



Original Article

Effect of interferential current on deep abdominal muscle thickness

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Abstract. [Purpose] We aimed to investigate the effects of various modulated interferential currents on deep abdominal muscle thicknesses of healthy participants using ultrasound imaging. [Participants and Methods] We recruited twenty-two healthy male participants for this study. We compared the rate of change in muscle thickness of the abdominal muscles under different stimulation interferential current conditions. [Results] The change in interclass correlation coefficient of muscle thickness for each electrical stimulation by attached electrode altering was 0.738–0.998, indicating normal to good reliability. The rate of change for all muscle thicknesses under interferential current at 2.5 kHz and 20 Hz was significantly greater than that under the other conditions. [Conclusion] An interferential current at 2.5 kHz and 20 Hz is a feasible and reproducible way to train the abdominal muscles.

Key words: Deep abdominal muscles, Interferential current, Transverse abdominis

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INTRODUCTION

Previous studies have demonstrated that the specific training of the transverse abdominis (TrA) provided functional and therapeutic benefits, such as unloading of the spine, anticipatory postural control, intersegmental stabilization of the spine, and long-term pain relief^{1, 2)}. However, effective therapeutic exercises, known to strengthen the TrA, preferentially involve deep muscle activation with minimal co-activation of the superficial muscles, such as the external oblique (EO) muscle³⁾.

Draw-in is a typical TrA exercise. It is supposed to allow for selective contraction of the TrA and is considered important because it can prevent low back pain. Springer et al.⁴⁾ measured TrA thickness using ultrasonography in a healthy group of individuals. They reported that muscle thickness significantly increased during draw-in as compared to muscle thickness at rest. Urquhart et al.⁵⁾ and Larivière et al.⁶⁾ clearly demonstrated the effectiveness of the draw-in exercise.

However, in addition to the difficulty in palpating the TrA, application of draw-in exercise in clinical practice can be challenging because the execution of this exercise can be difficult to understand.

Neuromuscular electrical stimulation (NMES) is beneficial if an individual is incapable of intense voluntary exercise. Interference current (IFC) is capable of achieving uniform stimulation and high reproducibility, although it requires specialized equipment. NMES has been reported for many years to reeducate and strengthen skeletal muscles^{7–9)}. Cho et al.¹⁰⁾ indicated that NMES by low-frequency rectangular pulsed current (LFRP) can stimulate contractions in deep abdominal stabilizing muscles. Most importantly, when analyzing with imaging ultrasonography, it was noted that 50 Hz LFRP produced greater increases in muscle thickness than 20 or 80 Hz LFRP.

IFC is a method of generating interference waves of 1–100 Hz by interfering two types of mid-frequency currents (carrier frequencies) *in vivo*. Because it uses a mid-frequency band with low skin resistance, it is thought to be less stressful, as well

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as enhance deep muscle contraction and promote blood circulation^{11, 12}).

The purpose of this study was to investigate the effect of four different modulated IFCs on the thickness of deep abdominal muscles in healthy subjects using real-time ultrasound images.

PARTICIPANTS AND METHODS

Twenty-two healthy male participants were recruited for this study. Their age, height, weight, body mass index, and body fat percentage were 21.3 ± 3.5 years, 172.7 ± 5.6 cm, 62.8 ± 9.1 kg, 21.0 ± 2.7 kg/m², and $12.3 \pm 5.7\%$, respectively. Participants with a history of heart or skin diseases were excluded.

The participants provided written informed consent for inclusion in this study. The study was approved by the Ethics Committee of the International University of Health and Welfare (approval no. 20-Io-78).

Three different muscles (left TrA, left internal oblique (IO), and left EO) were selected as the target for measurement. All measurements were performed with the participants in the supine position with both hips and knee joint flexed at 0 degrees.

We generated the stimulation pulses by attaching the four electrodes, as specified by the manufacturer, using an interference wave type low-frequency electric therapy device (Superkine SK-10WDX; Minato Medical Science, Co., Ltd., Tokyo, Japan).

Electrical stimulation was applied through two sets of two electrodes on the left side of the anterolateral abdominal wall. The first electrode was located at the anterior superior iliac spine (ASIS), the second electrode was located on the lower costal margin at an intersection of the vertical line from the ASIS, and the third and fourth electrodes were placed symmetrically across the anterior axillary line to the first and second electrodes. Electrodes were set in pairs: the first and third electrodes and the second and fourth electrodes (Fig. 1).

For selecting IFC stimulation parameters, the interferometric low-frequency electrotherapy device provided electrical stimulation using a kilohertz-frequency alternating current modulated to 20–60 Hz.

Carrier frequencies that affect the depth to which the electrical stimulus reaches are 2.5 kHz and 5.0 kHz, and 20 Hz and 60 Hz were selected for LFRP, respectively. In previous studies, 60 Hz, which has been shown to be effective for fast-twitch muscles, and 20 Hz, which has been shown to be effective for slow-twitch muscles, have been employed¹²). The participants were measured under all five measurement conditions; control: rest (condition 1); 2.5 kHz modulated at (condition 2) 20 Hz and (condition 3) 60 Hz; and 5.0 kHz modulated at (condition 4) 20 Hz and (condition 5) 60 Hz. The five conditions were randomly performed. The current strength was unified to 10 mA, which is within the pain-free range, in line with the reports of previous research¹³).

The thicknesses of the TrA, IO, and EO muscles were determined using the ultrasonogram SonoSite 180 Plus (FUJIFILM SonoSite, Inc., Bothell, WA, USA). A 5-MHz linear ultrasound probe in B-mode was placed transversely across the abdominal wall between the costal margin and iliac crest, along the left anterior axillary line (at the intersection of the vertical line from the left anterior axillary line and the straight line from the navel). A single, experienced physiotherapist calculated the thickness of each muscle using images obtained from Image J (U.S. National Institute of Health) (Fig. 2). Participants were placed comfortably and instructed to breathe normally. Muscle thickness at rest and during electrical stimulation was measured during final exhalation. The measurement was performed twice in 0.1 mm units, and the average value was calculated. The percent change in muscle thickness was calculated as follows:

$$(\text{muscle thickness during IFC} - \text{muscle thickness at condition 1}) / \text{muscle thickness at condition 1} \times 100.$$



Fig. 1. Electrode position.

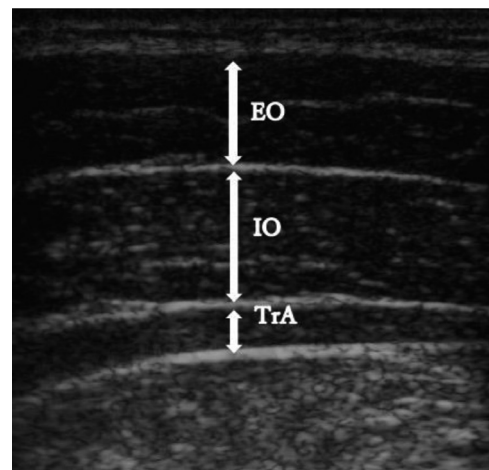


Fig. 2. Ultrasound images of abdominal muscles.

EO: External oblique; IO: Internal oblique; TrA: Transverse abdominis.

The validity of ultrasound imaging has been tested against criterion methods, such as magnetic resonance imaging and computed tomography^{13, 14}. Prior studies have also evaluated their reliability with intraclass correlation coefficients¹⁴. Ultrasound imaging is a highly reliable method for the assessment of the TrA and lumbar multifidus thickness in the static and dynamic position^{15–17}; hence, this method was used in this study.

The interclass correlation coefficient (ICC) (1.1) obtained from the first and second measurements under each condition was used to examine the intra-evaluator reliability of the TrA, IO, and EO thickness. Furthermore, to ensure the reliability of the electrode position during electrical stimulation, the electrodes were reconnected after the first measurement and then the second measurement was performed.

Regarding statistical analysis, the measured values of the first and second electrode attachments were tested with ICC. If normality was not demonstrated, a Friedman test was performed, and then comparisons were made among groups. The significance level was set at $p < 0.05$. Comparisons between groups were made using the Bonferroni correction method ($0.05/10 = 0.005$; $p < 0.005$). TrA thickness image data of one patient was excluded from the analysis due to its unclear nature. All analyzes were performed using IBM SPSS version 26.0 (IBM Corp., Armonk, NY, USA).

RESULTS

As a result of examining the reproducibility of the muscle thickness measurement, the ICC (1.1) were as follows: TrA, 0.989 to 0.998; IO, 0.992 to 0.997; and EO, 0.992 to 0.998. The change in ICC of muscle thickness for each electrical stimulation by altering the electrode attached was 0.841 to 0.998 for the TrA, 0.738 to 0.989 for the IO, and 0.992 to 0.998 for the EO muscles. The results of the Shapiro–Wilk test showed that the values of muscle thickness change for each condition were not normalized, while the rate of change in muscle thickness were normalized. A comparison of MFAC condition and abdominal trunk muscle thickness is shown in Table 1. The thicknesses in the TrA, IO, and OE muscles were significantly changed during IFC ($p < 0.01$).

In the TrA, the thickness was more significantly increased under condition 2 than under conditions 1 and 4. In the IO, conditions 2 and 3 yielded significantly thicker muscles than condition 1. In the EO, condition 2 produced significantly thicker muscles than conditions 1 and 5, and condition 3 yielded significantly thicker muscles than condition 1.

Table 2 shows the rate of change in muscle thickness. Under conditions 2, 3 and 5, the rate of change of the TrA was greater than that observed in the other muscles. Additionally, the rate of change of TrA muscle thickness under condition 2 was significantly greater than under the other conditions.

DISCUSSION

In this study, ICC (1.1) was examined for the reattached electrode in each condition. The ICC (1.1) resulting from the abdominal muscle thickness measurements was 0.738–0.998, which indicate “normal reliabilities”–“good reliabilities”.

The thickness of the TrA, IO, and OE muscles increased significantly with the 2.5 kHz modulated at 20 Hz. TrA thickness

Table 1. Change in muscle thickness for each condition

| | Condition 1 | Condition 2 | Condition 3 | Condition 4 | Condition 5 |
|---------------|-----------------|------------------|------------------|------------------|-----------------|
| TrA (mm) n=21 | 3.2 (2.9–3.6) | 3.9 (3.4–4.4)* | 3.7 (3.3–4.2) | 3.3 (3.1–3.7)† | 3.4 (3.1–3.9) |
| IO (mm) n=22 | 10.2 (9.2–11.8) | 11.4 (9.6–12.9)* | 11.1 (9.4–12.4) | 10.1 (9.0–12.0)* | 10.3 (8.8–11.7) |
| EO (mm) n=22 | 8.7 (7.2–10.1) | 10.3 (8.1–11.4)* | 10.2 (8.0–10.8)* | 9.2 (7.8–10.3) | 9.0 (7.7–10.3)† |

TrA: Transverse abdominis; IO: Internal oblique; EO: External oblique.

Statistics: Friedman test (subtest: Bonferroni correction, $p < 0.005$). *: vs. condition 1, †: vs. condition 2.

Condition 1: control (rest), condition 2: 2.5 kHz/20 Hz, condition 3: 2.5 kHz/60 Hz, condition 4: 5.0 kHz/20 Hz, condition 5: 5.0 kHz/60 Hz.

Table 2. Percent change in muscle thickness for each stimulus condition

| | Condition 2 | Condition 3 | Condition 4 | Condition 5 |
|----------|-------------|--------------|--------------|-------------|
| TrA n=21 | 21.1 ± 13.6 | 15.1 ± 14.4* | 3.0 ± 11.5*† | 9.1 ± 12.0* |
| IO n=22 | 9.3 ± 11.0 | 7.0 ± 8.5 | 1.5 ± 5.8*† | 1.2 ± 6.2* |
| EO n=22 | 16.4 ± 13.5 | 11.7 ± 11.7 | 5.2 ± 8.1*† | 5.3 ± 7.8*† |

TrA: Transverse abdominis; IO: Internal oblique; EO: External oblique.

Statistics: One way ANOVA (subtest: Bonferroni, $p < 0.05$).

*: vs. condition 2, †: vs. condition 3.

The percent change in muscle thickness was calculated as follows: (muscle thickness during IFC–muscle thickness at condition 1) / muscle thickness at condition 1 × 100.

increased by 1.21-fold at 2.5 kHz modulated with 20 Hz, when compared to the control, and the value was significantly higher than the one obtained at 5.0 kHz modulated with 20 Hz MFAC.

According to Ward¹⁸⁾, the optimum frequency of alternating current is 1 kHz for indirect stimulation via nerves and 2.5 kHz for direct stimulation to muscles. In the study, compared to the resting state, the thickness of all muscles increased at 2.5 kHz, but not at 5.0 kHz, which is the maximum carrier frequency. Furthermore, the IFC of 2.5 kHz/20 Hz was suggested to be the most involved in the muscle thickness change of the deep muscle.

Therefore, the application of 2.5 kHz (frequency) was more effective than the application of 5.0 kHz. The 2.5 kHz frequency may be an effective option for participants who have difficulty performing the draw-in exercise; however, it is necessary to consider increasing the fine setting from 2.5 kHz to 5.0 kHz.

According to Watanabe et al.¹³⁾, to strengthen the muscles, high-frequency pulse stimulation of 30–60 Hz is effective for fast muscles, and low-frequency pulse stimulation of 10–20 Hz is effective for slow muscles. Muscle fatigue and tetanus are less likely to occur at frequencies below 20 Hz. On the other hand, when the frequency is 30 Hz or higher, tetanus and muscle fatigue are more likely to occur.

The abdominal muscles are anatomically classified as slow muscles. It has been reported that the ratio of type I fibers to muscle fibers of the abdominal muscle group is 55% to 58%, and the difference between each muscle is small¹⁹⁾. The percentage of type I fibers in abdominal muscles is higher than that found in general limb muscles. This study also demonstrates that since the abdominal muscles are slow muscles, a greater increase in muscle thickness was produced at 20 Hz, which is the frequency found to be more effective in lowering muscle fatigue and tetanus¹⁹⁾.

Several studies have investigated changes in the thickness of the transverse abdominal muscles during exercise. It has been reported that trunk flexion exercise in the supine position increases muscle thickness by 114%²⁰⁾, and that lower limb elevation exercise increases muscle thickness by 13.1%²¹⁾. In addition, there are many reports of changes in TrA thickness caused by abdominal drawing-in maneuver, with an increased rate of 44–85%^{21–23)}.

Regarding the rate of increase in the thickness of the TrA muscle caused by electrical stimulation, Cho et al. reported an increase of 21–33%¹⁰⁾, while Coghlan et al. reported an increase of 16.8%²⁴⁾.

In this study, the rate of change in the thickness of the TrA muscle increased by an average of 21.1% under condition 2. It can be said that the effect of abdominal muscle contraction by electrical stimulation is more effective on the TrA muscle as demonstrated in other studies.

One of the limitations of the present study was that it was not clear whether MFAC penetrated deep tissues and evoked great fiber recruitment, as no significant difference was found in the change of thickness of the three muscles in the abdomen. In addition, since the results were not compared to LFRP, they could not be interpreted as IFC characteristics. Therefore, further research is needed, such as comparing IFC with LFRP.

In conclusion, IFC at 2.5 kHz and 20 Hz can be used as a feasible and reproducible way to train abdominal muscles.

Funding and Conflicts of interest

There are no financial and personal relationships with other people or organizations that could inappropriately influence or bias the contents of this manuscript.

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