2008

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## WMU ScholarWorks Citation

Miller, Michael G.; Cheatham, Christopher C.; Holcomb, William R.; Ganschow, Rosealin; Michael, Timothy J.; and Rubley, Mack D., "Subcutaneous Tissue Thickness Alters the Effect of NMES" (2008). *Human Performance and Health Education Faculty Research.* Paper 6.
http://scholarworks.wmich.edu/humanperformance_faculty/6

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*Journal of Sport Rehabilitation,* 2008, 17, 68-75

# Subcutaneous Tissue Thickness Alters the Effect of NMES

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***Context:*** No direct research has been conducted on the relationship between subcutaneous tissue thickness and neuromuscular electrical stimulation (NMES). ***Objective:*** The purpose of this study was to determine the effects of subcutaneous tissue thickness on NMES amplitude and NMES force production of the quadriceps. ***Design:*** Simple fixed design, testing the independent variable of subcutaneous thickness (skinfold) groups with the dependent variables of NMES amplitude and force production. ***Setting:*** Athletic Training Laboratory. ***Participants:*** 29 healthy women. ***Intervention:*** NMES to produce at least 30% of maximal voluntary isometric contractions (MVIC) of the quadriceps. ***Main Outcome Measure:*** Maximal NMES amplitude and percentage of MVIC using NMES. ***Results:*** A significant skinfold category difference $F_{2,28} = 3.92$, $P = .032$ on NMES amplitude was found. Post hoc revealed the thinnest skinfold category tolerated less amplitude compared to the thickest category. A significant correlation was found between NMES amplitude skinfold category $R = .557$, $P = .002$. ***Conclusion:*** Higher NMES amplitudes are needed for the thickest skinfold category compared to the thinnest skinfold category. ***Keywords:*** intensity, isokinetic, muscle function

Neuromuscular electrical stimulation (NMES) is a form of electrical stimulation specifically designed to elicit muscle contractions.[1] NMES may be used to minimize atrophy and strength loss associated with post-surgical immobilization[2,3] when voluntary exercise is contraindicated or coordinated muscular contraction is not possible. As an amplitude-dependent modality, the current must be strong enough to overcome the capacitive resistance of the tissues (ie, skin and fat) before the motor nerves can be stimulated.[4] Cheng et al[5] reported that subcutaneous tissue is anisotropic and electrical conductivities are independent of current density and pulse rate in pigs. This study suggests that subcutaneous thickness and muscle fiber recruitment is still speculative when using electrical stimulation.

An increase in skinfold thickness theoretically would increase the resistance of the electrical current to the underlying muscle.[6] Patients with an increased skinfold

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thickness may require an increase in electrical stimulation to produce the same desired therapeutic benefits. Although not the purpose of their study, Hortobagyi et al[7] found no correlation between the electrical stimulation amplitude and skinfold thickness of the biceps and triceps when examining force production in the elbow flexors and extensors. Skinfold thickness of the upper extremity may be lower compared to the lower extremity and most studies examining peak torque values with electrical stimulation have used the lower extremity.[2,3,8-11] No direct research has been found by the authors examining the relationship between subcutaneous tissue thickness and NMES, however. This relationship may affect the parameters of NMES needed to achieve a desirable percentage of maximum voluntary isometric contractions (MVIC) to minimize atrophy and promote strength gains during rehabilitation. Therefore the primary purpose of this study was to determine the effects of subcutaneous tissue thickness on NMES amplitude and NMES force production of the quadriceps.

# Methods

## Design

This study was designed to test the independent variable of subcutaneous tissue thickness with the dependent variables of NMES amplitude and force production using NMES. Force production using NMES was expressed as a percentage of the peak maximum voluntary isometric contraction.

## Subjects

Of 46 subjects who volunteered for the study, 43 healthy subjects (14 men and 29 women) met the minimum criteria of 30% MVIC induced by NMES. We chose to use a minimum 30% of MVIC because research has reported that strength gains can be seen with torque production ranging from 30% to 50% of MVIC.[8] Hartsell and Kramer also found that at maximum comfortable intensity subjects averaged around 36% of MVIC.[9] Subjects were placed into 3 groups, dependent on skinfold thickness means using the categorization procedure of SPSS (version 14.0, Chicago, Ill). After careful analysis of the groups based upon skinfold, it was determined that the males were predominately found in the skinfold group 1, which was classified as the thinnest. Because of the lack of heterogeneous male sampling into the skinfold groups and based upon preliminary analysis, we decided to exclude the males and only use the females who had a better heterogeneous group sampling (Table 1). Therefore, 29 females (21.5 ± 1.91 yrs, 66.6 ± 2.6 cm, 70.4 ± 13.3 kgs) were used for the analysis.

Subjects reported to an athletic training research laboratory on two separate days, with two days between. The first day was to measure skinfold and become acclimated to the procedures, and the second day was to conduct the study. The study was approved by the Human Subjects Institutional Review Board (HSIRB) and all subjects were informed of potential risks of the study and signed an approved consent form. Each subject refrained from exercising 24 hours prior to each testing session.

**Table 1 Skinfold Categories Means and Ranges Expressed in Millimeters**

| Statistic | Skinfold Category 1 | Skinfold Category 2 | Skinfold Category 3 |
|---|---|---|---|
| Total | 10 | 9 | 10 |
| Mean | 17.7 | 22.2 | 31.6 |
| Standard deviation | 3.9 | 1.4 | 5.1 |
| Range minimum | 7.0 | 20.8 | 25.1 |
| Range maximum | 20.6 | 24.8 | 38.5 |

## Procedures

Subjects reported to the athletic training research laboratory on day one to have the right anterior thigh shaved and skin cleaned with isopropyl alcohol wipes. A Vectra Genisys electrical stimulation unit (Chattanooga Group, TN), utilizing a combination protocol of high volt stimulation current with an ultrasound head to mimic a motor point probe, was used to find the specific motor point of the vastus medialis oblique (VMO) of the right quadriceps and upper thigh, similar to the procedures used in a previous study.[12] The VMO motor point and 6 inches above the VMO motor point were marked with a permanent marker. Skinfold measurements were taken at both sites using a Lange skinfold caliper (Beta Technology Inc, Cambridge, MD) by a certified athletic trainer who was trained and certified as a Michigan High School Athletic Association (MHSAA) wrestling skinfold assessor to ensure intrarater reliability of measurements. Three measurements were taken and averaged from each site and the sums of both sites were used for the skinfold group categories.

After determining skinfold thickness, a 5-minute warm-up on an elliptical trainer followed by quadriceps and hamstring stretching (eg, modified hurdle, standing knee flexion, straight toe touches) was performed (3 sets for 20 seconds for each stretch) by each subject. Within 10 minutes of stretching, subjects were then positioned on the Kin-Com™ Dynamometer (Chattanooga Group, Inc., Hixon, TN; Figure 1) with hip flexion at 90˚ and knee flexion at 70˚. The axis of rotation of the dynamometer was aligned to the anatomical axis of the right knee. To ensure reliable measurements, the dynamometer was calibrated, all stabilization straps were used to prevent unwanted movement, and participant's hands were required to remain free. No visual or verbal feedback was provided during testing.

Subjects were asked to extend the knee against the fixed lever arm of the dynamometer submaximally. After three repetitions, subjects were then asked to extend the knee with maximal force for 10 seconds. Peak MVIC torque values were recorded from three trials of MVIC with two minutes rest between each repetition.

After completion of the three repetitions of MVIC, subjects were given 10 minutes of rest before proceeding with NMES. NMES was provided by an OrthoDx™ (Rehabilicare, New Brighton, MN). The OrthoDx™, which was a new unit calibrated by the manufacturer, is a constant voltage electrical stimulator unit which produces a biphasic, symmetrical current waveform at a fixed frequency of

**Figure 1** — Position of subject on the Kincom™ Dynamometer with OrthoDx attached to subject.

33 pps and a phase duration of 300μs. The OrthoDx™ has been used in previous research and has been shown to be a sufficient provider of NMES.[12] Current was delivered via two active electrodes. A 4″ × 6.75″ self adhesive Stimcare™ electrode (Rehabilicare, New Brighton, MN) was centered on the anterior thigh six inches above the VMO motor point, and a 4″ × 2″ self adhesive Stimcare™ electrode was placed over the marked motor point of the VMO after shaving and cleaning the sites.

Subjects were told to increase the NMES amplitude of the unit until a sensation was felt, further until a muscular contraction was noted, and further until maximum comfortable amplitude was reported. Subjects were asked to relax and allow the knee to passively (no voluntary action) extend against the fixed lever arm. This process was repeated until the subject's maximum comfortable amplitude was reached. Subjects failing to reach 30% of MVIC were excluded from the study. The final NMES amplitude was recorded and served as a starting value for session two.

The second session was scheduled for each subject a minimum of 2 days and a maximum of 5 days after session one. Subjects performed the same warm-up protocol as session one before being positioned on the Kin-Com™. The electrodes were placed over the same marks on the VMO and anterior thigh after shaving and cleaning the sites. Subjects were allowed three trials to reach or exceed the final amplitude level of the first session. Torque values were measured to make sure subjects reached the minimum of 30% MVIC. The subjects were given a minimum of 2-minute rest periods before actual testing began. Three trials of ten seconds each with a 2-minute break between sets were performed during the testing session. The amplitude was not altered between individual repetitions. Peak torque values were recorded for each repetition.

## Analysis

A one way ANOVA was used to determine effects of skinfold groups (category 1-3) with the dependent variables of NMES amplitude and NMES force production.

Tukey post hoc tests were used to determine differences between skinfold groups. A two tailed Pearson Correlation was used to examine the skinfold thickness scores, NMES amplitude, and NMES force production. The alpha level was set a priori at .05. All data was expressed as means and standard deviations.

## Results

The values for amplitude and NMES force production with respect to skinfold category are listed in Table 2. For the dependent variable of NMES amplitude, there was a significant skinfold category difference $F_{2,28} = 3.92$, $P = .032$. Post hoc testing revealed that skinfold category 1 tolerated less amplitude compared to skinfold category 3 (75.5 ± 7.9mV and 88.0 ± 11.4mV, $P = .025$). The effect for skinfold category was not significant, however, for NMES force production $F_{2,28} = 2.07$, $P = .146$.

There was a significant positive correlation between NMES amplitude and skinfold thickness values, R= .557, $P = .002$ (Figure 2) indicating that as the skinfold thickness increased, tolerated amplitude increased.

## Discussion

Electrical current tends to follow the path of least resistance. Tissue that contains high water and ion content is the best conductor of electricity.[4,6] The epidermis layer of the skin, however, has low water content, dead skin cells, and other debris that provide resistance to electrical flow. After penetrating the skin current must pass through the fat layer, which contains only 14% water and is therefore a poor conductor.[4] Skin thickness was assumed to be similar between subjects but the fat layer was believed to be different in our three groups. Once through the barrier provided by skin and fat current will flow in muscle, nerve, and blood which have high water content (70-75%) resulting in good conductance of electricity.[6] Although we could not measure electrical resistance under each electrode, we shaved and cleaned the skin with an isopropyl alcohol wipe for each trial to minimize electrical resistance.

Belanger[13] determined that tolerance to electrical current was limited by both cutaneous and muscular pain. When cutaneous sensation was eliminated through nerve block the discomfort experienced with NMES was reduced by 50%. In our groups the current that reached the skin should be similar as we prepared the skin

**Table 2 Skinfold Group Categories on Amplitude and Force Production**

| Skinfold Category | Final NMES Amplitude (mV) | NMES Force Production (%) |
|---|---|---|
| Skinfold Category 1 (N = 10) | 75.5 ± 7.9 | 49.1 ± 8.5 |
| Skinfold Category 2 (N = 9) | 81.7 ± 10.4 | 38.4 ± 7.2 |
| Skinfold Category 3 (N = 10) | 88.0 ± 11.4 | 45.3 ± 16.4 |

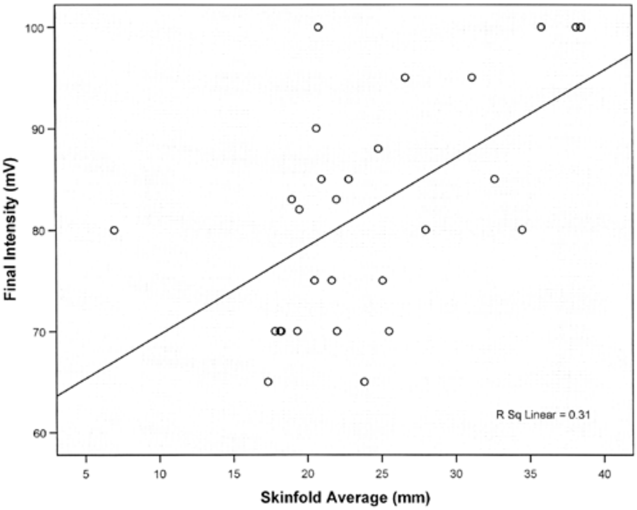

**Figure 2** — Correlation of NMES amplitude and skinfold categories. As the skinfold thickness increased, the amplitude increased.

and electrodes in an identical manner for each group. We believe, however, that subcutaneous tissue provided a barrier to electrical current thus less current reached the underlying muscle in those with a thicker subcutaneous layer. Therefore, greater amplitude was required to cause discomfort in the muscle, which Belanger[13] showed to be a contributing factor in determining tolerance. This would explain why greater amplitude was tolerated in the group with the thickest subcutaneous layer.

When comparing groups of similar subjects, it would be expected that greater NMES amplitude would result in a greater contraction force. We compared groups that were different based on subcutaneous tissue thickness and found that an increase in amplitude did not result in a greater contraction force. Those with thicker subcutaneous tissue tolerated greater amplitude but the subcutaneous likely impeded the current, thus allowing less current to reach the underlying muscle. Therefore, the resulting contraction force was no greater in the group tolerating greater amplitude than in the group with less subcutaneous tissue that tolerated less amplitude. This phenomenon might be explained by the type of muscle fibers stimulated and not of subcutaneous tissue as thought in our study.

Waveform of the stimulation unit may also have an effect on the overall NMES force production. Because of the variability in waveform of NMES units, a consistent or standard protocol to induce muscular contraction is confounded. Hartsell and Kramer[9] and Brooks, Smith, and Currier[14] used sinusoidal waveforms and produced averages of 36% of MVIC with NMES. Bergman et al[15] used a symmetrical biphasic current that produced a mean of 46.5% of MVIC. The previous studies show that varying ranges of NMES force production can be reached with different types of waveforms and various perceived levels of discomfort for the subjects. We used a biphasic symmetrical waveform; however, some of the aforementioned studies used various waveform types demonstrating that various waveform can be used to produce the desired MVIC. As clinicians, the best suited waveform should be the one that produces the desired force with minimal discomfort for the patient.

With repeated stimulation in a single treatment session, motor nerves will begin to accommodate and a greater amplitude is required to excite an equal number of fibers.[16] This increase in amplitude is possible because of increased tolerance to current intensity.[17] This practice may be used in an acclimation period to assist the subject to become acclimated to the amplitude and discomfort and reach the required percent MVIC set for this study. We did not record the MVIC values during the acclimation period, and although our results are reversed, these percentages are in close comparison to the values found in Snyder-Mackler, Ladin, Schepsis, and Young[17] and may suggest that several more days of accommodation are required to increase the percentage of force production. We suggest examining the amplitude increases over time to determine when patients reach tolerable and consistent final muscular contraction, regardless of increases in amplitude to determine when acclimation is achieved.

Our electrodes were relatively large and the current density was low under each electrode. Using smaller electrodes that have higher current densities may alter the MVIC values when compared with subcutaneous tissue thickness. We suggest conducting trials to determine the appropriate size electrodes needed to produce the desired MVIC with various subcutaneous tissue thicknesses while also minimizing discomfort as a result of electrical stimulation.

This study was an initial investigation as to the effects of electrical stimulation on MVIC with patients of various subcutaneous tissue thicknesses. It appears that greater amplitude is required for those with thicker subcutaneous tissue to achieve a desired contraction force. This is likely the result of adipose tissue being a poor conductor of electricity. Our results also suggest that those with thicker subcutaneous tissue tolerated greater amplitudes. Therefore, clinicians should help athletes with greater subcutaneous tissue acclimate to the higher amplitudes required for successful NMES.

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