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ORIGINAL ARTICLE

Development of the Protocol to Deliver Graded Stimulation Intensity on Lower Limbs Using Belt-shaped Electrode Skeletal Muscle Stimulation

Toru Ogata, MD [a] Hitoshi Sekiya, MD [b] Yoshihiko Kono, MD [c] Yoshimi Watanabe, RPT [b] Tsuyako Koyama, RPT [c] and Hiromi Oda, MD [d]

Objectives: Current advancements in neuromuscular electrical stimulation (NMES) include belt-shaped electrode skeletal muscle electrical stimulation (B-SES), which was developed to induce whole leg muscle contraction in a single session. Delivering the optimal amount of stimulation is critical in NMES; therefore, we set out to establish a method to determine the B-SES stimulation intensity needed to induce muscle contraction sufficient for clinical purposes. **Methods:** We used the Auto Tens Pro system (Homer Ion Laboratory), which is a B-SES device. Stimulation at 20 Hz was delivered for 5 s, followed by 2 s rest. Twenty-four patients who were hospitalized for musculoskeletal diseases were enrolled at two hospitals. Patients were randomly assigned to one of three groups of subjectively graded stimulation intensities: moderate, strong, or very strong. To achieve each target intensity, we developed a structured verbal instruction protocol that aimed to help therapists deliver the target level of stimulation. As a physiological assessment of muscle contraction, serum lactate levels were measured before and after a single 20-min B-SES session. **Results:** The electric current intensity required to achieve a target subjective muscle contraction gradually increase according to the subjective contraction level. The increase in serum lactate level was significantly larger in the very strong group than in the moderate group. **Conclusions:** B-SES stimulators have the potential to induce efficient muscle strengthening in patients with musculoskeletal diseases. The structured verbal protocol developed here could help therapists achieve the appropriate stimulation intensity for each patient.

Key Words: current density; disuse syndrome; muscle strengthening; neuromuscular electrical stimulation; serum lactate

INTRODUCTION

Neuromuscular electrical stimulation (NMES) has been widely used to induce skeletal muscle contraction in the field of clinical medicine, health care, and sports.[1)] In general, the electrodes located on the skin surface cover peripheral nerve endings, called motor points, on the targeted muscles. Sequential electrical stimulation induces depolarization of the peripheral nerves and then induces muscle contraction.[2)] Currently, various types of devices are available with a variety of electrode shapes, electrical wave forms, and stimulation intensities.[3)] NMES has various purposes, including muscle strengthening, exercise, and massage. Studies have proved the efficacy of NMES in strengthening muscles in both young adults and the elderly population.[4–6)]

NMES has been utilized in the field of musculoskeletal

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[a] Department of Rehabilitation Medicine, The University of Tokyo Hospital, Tokyo, Japan
[b] Department of Orthopaedic Surgery, Shin-Kaminokawa Hospital, Kaminokawa, Japan
[c] Department of Orthopaedic Surgery, Musashidai Hospital, Hidaka, Japan
[d] Department of Orthopaedic Surgery, Saitama Medical University, Moroyama, Japan
Correspondence: Toru Ogata, MD, PhD, Department of Rehabilitation Medicine, The University of Tokyo Hospital, 7-3-1 Hongo, Bunkyo-Ku, Tokyo 113-8655, Japan, E-mail: toogata-tky@umin.ac.jp

diseases as one treatment component for physical strengthening, particularly for treatments targeting the knee extensor muscles.[7,8] The strength of the knee extensor has crucial effects on the symptoms of bone and joint disorders, such as knee osteoarthritis and anterior cruciate ligament (ACL) injury.[4,9,10] However, evidence for the efficacy of NMES in these diseases has not been fully established. Several systematic reviews and clinical guidelines have mentioned that the broad range of available stimulation modalities prevents the accumulation of consistent evidence.[7,9,11] Comparisons of stimulation intensities using different devices is difficult.[7] In many reports of NMES-based muscle strengthening, the intensities are set as strong as can be tolerated by the subjects.[12] For objective assessment of the stimulation intensity, the knee extension torque induced by the stimulation is recognized as one of the standardized ways to quantify the intensity of stimulation.[13] For example, Talbot et al. reported that an intensity of 18% of the maximum voluntary isometric contraction is required to increase muscle strength in patients with knee osteoarthritis.[14]

Among NMES devices, belt electrode skeletal muscle stimulation (B-SES) represents a new approach that uses a belt-shaped electrode set around the lower trunk, thighs, and ankles. The large electrode area enables reduction of pain during stimulation and induces whole muscle contraction in the lower limbs.[15,16] The benefits of B-SES in maintaining the knee extensor muscle after ACL reconstruction surgery have been reported.[17] In previous reports, the intensity of the stimulation by B-SES devices is described as being set to the maximum intensity that the subjects could endure. Because B-SES induces muscle contraction in both knee extensor and flexor muscles simultaneously, the stimulation intensity cannot be measured using the joint torque and the maximum voluntary isometric contraction. Therefore, a method that standardizes the stimulation intensity is required to facilitate the accumulation of evidence of the effects of B-SES in clinical practice.

In the present study, we set out to establish a specific verbal instruction protocol for patients with musculoskeletal diseases that would allow induced muscle contraction of a subjectively graded strength. We also aimed to evaluate whether the subjectively graded muscle contraction strength across the patient cohort corresponded to the objective index for muscle contraction.

METHODS

Subjects

The subjects for this study were recruited from two hospitals. Patients were aged at least 60 years and were hospitalized because of musculoskeletal diseases. The subjects were at risk for losing muscle strength because of the necessity for bed rest. NMES procedures were performed as part of the physical exercise for their lower limbs. Patients with skin problems or mental illness were excluded. Before the experimental NMES procedures were carried out, the baseline knee extension force was evaluated using a hand-held dynamometer (μTas F-1, Anima, Tokyo, Japan), and the time required to perform five sit-to-stand (5STS) cycles was measured (longer times indicate weaker leg muscles).

This study was carried out in accordance with the Declaration of Helsinki and was approved by the institutional review board. Written informed consent was obtained from each participant. This study was approved by the Institutional Review Board of the National Rehabilitation Center for Persons with Disabilities (reference number 30–136). The study was registered as UMIN000024889.

Stimulation Procedure and Blood Sample Collection

We used the Auto Tens Pro device (Homer Ion Laboratory, Tokyo, Japan), which is a commercially available device for performing B-SES. According to the manufacturer's instructions, the belt-shaped electrodes were set around the thigh, ankle, and trunk, just above the iliac crests. The stimulation mode was set to "Disuse Mode," which consisted of 20-Hz stimulation that was on for 5 s and off for 2 s. Before the experimental procedure, three test sessions were performed with each subject so that they were accustomed to the stimulation.

On the examination day, the subjects were instructed to rest on their beds for at least 30 min, and the electrodes were attached with the patient on the same bed. One session lasted for 20 min, and the stimulation intensity was fixed at the targeted intensity (as described below) within 1 min from the start. Because the intensity indicator of the B-SES device shows an arbitrary scale, the actual stimulation amplitude (in milliamperes) was calculated from a correspondence table provided by the manufacturer. Blood samples were taken from a vein to measure serum lactate levels before the start of the stimulation and at the end of the session (i.e., within 5 min after the stimulation ceased).

Table 1. Demographic data of subjects in the three groups with different subjectively set NMES intensities

	Target stimulation intensity			
	Very strong (n=9)	Strong (n=8)	Moderate (n=7)	P value (Kruskal–Wallis)
Age (years)	69.7±7.5	78.4±6.3	73.9±5.8	0.070
Sex (male:female)	5:4	6:2	2:5	
Body mass index (kg/m^2)	23.8±3.3	23.8±3.7	24.9±4.5	0.799
Knee extension force (N)	23.2±10.0	20.2±7.5	17.3±7.5	0.499
5STS (s)	11.8±5.0	17.6±7.5*	15.7±7.5*	0.245

Data are means±SDs.
*Longer than the 12-s cutoff time for a healthy elderly person.

Setting the Stimulation Intensity

Because this study was aimed at establishing a standardized method to set the stimulation intensity, we carefully designed the verbal instructions used to determine the intensity. We randomly divided the subjects according to the intended stimulation intensity: very strong, strong, and moderate. The procedure was carried out as follows:

1. The therapist explained to the patient that the higher the stimulation, the higher would be the expected muscle strengthening outcome.

2. After stimulation commenced, the therapist gradually increased the intensity while asking the subject whether the stimulation was at the limit they could endure.

3. Once the subject stated that they could not endure the current stimulation intensity for 20 min, the therapist slightly decreased the intensity and defined that intensity as "very strong".

4. For those who were assigned to the strong group, the intensity was further reduced. The instruction given was as follows: "Please recall the pain you felt as 'very strong' and determine the intensity of 'strong' at which you feel it is difficult but possible to endure the stimulation for 20 min."

5. For those who were assigned to the moderate group, the intensity was further reduced to the level at which the subjects felt it was easy to endure the stimulation for 20 min.

Statistics

All measured items were analyzed by SPSS software ver. 22 (IBM, Armonk, NY, USA). Comparisons among the three groups were analyzed using the Kruskal–Wallis test, followed by Bonferroni post hoc correction. Correlations between two parameters were analyzed by Spearman's rank correlation. Statistical significance was determined as $P<0.05$.

RESULTS

Patient Characteristics

We recruited 35 patients from two hospitals, but the initial eleven subjects were excluded because blood sampling was not performed within the specified timing. Consequently, we analyzed the data from 24 subjects (13 men, 11 women) whose ages varied between 60 and 90 years (mean, 73.8±7.2). The reasons for hospitalization were lower limb surgery (mainly total knee arthroplasty; 9 cases), decompression for degenerative spine (6 cases), lower limb fracture (3 cases), and spinal column fracture (6 cases). The mean time between admission or operation and stimulation was 42.8±16.9 days. After the subjects were divided into three groups according to the target stimulation intensity, their physical characteristics and muscle strength test results were assessed and are listed in **Table 1**; there were no statistical differences between the three groups.

Objective Stimulation Intensity Was Correlated with Subjective Intensity

After the subjects were assigned to one of the three graded stimulation intensity groups (very strong, strong, or moderate), they underwent stimulation using the B-SES device. **Figure 1** shows the objective stimulation intensity (i.e., the intensity at which the stimulation was actually delivered to the subjects) in the three groups. The subjects in the very strong group received median stimulation at 8.4 mA, and the strong and moderate groups received median stimulation at 7.25 and 5.2 mA, respectively. A significant difference was found between the intensities of the very strong group and the moderate group ($P=0.005$, Kruskal–Wallis test followed by Bonferroni post hoc correction). These results indicate that the intensity as determined according to the present subjective method led to a similar trend in the objective physical

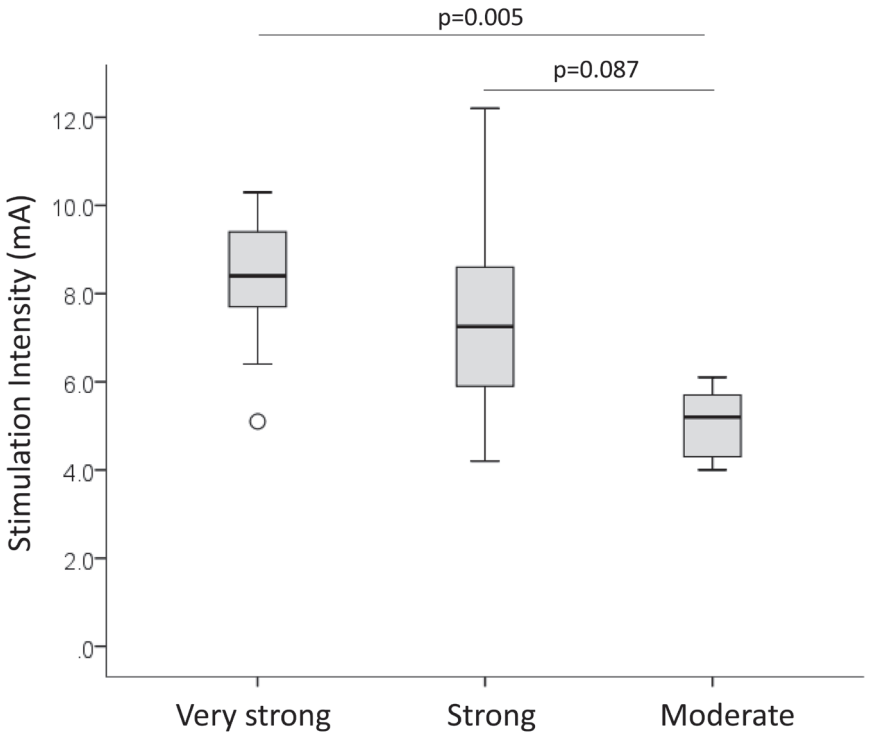

Fig. 1. Average NMES current applied to bilateral thighs. The current intensity was compared among the three groups. Subjects whose target subjective stimulation intensity was higher tended to receive a higher current.

stimulation parameter.

Relative Muscle Strength Affected the Output Current

The relationship between the output current (NMES device setting) and the strength of the induced muscle contraction is known to vary among subjects. The volumes of subcutaneous fat and muscles affect the conductance for the electrical stimulations and leads to inter-subject difference in the response to NMES.[1,18] To assess the relevant physical characteristics of the subjects, we utilized the 5STS test, which reflects both the body weight and the lower limb muscle strength. The resulting times to complete the 5STS test varied from 5.5 to 31.1 s (mean 14.7±6.7), and 57.1% of subjects took longer than the reported cut-off value of 12 s for a healthy elderly person.[19] There was no correlation between the length of hospital stay before stimulation and the time required to complete the 5STS test (P=0.366, Pearson's correlation analysis, data not shown).

Figure 2 shows the relationships between the 5STS time and the output current required to obtain the intended subjective stimulation intensity. No statistical correlation was found between lower limb performance and the required output current in the very strong and moderate groups. However, in the strong group, the output current was higher in subjects with longer 5STS times (i.e., those having lower limb weakness) (P=0.014, Spearman's rank correlation).

Increases in Serum Lactate Were Correlated with Subjective Intensity

To examine whether the subjectively graded intensities reflected the resulting muscle responses, we measured serum lactate levels to evaluate the physiological muscle response. Serum lactate increases as a result of metabolic reactions in muscles and therefore reflects the intensity of muscle contraction.[20] We evaluated the serum lactate responses by calculating the percentage increases from the baseline. This approach was used because of the variations in the basal lactate levels and the physical characteristics among subjects. When we compared the three groups, we found that there was a tendency for a larger induced increase in serum lactate level in subjects who received stronger subjective stimulation (**Fig. 3**). In the post-hoc analyses, a statistical difference was found between the very strong and moderate groups (median

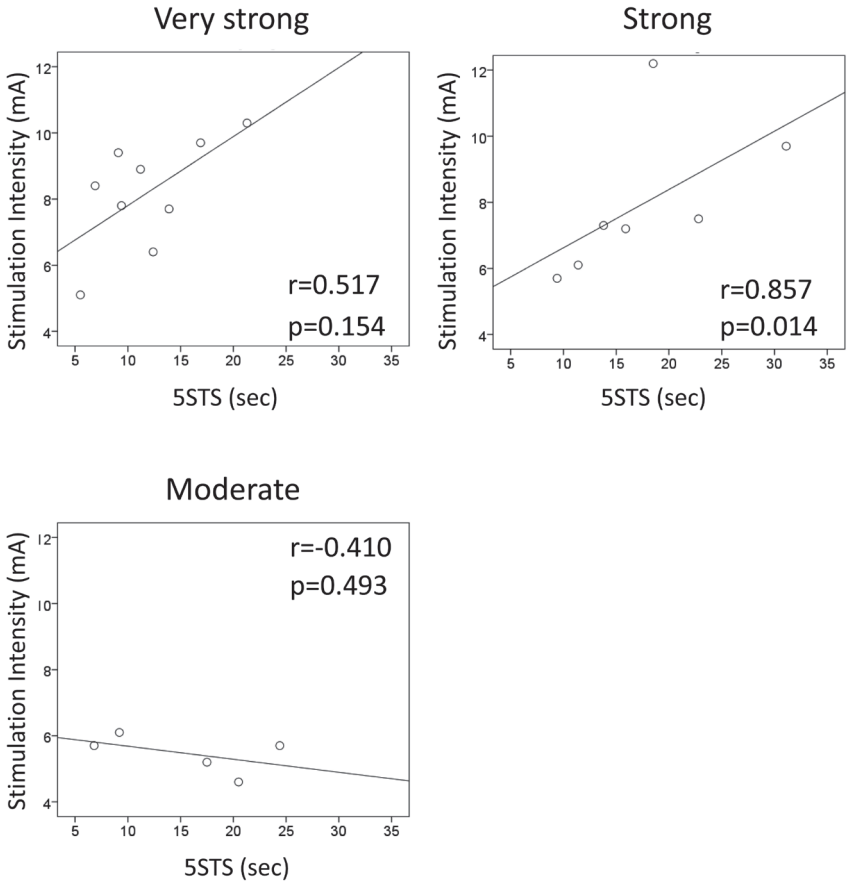

Fig. 2. Correlations between the 5STS time and NMES current intensity. The time required to complete the 5STS test was compared with the current required for the target subjective stimulation intensity. A statistically significant correlation was found only in the strong group. Those who had longer 5STS times (weaker performance) needed a higher current intensity to achieve strong muscle contraction.

72.6% vs 19.0%, P=0.005, Kruskal–Wallis test, followed by Bonferroni post hoc correction).

DISCUSSION

In the current study, an NMES device that utilizes belt-shaped electrodes was used in an attempt to standardize the method for inducing sufficient contraction for therapeutic intervention in elderly patients with musculoskeletal diseases. Using predesigned verbal instructions, we developed three specific subjective muscle contraction grades. Serum lactate levels that reflected the three subjective intensity grades indicated the feasibility of determining the intensity using this approach.

Belt-shaped electrodes have been recently developed to enable the induction of whole muscle contraction in the lower limbs. The large electrode area allows the delivery of high-amplitude current across the skin while avoiding intense pain sensations at the surface.[15,21] This method has the advantage of inducing contraction in multiple muscles, even in deep muscle layers.[22] Because the stimulation intensity in B-SES sessions cannot be evaluated using the joint torque, previous studies mostly used the strongest intensity that the subjects could endure.[17] In the present study, we assumed that the very strong intensity was close to the stimulation levels used in previous studies. The fact that a physiological muscle response, reflected by the increase in serum lactate level, occurs even at the strong and moderate stimulation levels may indicate that not only very strong stimulation but also stimulation with submaximal intensity can induce muscle strengthening. However, further longitudinal studies are required to reveal the appropriate stimulation intensity for muscle strengthening with B-SES.

The amount of current required to achieve a given subjec-

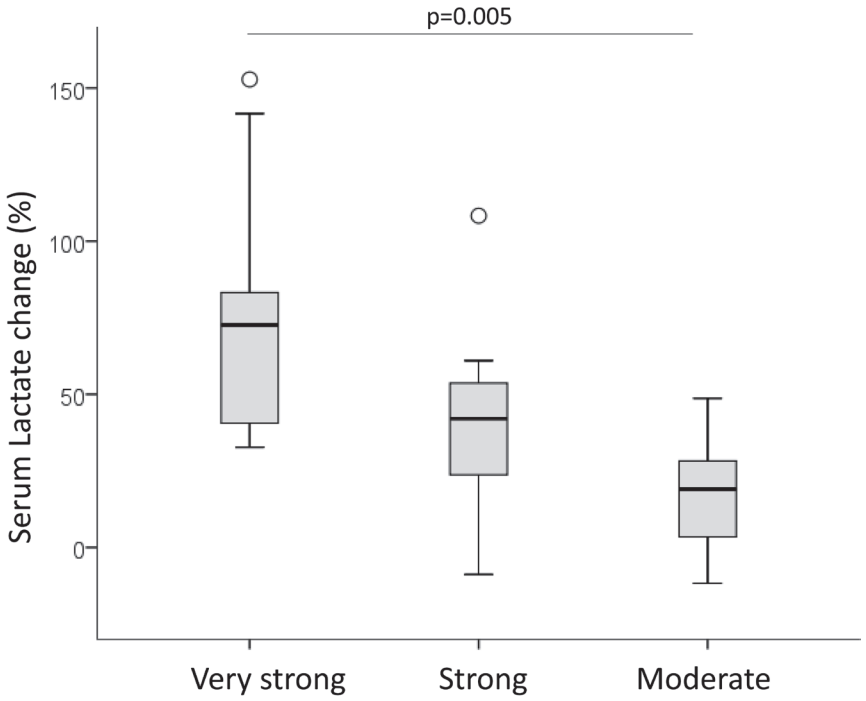

Fig. 3. Comparison of increases in serum lactate levels. Those who received stronger stimulation based on the subjective method showed larger changes in the serum lactate level before and after the NMES session.

tive contraction intensity differed among subjects because it is affected by the individual muscle volume and subcutaneous fat volume. In general, the thicker the fat tissue, the higher is the required level of current to induce the target level of electric current in the muscle. The responsiveness to electrical stimulation is also affected by the muscle volume; consequently, estimating the most appropriate current for the targeted contraction intensity may require consideration of both muscle and fat tissue. Magnetic resonance imaging is able to evaluate both parameters; however, its use is not feasible for daily clinical practice. In the current study, we utilized the time required to complete the 5STS test, because the time reflects muscle power relative to body weight, which is related to the fat mass in the lower limbs. Because the stimulation was applied to subjects 6 weeks after admission or surgery, the data in the present study represents measurements taken from subjects under stable conditions. We found a tendency for a slight increase in current intensity as the 5STS time increased, indicating that either weak muscles or thick fat layers require higher currents to obtain the targeted contraction. However, a larger number of subjects will be needed to confirm the relation between lower limb composition and current strength.

Notably, in this study, the subjects in both the strong and very strong groups received an average stimulation of 7.0 mA or higher. Despite the attention required because of the individual specificity mentioned above, the use of the B-SES device at 7.0 mA or higher would be a simple way to secure appropriate stimulation for treating elderly patients. In clinical practice, the level of electrical stimulation tends to be low because patients' fear often leads to insufficient muscle contraction and strengthening failure. Therefore, the use of a certain criterion for the stimulation, with absolute values in device settings, may help physicians utilize the device appropriately.

This study has several limitations. For blood sampling, we took serum venous blood samples, which resulted in some delay between the end of stimulation and sampling. Because serum lactate levels may decrease during the post-stimulation period, we might have underestimated the serum lactate levels. To obtain peak lactate levels, we need to undertake sequential blood sampling. In the present analysis, we did not consider sex differences. Men and women have different characteristics in terms of the balance between muscle mass and fat mass in the extremities. In addition, the disease backgrounds varied, but all subjects were analyzed

in the same manner. In this study, we attempted to find a general relation between the subjective stimulation intensity and the objective stimulation intensity that was not directly affected by disease, sex, or age. However, it is possible that the physiological responses may differ between those with lower leg disorders and those with spinal disorders. To obtain deeper insights, future prospective studies are required in which the electrical stimulation current is determined based on patients' physical parameters and backgrounds. For that purpose, we need further studies of patient cohorts with homogeneous diseases, sex, and age.

In conclusion, we utilized B-SES, a recently developed NMES device, in a cohort of elderly patients with musculoskeletal diseases. The disadvantage of B-SES lies in the fact that the stimulation intensity cannot be determined based on joint torque; however, this problem can be overcome by using standardized verbal instructions to achieve a target subjective stimulation intensity, as carried out in the current study. The subjectively graded contraction levels corresponding to moderate, strong, and very strong discomfort elicited three different physiological responses in muscles, as evaluated using serum lactate levels. This standardized method for determining the stimulation intensity will facilitate the use NMES based on B-SES for clinical interventions.

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CONFLICTS OF INTEREST

There are no conflicts of interest to declare.

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