertonia and many studies have reported its effectiveness[7–9]. The combined effects of stretching and thermotherapy have also been investigated. In the 1970s, Lehmann et al.[10] and Warren et al.[11] described the usefulness of the combined effects of thermal stimulation and stretching, and it has been continuously investigated[12, 13].

We assumed that the combination of HI-LPNR irradiation exhibiting superior deep thermal effects and stretching would be effective for treating hypertonia in CVD patients, but no study on this has been reported. The purpose of this study was to clarify the influence of this combination on hypertonia in CVD patients.

SUBJECTS AND METHODS

The subjects were 40 CVD patients with hypertonia of the ankle joint plantar flexor muscle on the paralytic side (Table 1). The inclusion criterion was a score of the Ankle Plantar Flexors Tone Scale[14] (APTS) of "1" or higher in at least one item (Table 2). The exclusion criteria were the presence of surgical treatment or drug therapy for spasms (regardless of oral or injection), restriction of range of ankle joint motion on the paralytic side due to a reason other than hypertonia, and influence of pain or other reasons on measurement. This study was a developmental continuation of our previous study on the effects of HI-LPNR irradiation on hypertonia[6] and some subjects from the previous study were included in this study.

This study was performed after approval by the ethics committee at Honjo General Hospital (approval number: 20110907). The objective and methods of this study were explained to all subjects and written consent was obtained.

The subjects were randomly allocated to groups undergoing treatment with HI-LPNR irradiation (HI-LPNR group), stretching (stretching group), HI-LPNR irradiation followed by stretching (combination group), and without HI-LPNR irradiation or stretching (control group) (10 subjects each). The HI-LPNR, stretching, and combination groups were intervened by the methods described below. The control group rested in the supine position for 5 minutes. In all groups, the passive range of motion of ankle dorsiflexion (PROM) and passive resistive joint torque of ankle dorsiflexion (PRJT) were measured before and after the specified intervention.

For the HI-LPNR therapeutic equipment, the Super Lizer PX (Tokyo Iken Co., Ltd.) was used, and a 20-mm diameter irradiation probe was selected. This equipment emits pulse irradiation (irradiation: 3 milliseconds, interval: 7 milliseconds) at a maximum output of 10 W. The irradiation output was set at 8 W, and the total irradiation time was set at 5 minutes. Irradiation was applied to 4 sites on the origin side of the triceps surae muscle-tendon junction on the paralytic side. One site was irradiated for 3 seconds and then irradiation was moved to the other, and this procedure was repeated for 5 minutes. The irradiation probe tip was lightly contacting the skin, avoiding excess pressure. Irradiation was applied in the lateral recumbent position on the paralytic side, and the bilateral hip and knee joints were slightly bent. The HI-LPNR and combination groups were irradiated using this method.

Carey's stretch method[7] was adopted to the stretching and combination groups. The subject laid in the supine position and maximally extended the paralytic-side knee joint. A physical therapist held the patient's calcaneus from the sole with

Table 2. Ankle Plantar Flexors Tone Scale[14)]

Stretch reflex
0: No twitch.
1: Twitch and no clonus.
2: Mild clonus, persisting <3 s.
3: Moderate clonus, persisting 3–10 s.
4: Severe clonus, persisting >10 s.
Middle range resistance
0: No resistance.
1: Mild resistance, slight increase in resistance.
2: Moderate resistance, greater increase in resistance.
3: Severe resistance, considerable increase in resistance, but able to achieve passive movement.
4: Passive movement is difficult.
Final range resistance
0: No resistance.
1: Mild resistance, slight increase in resistance.
2: Moderate resistance, greater increase in resistance.
3: Severe resistance, considerable increase in resistance, but able to maintain final position.
4: Unable to maintain final position or passive movement is difficult.

the palm, pressed the patient's anterior foot region with the therapist's distal forearm to passively apply dorsiflexion to the patient's foot to maximally stretch and extend the ankle joint plantar flexor muscle within a range avoiding stretch pain. After retaining the maximum stretch position for 20 seconds, the ankle joint was returned to the neutral position of plantar dorsiflexion to relax the muscle. The total stretching time was set to 5 minutes, and retention of the maximum stretch position for 20 seconds and relaxation for less than 1 second were repeated in this period. Stretching was performed using this method in the stretching and combination groups.

Stretching was performed after HI-LPNR irradiation in the combination group employing the same procedures performed in the HI-LPNR and stretching groups, respectively. The control group rested in the supine position for 5 minutes.

PROM and PRJT were adopted as the evaluation indices and measured in the supine position with maximum knee extension in all subjects. In PROM, setting a line vertical to the fibula as a baseline axis and the 5th metatarsal bone as a moving axis, the maximum passive dorsiflexion angle of the ankle was measured in 1-degree units. In PRJT, the central region of the sensor pad of a hand-held dynamometer (HHD) (Power TrackII, Jtech Medical Industry) was contacted to the head of the 2nd metatarsal bone, and the minimum force required for passively applying maximum dorsiflexion through HHD was measured. This HHD value [N] was multiplied by the distance [m] between the lower end of the medial malleolus and head of the 2nd metatarsal bone, which is the ankle joint plantar dorsiflexion movement axis, to calculate the torque. For the dorsiflexion-resistive torque after intervention, the value at the maximum dorsiflexion angle before intervention was adopted (this was not the force required to retain the maximum dorsiflexion after intervention). This value was regarded as the dorsiflexion-resistive torque.

The age, duration (days) of illness, and PROM and PRJT before intervention were analyzed using a one-way layout analysis of variance. The gender, paralytic side, and diagnosis were analyzed using the χ^2 test and APTS of the paralytic-side lower limb was analyzed using the Kruskal-Wallis test in each group to investigate the between-group differences before intervention. Regarding PROM and PRJT, changes after intervention were determined and analyzed using a one-way layout analysis of variance followed by multiple comparison (Scheffe's method). All analyses were performed using statistical analysis software, SPSS23.0 J for Windows (Japan IBM), and the significance level was set at 5%.

RESULTS

Table 1 shows the attributes of the subjects. No significant differences were noted in the age, gender ratio, diagnosis, paralytic side, or duration of illness among the groups. No significant differences were noted in APTS, PROM, or PRJT before intervention. No patient met the exclusion criteria.

Changes in PROM and PRJT after intervention are shown in Table 3. The change in PROM was 2.70° in the HI-LPNR group, 5.30° in the stretching group, 6.30° in the combination group, and −0.50° in the control group. A significant difference was detected on one-way layout analysis of variance ($p<0.001$), and a significant increase in PROM was noted on subsequent multiple comparison in the stretching ($p=0.003$) and combination ($p<0.001$) groups compared with that in the control group.

The change in PRJT was −1.42 Nm in the HI-LPNR group, −1.96 Nm in the stretching group, −1.77 Nm in the combina-

Table 3. Change in passive range of motion and passive resistive joint torque

		Mean ± SD	
PROM [°]	HI-LPNR	2.70 ± 2.45	
	Stretching	5.30 ± 2.21	
	Combination	6.30 ± 5.10	** (Stretching vs Control)
	Control	−0.50 ± 1.72	** (Combination vs Control)
PRJT [Nm]	HI-LPNR	−1.42–0.57	
	Stretching	−1.96–0.83	* (HI-LPNR vs Control)
	Combination	−1.77–0.93	** (Stretching vs Control)
	Control	−0.26–0.74	** (Combination vs Control)

PROM: passive range of motion; PRJT: passive resistive joint torque; SD: standard deviation
**p<0.01, *p<0.05

tion group, and −0.26 Nm in the control group. A significant difference was detected on one-way layout analysis of variance (p<0.001), and a significant decrease in PRJT was noted on subsequent multiple comparison in the HI-LPNR (p=0.012), stretching (p<0.001), and combination (p<0.001) groups compared with that in the control group.

DISCUSSION

PROM significantly increased in the stretching and combination groups compared with that in the control group. In addition, PRJT significantly decreased in the HI-LPNR, stretching, and combination groups compared with that in the control group. PROM is an index reflecting the maximum stretch of the ankle joint plantar flexor muscle, and PRJT is an index reflecting the force required to stretch the muscle (resistance to muscle stretch).

We previously reported the muscle tone-inhibitory effects of HI-LPNR irradiation[6]. Demura et al.[15] reported that LPNR irradiation increased the range of motion in healthy subjects. In these reports, the efficacy of LPNR irradiation for extensibility of soft tissue, including muscle, was described, and involvement of the thermal effects of LPNR in the mechanism was suggested.

The thermal effects on muscle tone are roughly divided into those through extensibility of non-neurological (or non-reflex) elements, such as muscle fibers and fascia, and neurological (or reflex) elements mainly through the stretch reflex[14, 16, 17]. PRJT significantly decreased in the HI-LPNR group compared with that in the control group, for which improvement of extensibility of muscle fibers and fascia of the triceps surae muscle by the thermal effect of HI-LPNR irradiation may have been one cause, and this is an effect on non-neurological elements of muscle tone. Additionally, muscle spindle, Ia sensory neuron, and α motor neuron activities may have been inhibited and attenuated the stretch reflex. This is an effect on neurological elements of muscle tone.

Stretching is a treatment through morphological change of muscle by physical extension. PROM increased in the stretch-applied stretching and combination groups suggesting that directly extending the muscle is effective to improve the maximum muscle stretch. Many studies on the effects of stretching on hypertonia in CVD patients have been reported, and intermittent stretching was performed in many studies, similar to in our study. Bressel et al.[17] reported that they performed intermittent or continuous stretching on the ankle joint plantar flexor muscle in stroke patients, and the resistive joint torque decreased in both groups. Carrey[7] reported the joint movement-improving effects of intermittent stretching of the finger flexor muscles in stroke patients. In the data reported by Bressel et al.[8], when intermittent stretching was performed, the resistive torque decreased at the beginning of the stretch, but the change decreased within about 5 minutes and plateaued. In our study, PRJT was decreased by a 5-minute stretch, which is consistent with the results reported by Bressel et al.[8] with regard to the reduction of the muscle stretch time and PRJT. However, changes in PRJT as well as the cumulative and carry-over effects of 5-minute or longer stretching cannot be discussed and is a limitation of this study.

PROM significantly increased and PRJT significantly decreased in the combination group compared with in the control group. PROM also significantly increased in the stretching group, and PRJT significantly decreased in the HI-LPNR and stretching groups. On the other hand, no significant differences were noted in PROM or PRJT among the 3 intervened groups.

PRJT decreased in the HI-LPNR group, suggesting that muscle extensibility may be improved by HI-LPNR irradiation alone. Warren[11] stated that warming of tissue decreases the load required for stretching, reducing the risk of tissue damage. No additive effects of the combination of HI-LPNR irradiation and stretching was noted in PROM or PRJT, but it was clarified that HI-LPNR irradiation alone can reduce the load required to stretch muscle, indicating that stretching under this condition enables treatment with reduced risks, thus suggesting this combination to be clinically useful.

We acknowledge limitations of this study. The rater performing the measurement and the intervention was not blind to group allocation. Additionally, only 40 subjects were included in this study. Thus, more knowledge could be obtained by increasing the number of subjects in future studies.

Conflict of interest

The authors have no conflict of interest to declare.

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