Japanese Journal of Comprehensive Rehabilitation Science (2024)

Original Article

Effects of repetitive peripheral magnetic stimulation on knee joint extensor strength in older persons receiving day services

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ABSTRACT

Kamiue M, Tsubahara A, Ito T, Koike Y. Effects of repetitive peripheral magnetic stimulation on knee joint extensor strength in older persons receiving day services. Jpn J Compr Rehabil Sci 2024; 15: 49–57.

Objective: To verify the effects of repetitive peripheral magnetic stimulation (rPMS) on knee joint extensor strength and motor ability in older adults receiving day services.

Methods: Thirty Hz rPMS using Talent Pro® was applied to the bilateral vastus lateralis, vastus medialis, and rectus femoris of 12 older persons (mean age 83.8 ± 4.5 years) attending a day service center and receiving functional training by a physical therapist. The intervention was performed for 20 minutes per day, three times per week, for a total of 4 weeks. Evaluations before and after the intervention included maximum voluntary contraction (MVC), knee extensor torque induced by rPMS (rPMS-induced torque), pain (visual analog scale: VAS), thigh circumference, comfortable 5-m walking time, 30-second chair-stand test (CS-30), Timed-Up-and-Go Test (TUG), and Functional Reach Test (FRT). MVC and rPMS-induced torque were measured using the μ-Tas F-1®.

Results: MVC significantly increased in both lower limbs after the intervention (right/left: 72.4 ± 23.5 Nm/72.9 ± 23.0 Nm) compared with immediately before the intervention (right/left: 59.9 ± 17.2 Nm/64.5 ± 21.0 Nm). No significant changes were observed in MVC between one month before the intervention and immediately before the start of the intervention, and between the end of the intervention and one month after the end of the intervention. rPMS-induced torque, TUG, and CS-30 improved significantly after the intervention compared with immediately before the intervention.

Conclusion: Intervention using rPMS increases MVC- and rPMS-induced torque and improves motor ability in older adults. Because rPMS is a simple means of increasing muscle strength, it is expected to be widely used in the future.

Key words: repetitive peripheral magnetic stimulation, knee extensor torque, older persons, muscle strengthening, motor ability

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Accepted: July 9, 2024.
COI: Our university signed a joint research agreement with OG Wellness Technologies Co., Ltd. We borrowed equipment and received research funds from OG Wellness Technologies Co., Ltd. The funders did not have any role in the study design, collection and analysis of data, preparation of the manuscript, or the decision to submit the manuscript for publication.

Introduction

The population aged 65 years and above continues to increase every year, and the average life expectancy according to the 2021 simplified life table is 87.57 years for women and 81.47 years for men [1]. Healthy life expectancy, the period during which daily life activities can be performed without restrictions, is gradually being extended, and physical abilities are expected to be maintained as much as possible. In particular, muscle weakness due to aging leads to a decline in physical function [2, 3], risk of falls, and

increased mortality [4, 5]; hence, maintaining or increasing muscle strength is necessary to achieve a high quality of life in the elderly. Recently, the number of older adults using day rehabilitation or services provided by the long-term care insurance system has increased. In addition to these outpatient facilities, resistance exercises to strengthen muscles are often planned to maintain the health and physical function of older persons in residential facilities [6, 7]. However, the effectiveness of resistance exercise depends on the motivation of the elderly, who need to be actively engaged to achieve good results. Additionally, it is not always easy for older people and patients with dementia to continue training independently for long periods. There are also issues associated with the long-term care insurance system. While medical rehabilitation is permitted for a relatively long time in acute and Kaifukuki (convalescent) hospitals, it is difficult to allocate long hours for training by specialized therapists in elderly facilities such as day service centers and group homes because the fees paid for individual training by functional training instructors are low. Therefore, easier methods are required to maintain or increase the muscle strength of patients.

Recently, repetitive peripheral magnetic stimulation (rPMS) has been used as an effective modality to maintain or increase muscle strength. rPMS is gaining attention as an alternative to neuromuscular electrical stimulation because it can contract deep muscles with less pain [8−11]. Before rPMS was introduced, electrical stimulation therapy was administered to increase muscle strength. However, Braid et al. reported no significant effects on muscle strength in elderly patients after femoral fracture due to pain and discomfort during electrical stimulation [12]. The advantage of rPMS is that it is not only less painful than electrical stimulation but also induces a stronger muscle contraction force [8, 13]. Other advantages include the fact that there is no need to attach electrodes to the skin, stimulation can be applied even over clothing, and different muscles can be stimulated individually [11, 13, 14]. Previous studies using rPMS for muscle contraction reported that muscle strength can be increased not only in healthy subjects but also in patients with chronic obstructive pulmonary disease, hip replacement surgery, or stroke [15−19]. Nevertheless, no significant changes were observed in muscle thickness or muscle cross-sectional area even after administering rPMS to healthy subjects for 4 weeks [19]. In a single case study of cerebral infarction, muscle strength in the lower limbs was maintained but did not clearly increase after rPMS intervention [20].

The reasons for the inconsistent results of intervention studies include differences in the devices used, stimulation methods, and subject characteristics such as the thickness of subcutaneous fat at the stimulation site [13, 14, 21]. Recently, it has been reported that strong contractions can be induced by searching for stimulation points [13, 14] and that a wide range can be stimulated by magnetic stimulation using a circular coil [14]. It is also known that when the subcutaneous fat is thin, the distance between the coil and the muscle becomes shorter, which increases muscle contractile force [21].

Strong contractions are required to increase muscle strength. Because rPMS causes less pain, it can be effective if stimulated with strong intensity and high frequency. However, with magnetic stimulators, the devices themselves generate high heat when a high output intensity continues. In recent years, advances in cooling methods have led to the development of devices dedicated to rPMS that can be used for longer periods than the magnetic stimulators used in previous studies. Although the number of studies investigating the effectiveness of rPMS in increasing muscle strength in hospitalized patients is gradually increasing, to the best of our knowledge, there have been no studies on frail older adults living at home. The purpose of this study was to examine whether it is possible to increase lower limb muscle strength and improve the motor ability of older persons using a magnetic stimulator dedicated to rPMS.

Methods

1. Subjects

The study involved individuals over 65 years old who were classified as “in need of long-term care” and who attended “Day Service Kagayaki” at least three times a week. The prerequisite was receiving functional training from a physical therapist for 20 minutes a day, three times a week. Functional training consisted of range-of-motion exercises in the supine position and muscle-strengthening exercises performed in anti-gravity positions or manually. The exclusion criteria were (1) stroke patients, (2) patients with neuromuscular diseases, (3) patients with implanted medical devices that are affected by magnetic stimulation, such as a cardiac pacemaker or ventriculoperitoneal shunt, (4) patients with severe dementia who were unable to understand the purpose of the research, and (5) severely obese patients with a body mass index (BMI) > 35 kg/m^2. This study was conducted in accordance with the principles of the Declaration of Helsinki.

As of July 2022, 288 people were using the facility, but only 38 met the eligibility criteria. Of these, 24 were excluded from the study. The most common reasons for exclusion were stroke, neuromuscular disease, cardiac pacemaker implantation, and severe dementia. The purpose, methods, and safety of the intervention study were explained in detail to the prospective subjects verbally and in writing. Participation in the study was voluntary, and informed consent was obtained from all participants after confirming that they understood the content of the study. Two prospective subjects for whom explanations were given did not provide consent to

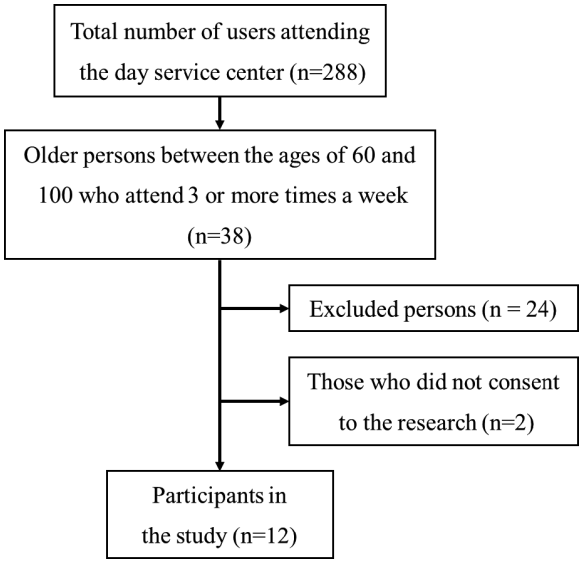

Figure 1. Procedure for selecting eligible participants.

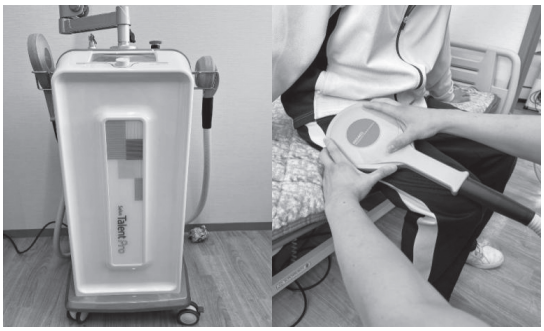

Figure 2. Magnetic stimulator (left) and placement (right).

participate in the study. The remaining 12 persons (mean age 83.8 ± 4.5 years, 5 men, 7 women) who agreed to participate became the subjects (Figure 1). This study was approved by the Ethics Committee of Kawasaki University of Medical Welfare (approval number: 21-088).

2. Intervention Methods Using rPMS

The stimulator used for rPMS was Talent Pro® (ReMed Co., Ltd., Republic of Korea), and stimulation was performed using a large circular coil (radius: 7.8 cm) (Figure 2). The participants' bilateral quadriceps femoris was stimulated isometrically with the knee flexed at 90° while in a sitting position with the soles of their feet on the floor and immobilized. The vastus lateralis (VL), vastus medialis (VM), and rectus femoris (RF) were stimulated as the intervention, after identifying the optimal stimulation site of each muscle to induce strong muscle contraction. The method for determining the optimal stimulation site was the same as that used for measuring the muscle torque induced by magnetic stimulation, which will be described later. During rPMS, the participants were instructed to relax their entire body as much as possible to avoid voluntary contractions of the quadriceps femoris. The total stimulation time for one session was approximately 20 min; therefore, each bilateral muscle was stimulated for the same amount of time (3 minutes and 20 seconds). The stimulation frequency was set at 30 Hz. Stimulation was administered for 3 seconds, followed by 6 seconds of rest, and this process was repeated. The stimulation intensity was set at 60% of the maximum output of the device (1.47 Tesla just below the probe surface). The intervention using rPMS was carried out for 4 weeks, three times a week, for a total of 12 sessions. Regular functional training, which was conducted for 20 minutes per day, three times per week, was not performed during the rPMS intervention period.

3. Measurement of maximum voluntary contraction force of knee joint extensors

Measurements of the maximum voluntary contraction (MVC) force of the bilateral knee joint extensors were performed 1 month before the rPMS intervention, immediately before the start of the intervention, at the first visit after the end of the 1-month intervention, and at the visit 1 month after the end of the intervention. Knee extensor torque was measured isometrically using the μ-Tas F-1® (Anima Co., Ltd., Tokyo, Japan). The participants sat on the edge of a chair, and a folded towel was placed on the popliteal fossa to prevent pain due to pressure on the popliteal fossa. The sensor pad was attached to the distal end of the lower leg, and a fixation belt was used to connect the sensor pad to the foot of the bed. The belt length was adjusted to maintain the knee joint angle at 90° when the knee extensors contracted. The participants were instructed to cross their arms in front of their trunk and keep their trunk as vertical as possible during the measurements.

Muscle strength was measured while the participants were instructed to perform maximum contraction for 3 seconds. Measurements were taken twice, with a 5-second interval. The torque value (Nm) was calculated by multiplying the measured value (N) by the distance from the knee joint space to the center of the sensor pad, and the mean value was used for the analysis.

4. Measurement of muscle torque induced by magnetic stimulation

The knee extensor torque induced by rPMS (rPMS-induced torque) was measured immediately before the start of the intervention and at the first visit after the end of the 1-month intervention. rPMS-induced torque was also measured using the μ-Tas F-1®. The bilateral VLs were selected as the muscles from which to measure rPMS-induced torque based on previous studies [14–17, 21]. The posture and position of the limbs during the measurement were the same as those for the measurement of MVC, and the knee joint angle was maintained at 90°.

First, the stimulation site that induced the strongest contraction of the VL was identified using rPMS. The area searched was the proximal and distal one-third of the line connecting the anterior superior iliac spine and the lateral superior margin of the patella [14]. The optimal stimulation site that could induce maximal contraction was determined through approximately five explorations using 60% of the maximum output of the device.

During the measurement of the rPMS-induced torque, the center of the probe containing the coil was carefully and exactly aligned with the optimal stimulation site, and the long axis of the probe was held parallel to the long axis of the thigh. The stimulation frequency was 30 Hz and the stimulation time was 3 seconds [22]. The stimulation intensity corresponded to the maximum output of the device (1.47 Tesla). The participants were instructed to relax their entire body as much as possible to avoid voluntary contraction of the quadriceps femoris. Muscle torque measurements were performed twice with a 5-second interval, and the mean value was used for the analysis.

5. Pain assessment during magnetic stimulation

The participants self-rated their pain level during rPMS using a visual analog scale (VAS) immediately before the start of the intervention and on the last day of the intervention. The degree of pain felt was evaluated when stimulated with an intensity of 60% of the maximum output of the stimulator (1.47 Tesla). The participants were instructed to mark an "x" on a 100-mm-long straight line drawn on a piece of paper. The left end (0 mm) of the line was set as "no pain" and the right end (100 mm) as "pain too intense to be tolerated." The VAS score was recorded to the first decimal place.

6. Other evaluations

The following five evaluations were performed immediately before the start of the intervention and at the first visit after the end of the intervention.

1) Timed-Up-and-Go Test (TUG): The participants stood up from a chair, walked around a cone 3 meters away, and sat down in the chair as quickly as possible, and the time required was measured. The starting point of the measurement was the moment at which the back separated from the backrest. Measurements were performed twice, and the average value was used for the analysis. Values were recorded to the first decimal place. A chair with armrests was used for the test.

2) 30-second chair-stand test (CS-30): The participants sat on a 40-cm-high chair with their feet shoulder-width apart. The starting position was with the arms crossed in front of the trunk. The participants were asked to repeat the motion of standing up and sitting down as quickly as possible, and the number of repetitions they could perform in 30 seconds was measured. If the time reached 30 seconds during the operation, it was recorded as a measured value. The measurements were performed only once.

3) Comfortable 5-m walking time: The participants were asked to walk 11 meters on level ground without using a cane or walker, and the time required for the 5-meter section excluding the first and last sections was measured. Measurements were performed twice, and the average value was used for the analysis. Values were recorded to the first decimal place.

4) Functional Reach Test (FRT): The participants were asked to stand with their legs together, shoulders flexed at 90°, and elbows, wrists, and fingers extended. In this case, the tip of the third finger was set as the starting point. Following the cue, they performed a maximum forward reach along the wall. When the most anterior point was reached, a piece of tape was placed on the wall near the tip of the third finger as a record. The distance between the starting point and most anterior point was measured twice, and the average value was used for the analysis. Values were recorded to the first decimal place.

5) Measurement of thigh circumference: The circumference was measured using a tape measure at four locations: just above the patella and at 5, 10, and 15 cm above the patella. Measurements were performed twice in 0.5-cm increments. As a representative value, an average circumference 15 cm above the patella was used for the analysis.

7. Statistical analysis

To examine the effect of rPMS on muscle strength, the mean MVC values one month before the rPMS intervention, immediately before the start of the intervention, at the first visit after the end of the intervention, and at the visit one month after the end of the intervention were compared. The Friedman test was used for multiple comparisons, and Bonferroni correction was performed as a post-hoc test. Regarding rPMS-induced torque, pain assessment using VAS, TUG, CS-30, comfortable 5-m walking time, FRT, and thigh circumference 15 cm above the patella, the average values immediately before the start of the intervention and after the end of the intervention were compared. Wilcoxon's signed rank test was used for analysis. Statistical analyses were performed using SPSS ver. 22.0 (IBM Co. Ltd., Armonk, New York, United States), and the significance level was set at $p < 0.05$.

Results

None of the participants withdrew from the study after it began. All participants were requested to continue rPMS after the 1-month intervention but agreed to only perform functional training for 1 month after the end of the intervention. The data for MVC, rPMS-induced torque, TUG, and comfortable 5-m walking time were normally distributed. However, the

data for VAS, CS-30, FRT, and thigh circumference 15 cm above the patella were not normally distributed.

1. Changes in maximum voluntary contraction force

MVC significantly increased in both lower limbs after the intervention (right/left: 72.4 ± 23.5 Nm / 72.9 ± 23.0 Nm) compared with immediately before the intervention (right/left: 59.9 ± 17.2 Nm / 64.5 ± 21.0 Nm). No significant changes were observed in MVC between 1 month before the intervention (right/left: 59.4 ± 17.2 Nm / 61.0 ± 24.1 Nm) and immediately before the start of the intervention, and between the end of the intervention and 1 month after the end of the intervention (right/left: 68.7 ± 21.9 Nm / 72.6 ± 22.7 Nm). Only regular functional training was performed during this period (Figure 3).

2. Changes in knee extensor torque induced by magnetic stimulation and pain assessment

The rPMS-induced torque after the end of the intervention (right/left: 12.3 ± 4.9 Nm / 12.3 ± 4.7 Nm) was significantly higher than that immediately before the start of the intervention (right/left: 10.0 ± 4.7 Nm / 10.6 ± 4.6 Nm) ($p < 0.05$) (Figure 4). The mean VAS value was 8.0 ± 13.9 mm immediately before the intervention, but it became 0 mm in all participants after the intervention ($p = 0.07$) (Figure 5).

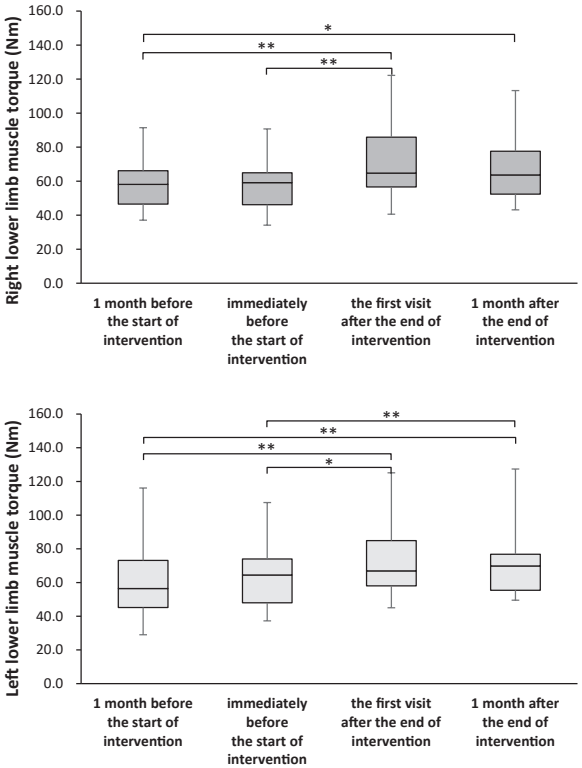

Figure 3. Change in maximum voluntary contraction force.
Friedman test, *$p < 0.05$, **$p < 0.01$.

3. Comparisons before and after intervention: TUG, CS-30, comfortable 5-m walking time, FRT, and thigh circumference

TUG was significantly shorter after the intervention (12.1 ± 5.1 s) compared with immediately before the intervention (16.0 ± 5.5 s) ($p < 0.01$). CS-30 also significantly increased after the intervention (12.8 ± 4.4 times) compared with immediately before the intervention started (9.5 ± 4.5 times) ($p < 0.01$). However, no significant changes were observed in the comfortable 5-m walking time, FRT, or thigh circumference 15 cm above the patella (Figure 6).

Discussion

This study revealed that administering rPMS to the quadriceps femoris in older persons increased knee extensor strength and improved motor ability, supporting previous research [16−19]. Yang et al. [19] reported that the longer the stimulation time and the higher the stimulation frequency, the more effectively muscle strength is increased. In this study, the intervention was carried out three times per week for 4

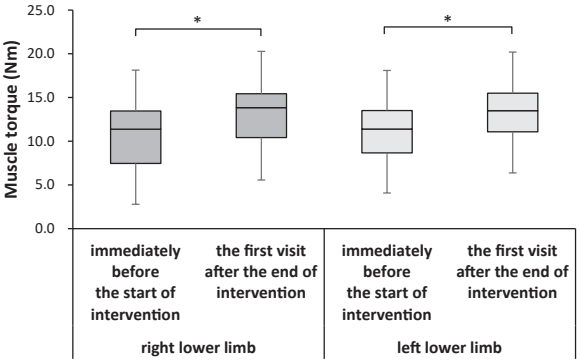

Figure 4. Comparison of knee extensor torque induced by magnetic stimulation before and after the intervention.
Wilcoxon signed-rank test, *$p < 0.05$.

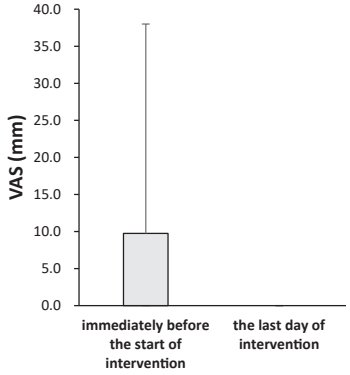

Figure 5. Comparison of pain during magnetic stimulation before and after the intervention.
Wilcoxon signed-rank test, $p = 0.07$.
VAS: visual analog scale.

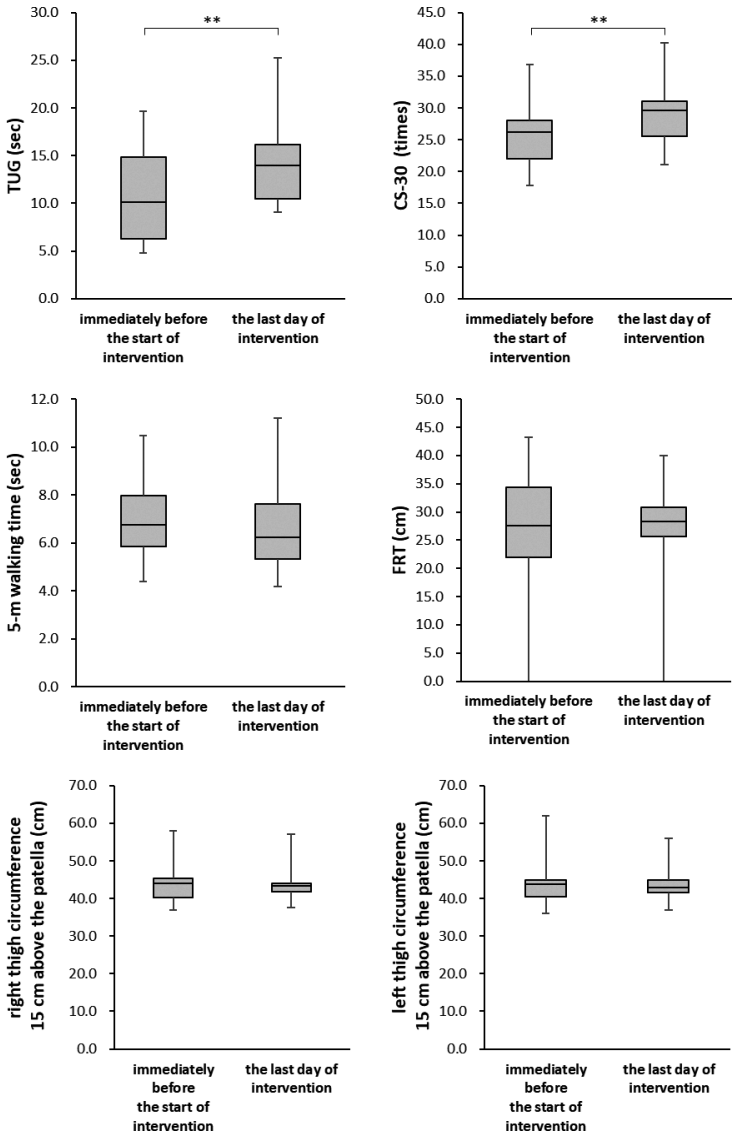

Figure 6. Comparisons of motor ability performance and thigh circumference before and after the intervention.
Wilcoxon signed-rank test, $^{**}p < 0.01$.
TUG: Timed-Up-and-Go Test.
CS-30: The 30-second chair-stand test.
FRT: Functional reach test.

weeks. The properties of the stimulator, named Talent Pro®, allowed stimulation to continue for 20 minutes at 30 Hz, higher than previous studies using frequencies of 10−20 Hz, without the device generating heat. Therefore, it is supposed that stimulation at a high frequency for the same amount of time as in previous studies contributed to an increase in muscle strength. In a report by Bustamante et al., which showed that rPMS intervention increased MVC, 108,000 stimulations were administered per leg over an 8-week period in patients with chronic obstructive pulmonary disease. However, the frequency was 15 Hz, and the intensity was 40% of the stimulator's maximum output (2 Tesla) [16]. Furthermore, previous studies showing increases in muscle action potentials and muscle cross-sectional areas reported that 22,500−108,000 stimuli were given during a 2−8 week intervention period [15, 17−19]. In the present study, approximately 144,000 stimulations (30 Hz × 400 seconds × 3 times × 4 weeks) were performed on each lower limb for 4 weeks. This means that the same number of stimulations could be performed in four weeks, which is half the period of previous studies that showed an increase in MVC. In other words, it is suggested that the muscle-strengthening effects were efficiently obtained.

In addition, to increase muscle strength, it is important that the induced muscle contraction force is strong. It has been reported that general resistance exercises aimed at increasing muscle strength require

an intensity of 40%−85% of MVC when performed 1−3 times a week for 6−52 weeks [23]. In previous studies on young healthy adults, we reported that 60% of the intensity of the magnetic stimulator used in the present study could induce contractile forces greater than 40% of the MVC [21, 24]. It is often difficult for older people to voluntarily perform resistance exercises of sufficient intensity to obtain sufficient muscle-strengthening effects. Using rPMS, it is possible to obtain strong muscle contraction force in individuals with low subcutaneous fat content [21, 25]. It has been reported that by using rPMS, a strong muscle contraction force can be obtained when the subcutaneous fat of the subjects is not thick [21, 25]. As the participants in this study were elderly, the average muscle contraction force induced by rPMS was approximately 17% of the MVC. The induction of muscle contraction above a certain level was one of the factors that led to an increase in muscle strength. The muscle-strengthening effects of rPMS have been reported to result from a combination of nervous system adaptations, muscle histochemical changes, and muscle fiber hypertrophy [19]. It has been speculated that rPMS promotes the reorganization of the central nervous system through the activation of afferent sensory pathways around stimulated muscles and increases the excitability of the primary motor cortex [26−28]. Furthermore, when muscles contract due to the excitation of intramuscular motor neuron axons caused by rPMS, it has been reported that they repeatedly contract and relax in a vibration-like manner, indirectly activating type Ia, type Ib, and type II afferent nerve fibers [29]. Gondin et al. stated that nervous system adaptations associated with muscle strengthening occur within 4 weeks, whereas changes in muscle mass require 4−8 weeks [30]. Therefore, the changes in muscle mass may have been small in the present study because the intervention period was 4 weeks and the thigh circumference remained unchanged. It has been suggested that increases in indicators directly related to muscle strength, such as MVC and CS-30, are due to neural adaptations.

In contrast, rPMS-induced torque was also increased by the intervention in this study. As the thigh circumference did not change, this condition can be interpreted as a gradual increase in peripheral nerve excitability, even though the initial magnetic stimulation did not induce a strong muscle torque. Immobility reduces the excitability of peripheral nerve axons [31] and suppresses the excitability of anterior horn cells [32]. In addition, it has been reported that nerve fiber refractoriness was more pronounced [33] and functional impairment of neuromuscular junction response occurs [34] in the elderly. The short-term increase in excitability with magnetic stimulation suggests that functional rather than morphological changes have occurred. Although it is speculated that the refractory period of peripheral nerves has been shortened, making it easier for fusion of twitch contractions to occur, excitatory inhibition of anterior horn cells has been suppressed, and various changes have occurred in the neuromuscular junction, further detailed research is needed to elucidate the mechanism. The results of this study showed that the TUG was significantly shortened after 4 weeks of rPMS intervention. Among the motor ability evaluations, the TUG test is generally considered an indicator of dynamic balance function [35]. Sufficient muscle strength in both lower limbs is believed to be important for older adults to maintain standing balance. Judging from a report that the application of rPMS to the quadriceps muscles improved tandem standing time [17], it is considered that the increase in bilateral lower limb muscle strength observed in this study led to the improvement in balance function assessed by TUG. From the above considerations, it is clear that rPMS can increase lower limb muscle strength and improve motor ability in older persons.

This study had some limitations. First, it included a small number of subjects, short study period, and the use of ABA design for multiple individuals. Therefore, although an increase in muscle strength was observed, the study did not reach the point where the thigh circumference changed; therefore, the study lacked convincing power. Additionally, although no participants were excluded from this study due to severe obesity, another limitation was that rPMS may not have caused sufficient muscle contraction in cases of severe obesity. In the future, it will be necessary to increase the number of subjects, extend the intervention period, and conduct randomized controlled trials. In this study, no comparison was made with functional training, such as that carried out in Kaifukuki rehabilitation wards, or with general training given to healthy individuals. Furthermore, satisfaction and quality of life were not objectively assessed. These aspects are important to confirm the usefulness of rPMS.

Conclusions

In this study, rPMS was applied to the quadriceps femoris of older persons for four weeks, and its effects on MVC, rPMS-induced torque, and motor ability, such as TUG and CS-30, were evaluated. All participants were able to perform rPMS with less pain and showed improved lower-limb muscle strength and motor ability. Because rPMS is a simple means of increasing muscle strength with almost no pain, it is expected to be widely used in the future.

Acknowledgments

We thank the staff at Day Service Kagayaki for their cooperation in the functional evaluation of this study.

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