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Brief Report

Measurement of maximal muscle contraction force induced by high-frequency magnetic stimulation: a preliminary study on the identification of the optimal stimulation site

Akio Tsubahara, MD, DMSc,[1] Masanori Kamiue, PT, MS,[2] Tomotaka Ito, PT, PhD,[1] Tomoya Kishimoto, PT, PhD,[1] Chiharu Kurozumi, OT, PhD[3]

[1]Department of Physical Therapy, Faculty of Rehabilitation, Kawasaki University of Medical Welfare, Kurashiki, Okayama, Japan
[2]Doctoral Program in Rehabilitation, Graduate School of Health Science and Technology, Kawasaki University of Medical Welfare (Student), Kurashiki, Okayama, Japan
[3]Department of Occupational Therapy, Faculty of Rehabilitation, Kawasaki University of Medical Welfare, Kurashiki, Okayama, Japan

ABSTRACT
Tsubahara A, Kamiue M, Ito T, Kishimoto T, Kurozumi C. Measurement of maximal muscle contraction force induced by high-frequency magnetic stimulation: a preliminary study on the identification of the optimal stimulation site. Jpn J Compr Rehabil Sci 2021; 12: 27−31.
Purpose: To identify the optimal stimulation site and technique for inducing strong muscle contraction using a high-frequency magnetic stimulator.
Methods: High-frequency magnetic stimulation was administered to the right vastus lateralis (VL) of eight healthy adults at maximal intensity within the range of tolerable pain. The stimulation sites were as follows: section A, the area between the lateral edge of the base of the patella (LEBP) and the distal one-third of the thigh (point D); section B, the area between point D and the proximal one-third of the thigh (point P). Isometric maximal muscle contraction forces induced by magnetic stimulation (Stim-MCF) were compared between the two sections.
Results: The Stim-MCF was significantly higher in section B than in section A. Additionally, the sites susceptible to stimulation were confined to a narrow area near point D in section A and the central part between points D and P in section B. The degree of pain was very low in both sections.
Conclusion: The optimal site for magnetic stimulation of the VL was limited to the central part of the thigh. In addition to the superficial proximal sub-branch, the deep proximal sub-branch and/or deeply clustered motor nerve endings may have been stimulated. Our results suggested that moving the probe was a useful way to identify the site that elicited the strongest muscle contraction force.
Key words: high-frequency magnetic stimulation, muscle contraction force, strengthening, quadriceps femoris, motor points

Correspondence: Akio Tsubahara, MD, DMSc
Department of Physical Therapy, Faculty of Rehabilitation, Kawasaki University of Medical Welfare, 288 Matsushima, Kurashiki, Okayama 701−0193, Japan.
E-mail: atsuba@mw.kawasaki-m.ac.jp
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Introduction

To maintain the motor skills of the elderly and prevent their dependence on others, aerobic exercise and resistance training are performed in exercise classes by community residents and in day care service centers [1−4]. However, easier ways to continuously increase or maintain muscle power are needed for individuals with problems such as dementia and decreased motivation.

In addition to strengthening exercises, electrical stimulation therapy is another method of inducing sufficient muscle contraction [5−8]. However, it has been reported to involve serious problems, such as pain and discomfort [9]. Recently, high-frequency repetitive peripheral magnetic stimulation (r-PMS) of the skeletal muscles has been reported as an alternative to electrical stimulation [10,11]. Nevertheless, magnetic stimulators with an output intensity of 1 Tesla have not been widely used to strengthen muscles of the lower extremities.

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Therefore, we have developed high-frequency magnetic stimulators through cooperative research between university and industry.

Since it has been reported that electrical stimulation can stimulate only the surface layer of muscles, either an active electrode is attached directly above the motor points or all the motor points are sandwiched between the proximal and distal electrodes [5−8]. Although a probe is placed on the muscle belly for magnetic stimulation, the optimal stimulation site and technique have not yet been identified. Therefore, the purpose of this preliminary study was to confirm whether a strong muscle contraction can be obtained when the probe is placed on the distal or central part of the vastus lateralis (VL), which is the largest muscle in the quadriceps femoris (QF) and has been examined in many previous studies [12,13]. The muscle contraction forces in both sections were compared when maximal magnetic stimulation was applied. Additionally, the distribution of sites susceptible to stimulation in each section was examined. We hope this study will contribute to the widespread use of magnetic stimulation for strengthening muscles in the elderly.

Methods

1. Subjects

Eight healthy adults (4 men, 4 women; mean age, 20.6 ± 0.5 years) without central nervous system, neuromuscular, or bone and joint diseases voluntarily participated in this study. After a detailed explanation of the study, written informed consent was obtained from all participants. This study was approved by the Institutional Research Ethics Committee (No. 19−072).

2. Methods of high-frequency magnetic stimulation

The participants were instructed to sit on a chair with the right knee and hip joints flexed at 75°. Points at the distal one-third (point D) and proximal one-third length (point P) on the straight line connecting the lateral edge of the base of the patella (LEBP) and the anterior superior iliac spine (ASIS) were marked before magnetic stimulation (Figure 1). A prototype of a high-frequency magnetic stimulator with a maximal output intensity of 1.3 Tesla (OG Wellness Technologies Co., Ltd.) was used to stimulate the right VL (Figure 2). The stimulation frequency was set at 30 Hz, and the intensity was gradually increased from minimal to maximal stimulation within the range of tolerable pain. Considering the reported position of the motor points [14], magnetic stimulation was performed in two sections: between the LEBP and point D (section A), and between points D and P (section B). We searched for a site where the strongest muscle contraction force was induced by moving the probe through sections A and B. During the search, the probe was allowed to move laterally by approximately 2 cm. Magnetic stimulation was performed isometrically

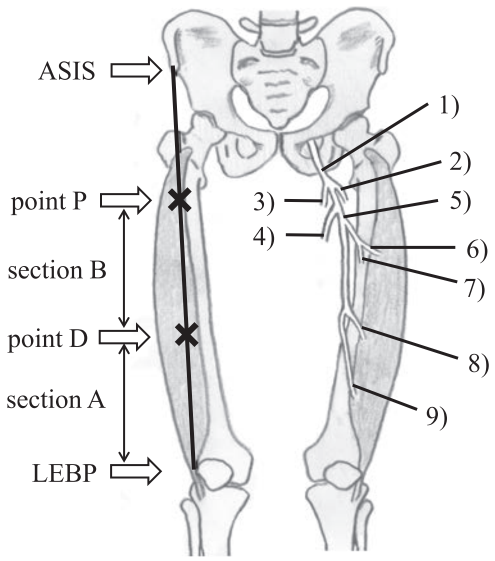

Figure 1. Places of magnetic stimulation and nerve distributions corresponding to each section.
ASIS: anterior superior iliac spine, LEBP: lateral edge of the base of the patella, point D: a point at the distal one-third length on the straight line connecting the LEBP and the ASIS, point P: a point of the proximal one-third length on the straight line connecting the LEBP and the ASIS, Section A: between the LEBP and point P, Section B: between points D and P, 1) femoral nerve trunk, 2) branch of the rectus femoris (RF), 3) branch of the vastus medialis (VM), 4) branch of the vastus intermedius (VI), 5) branch of the vastus lateralis (VL), 6) superficial proximal sub-branch of the VL, 7) deep proximal sub-branch of the VL, 8) mid-distal sub-branch of the VL, 9) distal sub-branch of the VL.

Figure 2. Probe of magnetic stimulator and scene of magnetic stimulation.
The size of the prototype probe is 19.5 × 21.5 cm, the surface area of the coil inside the probe is 18.2 cm^2, and the maximal output intensity is 1.3 Tesla.

for 3 s at the point where maximal contraction was obtained. After a 2-s rest, the next stimulation was administered. Stimulation was performed five times for both sections A and B. The order in which each section was stimulated was randomized.

3. Measurement of muscle contraction force

Prior to magnetic stimulation, participants were instructed to perform two isometric maximal voluntary contractions (MVCs) of the right knee extensor while sitting on the chair. Each contraction force was measured for 3 s with a rest of 5 s in between. The larger value was regarded as the representative MVC value at the time of the analysis.

Subsequently, the isometric extensor muscle contraction force induced by magnetic stimulation at maximal intensity (Stim-MCF) was measured. The measurement was performed five times in each section, and three Stim-MCFs, excluding the largest and the smallest values, were used as a part of the analytical data. Furthermore, the relative MCF was calculated by dividing the Stim-MCF by the MVC value.

A multi-mode computerized robotic dynamometer BIODEX SYSTEM 3® (Biodex Medical Systems, Inc.) was used to measure the muscle torque.

4. Assessment of pain intensity

After measuring the Stim-MCF, pain intensity during stimulation was assessed for sections A and B. A 10-cm visual analogue scale (VAS) was used for assessment [15], and the VAS score was expressed as a percentage (0%: no pain, 100%: severe pain).

5. Data analysis

The Stim-MCF and VAS score of all subjects were compared between sections A and B using the Wilcoxon signed-rank test. Statistical analysis was performed using SPSS ver. 22.0 software (IBM Corp., Armonk, NY, USA), and p values less than 0.05 were considered statistically significant. Additionally, the sites susceptible to stimulation, where the Stim-MCF was obtained, were indicated on the straight line connecting the LEBP and the ASIS, and the position was displayed as a percentage of the entire line (0%: LEBP, 100%: ASIS). When the site susceptible to stimulation was not on the straight line, a vertical line was drawn from the site to the straight line, and the intersections were displayed as a ratio. The values of the results were expressed as "mean ± SD."

Results

All participants were able to receive magnetic stimulation at the maximal intensity (1.3 Tesla) of the stimulator used in this study without severe pain. The mean VAS score during stimulation was very low, 20.4 ± 16.8% in section A and 20.4 ± 15.9% in section B, showing no significant difference between the two sections.

The mean MVC of all participants was 188.5 ± 61.1 Nm. The Stim-MCF was 11.2 ± 4.2 Nm in section A and 30.9 ± 17.0 Nm in section B; the value was significantly higher in section B than in section A (Figure 3). The mean value of relative MCF was 6.1 ± 1.8% in section A and 15.9 ± 5.0% in section B. Figure 4 shows the sites susceptible to stimulation in section A and section B. The sites were confined to a narrow area near point D in section A and the central part

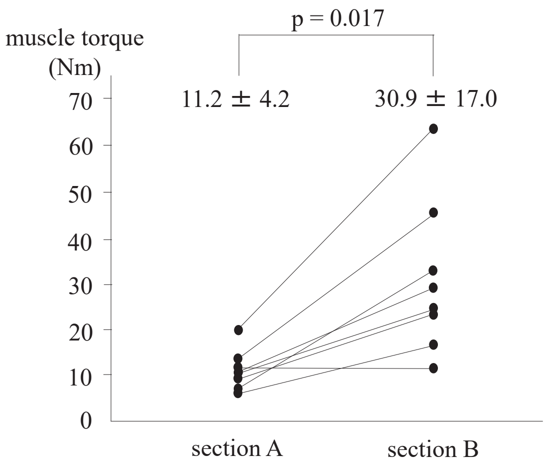

Figure 3. Comparison of maximal muscle contraction force (muscle torque) induced by magnetic stimulation. The values represent "mean ± standard deviation."

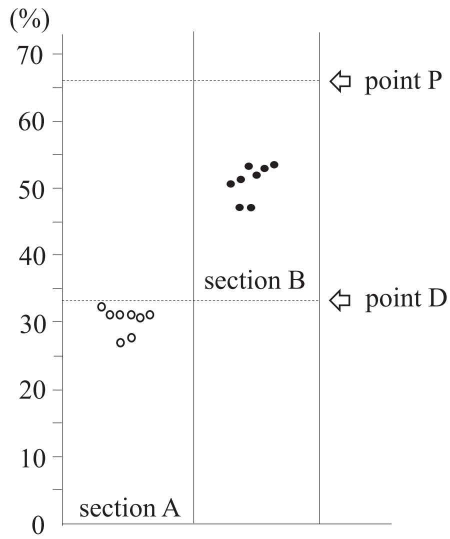

Figure 4. Sites susceptible to stimulation in sections A and B.
The vertical axis shows the position on the straight line connecting the lateral edge of the base of the patella (LEBP) and the anterior superior iliac spine (ASIS) as a percentage (0%: LEBP, 100%: ASIS). Point D denotes the location of the distal one-third of the thigh, and point P denotes the location of the proximal one-third of the thigh.

between points D and P in section B.

Discussion

A motor point has been reported to be the location where motor nerve endings are clustered at a high density and is known to be electrically excitable in spastic muscles [16]. However, recent studies on electrical stimulation in healthy individuals have reported that a motor point represents the location where the motor branch of a nerve enters the muscle belly and is a superficial point that can be searched by electrical stimulation [14, 17]. In other words, the definition of a motor point has changed slightly. Although the motor points of the VL were known to be located in three partitions of the branch of the VL arising from the femoral nerve trunk (the superficial proximal sub-branch, the mid-distal sub-branch, and the distal sub-branch), it has been pointed out that they have poor uniformity in position and are widely distributed [14]. Section A of the present study corresponds to the partitions of the central-distal and distal sub-branches, and section B corresponds to the partitions of the superficial proximal sub-branch (Figure 1). We found that the Stim-MCF was significantly higher when the probe was placed in section B than in section A. Since the optimal stimulation site was limited to a narrow area, it cannot be explained by the idea that only the motor point on the surface layer (the partition of the superficial proximal sub-branch) was stimulated. In addition to the superficial proximal sub-branch, the deep proximal sub-branch and/or deeply clustered motor nerve endings may have been stimulated, because magnetic stimulation can reach deeper than electrical stimulation. In fact, it is known that the deep proximal sub-branch of the VL runs through the middle of section B [14,18].

Our study showed that magnetically stimulated muscle contraction was achieved without pain. Moreover, approximately 15% of the contractile force of the entire QF was induced by stimulating only the VL. Assuming that the strength of the VL is one-third the strength of the entire QF, this value may correspond to 45% of the MVC of the VL alone. Since it was reported that the intensity of resistance exercise used in the elderly was 40–85% of the MVC [4], the contractile force obtained in this study is sufficient to prevent muscle weakness caused by disuse. Although we used a 1.3 Tesla prototype in the present study, it may be possible to obtain effective contraction forces even with a 1 Tesla conventional stimulator. The important factor is to move the probe and search for the point at which the strongest muscle contraction force is obtained. Since muscle contractions induced by electrical stimulation cause severe pain in the skin, a method that uses magnetic stimulation is preferred. In the future, it will be desirable to develop a magnetic stimulator with a stronger maximum output intensity. Additionally, it is necessary to verify that magnetic stimulation is effective for strengthening the muscles.

Conclusions

The optimal site to induce muscle contraction in the VL using magnetic stimulation was found to be located in the central part of the thigh. Our results also indicated that moving the probe is a useful way to identify the site that elicits the strongest muscle contraction force. Since r-PMS is a less painful method, future research on its effectiveness in strengthening muscles is needed.

Acknowledgments

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