ORIGINAL ARTICLE

Is the Ability to Maximally Activate the Dorsiflexors in Men and Women Affected by Indwelling Electromyography Needles?

Ruth E. Brown, BHK, Sara H. Bruce, MHK, Jennifer M. Jakobi, PhD


Objectives: To determine whether maximal force is similar between conditions with and without a microelectrode, and to evaluate potential sex differences when using invasive procedures.

Design: Crossover trial.

Setting: University laboratory.

Participants: Young men (n=8; mean ± SD age, 20.3±2.0y) and young women (n=8; mean age ± SD, 19.8±0.4y).

Interventions: Not applicable.

Main Outcome Measures: Subjects randomly performed 5 ankle dorsiflexion maximal voluntary contractions (MVCs) with an indwelling microelectrode in the tibialis anterior and 5 MVCs with the twitch interpolation technique without a microelectrode. Strength and contractile properties were measured. No visual or oral feedback was provided. When the greatest MVCs from each condition differed by more than 5%, 3 additional attempts were given with feedback in the lesser of the 2 conditions.

Results: Men were ~39% stronger than women, and contractile properties were ~11% faster, but maximal voluntary activation was similar between sexes (~95%). However, in men and women, the greatest MVC did not differ between the microelectrode and activation conditions (P=.87). In 9 of the 16 subjects, MVC was about 5% less in 1 of 2 conditions. Five of these 9 subjects were able to match or exceed their highest MVC with the aid of visual feedback.

Conclusions: This suggests that muscle strength and contractile properties differ between men and women. Indwelling microelectrodes do not hinder the ability to achieve MVC, but adequate feedback is necessary to achieve the highest force.

Key Words: Micro electrode; Muscle strength; Muscle contraction; Rehabilitation; Sex factors.

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INDWELLING TUNGSTEN OR FINE wire electrodes are commonly used to record motor units to facilitate the quantification of recruitment and discharge rate, and more recently synchronization and coherence measures.6-8 A variety of studies have used these recordings to report motor unit activity in young and older adults,1,5-8 in healthy and clinical populations,9 and as a consequence of fatigue or training.10,11 Motor unit activity is most frequently quantified at force levels relative to MVC. Thereby, the final assessment of motor unit activity is directly dependent on attaining MVC when the microelectrode is within the muscle. It is likely that the ability to produce an MVC with an indwelling microelectrode may be less in women because of a higher tendency to fear procedures that involve a needle.12 Women have a tendency to have stronger self-focused attention during anticipation of pain than men.13 Thus, women may be apprehensive to contract their muscle maximally in the presence of a microelectrode because of the perception of pain. To date, no study has directly assessed whether MVC can be obtained by both sexes when a recording microelectrode is within the muscle.

Twitch interpolation is a well known technique to evaluate voluntary activation. Although there are a variety of strategies used with respect to the number of interpolated pulses administered, the intensity of the pulses, and the mathematics used to quantify activation,14-15,17 the premise of delivering a superimposed pulse to the muscle during the contraction and when at rest is consistent. Studies1,15,18-20 have determined that certain muscle groups such as the ankle dorsiflexors and adductor pollicis are capable of being nearly or fully active in a variety of clinical populations20-22 and young healthy adults.3,23 Although voluntary activation is assumed to be similar between the sexes, no study has directly assessed this. Yet in young adult populations, fear of dental visits is higher in women24 because of the sight and sensation of a needle.24,25 Therefore, when an indwelling microelectrode is used to assess motor unit activity, a true MVC may be unattained because of the perception of pain or a negative experience with an invasive procedure, and this may be exacerbated in women. The purpose of the present study was to examine whether the presence of tungsten microelectrodes impedes the ability of young adult men and women to produce an MVC.

List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>ANOVA</td>
<td>analysis of variance</td>
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<tr>
<td>CD</td>
<td>contraction duration</td>
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<tr>
<td>HRT</td>
<td>half relaxation time</td>
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<td>MVC</td>
<td>maximum voluntary contraction</td>
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<tr>
<td>PT</td>
<td>peak torque</td>
</tr>
<tr>
<td>TA</td>
<td>tibialis anterior</td>
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<tr>
<td>TPT</td>
<td>time to peak tension</td>
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METHODS

Eight men (mean ± SD age, 20±3y) and 8 women (20±2y) signed a written informed consent according to the guidelines established by local university review and adhering to the Declaration of Helsinki. Subjects had no known muscular or neurologic conditions and were recreationally active. Exclusion criteria also included participation in studies in which MVCs were executed, regular use of needles (ie, persons with diabetes), and prior experiments that used tungsten microelectrodes. Thus, all subjects were naïve to the experimental procedures to assess MVC and the use of microelectrodes.

Subjects visited the laboratory once for a period of 1 to 1.5 hours. Isometric dorsiflexion contractions were performed in a custom-designed leg dynamometer and fully adjustable chair (University of Windsor). The nondominant left leg was placed into the dynamometer with the knee positioned to 90° and the foot placed in 30° plantar flexion with the ankle aligned at the axis of rotation. Placement was maintained by securing the foot, thigh, and pelvis with Velcro straps. Dorsiflexion torque outputs were transmitted through the rigid footplate at a fixed distance (21cm) from the strain gauge aligned at the axis of ankle joint rotation. The output from the linear calibrated strain gauge was amplified and sampled online at 500Hz (Power 1401). The hip angle was set to 90°, the right leg was placed on an adjacent box that held in place with constant experimenter pressure. A series of MVCs were attempted in the nondominant leg while subjects produced isometric MVCs in 1 of 2 randomized conditions: the microelectrode condition and the activation condition. The microelectrode condition involved producing an MVC with an indwelling tungsten microelectrode4 inserted into the midbelly of the TA of the left leg. The activation condition required the attempt at MVC to be made during assessment of maximum voluntary activation with the twitch interpolation technique and with the tungsten microelectrode removed from the leg. This enabled independent assessment of MVC between the 2 conditions. Five MVCs were attempted in each condition. Initial instructions centered on consistent information from the same investigator to dorsiflex the foot as hard and as fast as possible during all efforts. Visual and verbal feedback of the force output was not provided because of interference from antagonists; subsequently current was increased by 10%. Ten supramaximal single pulses were administered to assess twitch contractile properties, PT, TPT, HRT, and CD. Offline analysis consisted of quantification of twitch contractile properties, MVC with and without the tungsten microelectrode, and determination of voluntary activation with the twitch interpolation technique. The twitch interpolation technique consisted of applying a series of paired electrical supramaximal pulses (2 pulses at 100Hz) once a second during and after each MVC. Supramaximal intensity for the paired pulses was determined in a like manner to the single pulses. Maximal voluntary activation was calculated from a ratio of the amplitude of the paired interpolated response to the amplitude of a potentiated post-MVC paired-pulse response:

\[ \frac{1}{P} \] (amplitude of interpolated twitch/post twitch) \times 100.

Intramuscular tungsten microelectrodes (125μm in diameter, ~4cm in length) were inserted into the midbelly of the TA. Prior to insertion, the tungsten microelectrodes were sterilized, and the skin was cleansed with 70% alcohol. A reference electrode was placed 1cm distal to the microelectrode, and a ground electrode was set onto the skin overlying the middle of the patella.

To assess possible sex differences, the highest MVCs achieved irrespective of condition and twitch contractile properties (PT, TPT, HRT, CD) were compared with a 1-way ANOVA. To examine the ability to produce an MVC with and without a tungsten microelectrode, the dependent variable of dorsiflexion MVC was evaluated with a 2-way ANOVA between sex (men and women) and condition (with and without tungsten microelectrodes). A repeated-measures ANOVA was used to assess differences between the 10 MVCs that were attempted. All statistical analyses were executed in SPSS version 16.0.4 Values reported in the text, tables, and figures are mean ± SD. Statistical significance was set at \( P \) less than .05.

RESULTS

Results for age, height, and weight are presented in table 1. When the highest MVC for dorsiflexion was compared (sex \times condition), there was no statistical interaction (\( P=.94 \)) or main effect for condition (\( P=.87 \)) (fig 1). When the microelectrode was present, the average MVC for men and women was 33.60±1.77Nm. When there was no microelectrode and vol-

**Table 1: Age, Height, and Weight of Subjects**

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Women</th>
</tr>
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<tbody>
<tr>
<td>Age (y)</td>
<td>20.3±2.0</td>
<td>19.8±0.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177.5±5.4*</td>
<td>167±5.0</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>83±10.9*</td>
<td>68±13.5</td>
</tr>
</tbody>
</table>

*\( P<.05 \).

NOTE. Values are reported as mean ± SD.
Voluntary activation was measured, MVC was 34.01 ± 1.77 Nm. The main effect for sex ($P < .0001$) was significant. Irrespective of condition, men produced an average force of 42.03 ± 7.3 Nm, and women produced an average force of 25.58 ± 6.3 Nm (see fig 1).

Repeated Contractions

When individual MVC was assessed, 9 of the 16 subjects (3 women and 6 men) were at least 5% weaker in 1 of the 2 conditions and therefore were given up to 3 additional attempts to increase force in the lesser condition. One woman and 2 men (fig 2A) were weaker in the activation condition. When feedback was provided, only 1 of the men was able to achieve force within 5% of the microelectrode condition (see fig 2A). Two women and 4 men were at least 5% weaker in the microelectrode condition than the activation condition. When the microelectrode condition was repeated with force feedback, 1 woman (fig 2B) and 3 men (see fig 2A) produced a force that was within 5% of the initially greater activation condition. Overall, the addition of feedback enhanced force production.

Maximal Voluntary Activation

Although women were approximately 39% weaker than men (see fig 1), maximal voluntary activation was similar between sexes (fig 3). In the young women, activation ranged from 81.0% to 97.4%, whereas in young men, activation ranged from 83.3% to 96.3%. Five of the 8 young men achieved greater than 95% voluntary activation on 50% of the attempts at MVC, and 7 of the 8 women attained greater than 95% on 33% of the attempts at MVC. To determine statistically whether the variability in achieving maximal voluntary activation differed between women and men, the SD of maximal voluntary activation was compared with an independent $t$ test, and no difference was found ($P = .71$). When the activation values across the 5 trials were compared, the first attempt was higher than the percent activation value for the fifth attempt ($P = .01$). Voluntary activation for the second attempt at MVC was greater than the third, fourth, and fifth ($P < .05$) attempts at MVC.

Attempts at Maximum Voluntary Contraction

MVC force across the 10 trials was evaluated (fig 4). The first MVC did not differ from the second MVC ($P = .16$), but the first was greater than the third through the tenth MVC. The second MVC was significantly higher than the third ($P = .001$), fourth ($P = .003$), and fifth MVC ($P = .02$), while the third and fourth MVCs did not differ ($P = .4$). Because the second MVC did not differ from the first but was higher than the third and fourth, a minimum of 2 MVCs is necessary when feedback is not provided.

Twitch Contractile Properties

There was no difference in HRT ($P = .08$) between men and women (table 2). However, women took approximately 14%
Fig 3. The voluntary activation score for each of the 5 attempts at MVC is shown for men (open triangles), women (open circles), and the mean of all subjects (crossbar). Voluntary activation did not differ between men and women (P=0.66). The percent voluntary activation for the second attempt at MVC was greater than the third (P=0.02), fourth (P=0.04), and fifth (P=0.02) attempts at MVC, and the first attempt was greater than the fifth attempt at MVC (P=0.01). The first and second attempts at MVC were similar.

Fig 4. Average force values across the 10 attempts at MVC irrespective of condition and sex. The third through tenth MVC differed from the first and second attempt at MVC. The first and second attempt at MVC did not differ. Values are mean ± SD. *Significantly lower than first and second MVC.

Table 2: Tibialis Anterior Twitch Contractile Properties in Young Men and Women  

<table>
<thead>
<tr>
<th>Muscle Property</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT (Nm)</td>
<td>2.68±0.9*</td>
<td>2.30±0.4</td>
</tr>
<tr>
<td>TPT (ms)</td>
<td>75.25±4.1*</td>
<td>86.87±7.6</td>
</tr>
<tr>
<td>HRT (ms)</td>
<td>73.95±6.7</td>
<td>81.52±9.0</td>
</tr>
<tr>
<td>CD (ms)</td>
<td>149.20±7.6*</td>
<td>168.40±15.2</td>
</tr>
<tr>
<td>Average rise</td>
<td>0.02±0.006*</td>
<td>0.14±0.003</td>
</tr>
<tr>
<td>Average fall</td>
<td>-0.01±0.003*</td>
<td>-0.008±0.002</td>
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NOTE. Values are mean ± SD. *P<.05.

DISCUSSION

Many studies have used indwelling microelectrodes to study motor unit properties. However, no study has determined the ability to produce an MVC with an indwelling microelectrode in the muscle. The present study assessed MVC of the ankle dorsiflexors in young men and women with and without a tungsten microelectrode. The main findings were as follows:

1. Irrespective of sex, MVC was similar between the activation and microelectrode conditions. This suggests that indwelling microelectrodes do not hinder the ability to achieve MVC in men and women.

2. Men were stronger and had faster contractile properties than women.

3. Although men and women were not able to attain 100% maximal voluntary activation in the TA, a similar degree of activation (95%) was achieved between sexes (P=.71). This suggests that women are weaker than men, but this is not a result of an inability to produce MVC.

Strength and Twitch Contractile Property Differences

Men were stronger than women at all attempts at MVC, which is consistent with previous literature. Men also produced a higher peak torque, quicker time to peak tension, and faster contraction duration than women. These results are consistent with previous literature on sex-related differences. Although men were stronger than women, voluntary activation was similar between the sexes. Therefore, lower force in women was not a result of a failure in voluntary activation. Men generally have a greater cross-sectional area of fat-free muscle than women, which likely contributed to the sex differences observed in this and other studies. Holmback et al reported that the greatest contributor to strength differences between men and women in the TA was caused by a larger contractile cross-sectional area. In addition, men also had a larger type II to type I muscle fiber ratio than women, which would also contribute to greater force output. The slower isometric contractile properties in women than men in this study support the fiber type differences previously observed.

Microelectrode Use

Several studies have looked at sex differences with respect to fear of injections. Nir et al found that women were more prone to fear injections than men, with fear of pain highly correlated with injection phobia. Approximately 21% of women experience mild to intense fear of injections and injury. It was hypothesized that there would be a sex-related difference in ability to achieve MVC when a microelectrode was used because of a phobia related to injection and/or associated needle use in women. Results from this study demonstrate that in young men and women, force is similar between conditions when a microelectrode is present and in the activation condition when the microelectrode was absent. Thus, the microelectrode condition did not differ from the activation condition. Because subjects did not have a clear view of the microelectrode passing into the muscle as a result of the upright
positioning in the chair, the visual effect associated with needle insertion may have been masked, and sex-related differences might be evident only when the microelectrode is clearly visible. In addition, this study is the first to compare men and women objectively (see review') and determine that they can be studied in a like manner in motor unit investigations.

**Required Attempts at Maximum Voluntary Contraction**

Scherer et al. found that 3 to 4 attempts at MVC were necessary to produce the highest maximal activation when visual and strong verbal encouragement was provided in 1 session. Jakobi and Rice observed that when visual and verbal encouragement was provided, maximal voluntary activation scores were greater on the second day, when 5 attempts at MVC were provided in each session. Subjects in the present study performed a minimum of 10 attempts at MVC. When the consecutive attempts were compared, the second attempt at MVC was significantly higher than attempts 4 to 10. When percent activation was evaluated, there was no difference between the first and second attempt; however, the third, fourth, and fifth attempts were all lower than the second. Therefore, we can speculate that without feedback, the highest force achieved is within 2 attempts at MVC, and the voluntary activation score is modestly less than with visual feedback. When visual feedback is provided, more attempts at MVC result in further increases in force and attainment of higher maximal voluntary activation levels.

MVC was similar between conditions, but voluntary activation was lower than prior reports for ankle dorsiflexors. A potential explanation for this is that no form of feedback was initially provided to subjects. When MVC differed by more than 5% between conditions, visual and verbal feedback were given. Thus, initial MVCs were attempted solely on the basis of internal motivation and effort. It has been reported that dorsiflexion force is lower when high submaximal contractions are attempted without visual feedback than when visual feedback is provided. Also, when the ability to match force between contralateral homogenous limbs was assessed based on effort alone, the weaker limb produced significantly lower force when visual and verbal feedback were not provided. It is likely that our observation of 2 attempts at MVC is less than other studies because visual and verbal feedback and encouragement were not initially provided. This suggests the necessity of providing an optimal environment with proper encouragement to attain maximal voluntary activation and produce a true MVC, but the psychological association with this submission is beyond the scope of this study.

**Study Limitations**

There are inherent limitations to using the interpolated twitch technique such as force variability, muscle length, and sensitivity of the recording device that might have influenced these data. Moreover, results may differ between the tibialis anterior and upper body muscles because subjects did not see the needle when it was inserted. Using muscles where the needle would be visible to the subject such as the quadriceps femoris or biceps brachii may have an effect on the anticipation/perception of pain and should be further investigated.

**CONCLUSIONS**

This is the first study that we know of to centralize investigation of whether MVC can be obtained when a tungsten microelectrode is present, as well as addressing the issue of whether there are sex-related differences in using microelectrodes. Results from this study indicate that both men and women were able to produce a similar amount of force when a microelectrode was present compared with when it was absent from the muscle. However, this statement assumes that sufficient attempts at MVC are provided. When visual feedback is not provided, 2 attempts at MVC result in the greatest force production in both men and women, but voluntary activation scores and MVCs are likely to be greater when visual and verbal encouragement are used. The number of attempts at dorsiflexion MVC for men and women are similar irrespective of absolute differences in muscle strength, contractile properties, and use of invasive microelectrodes.

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**References**


Suppliers:
- a. Cambridge Electronic Design Ltd, Science Park, Milton Road, Cambridge, England CB4 0FE.
- b. FHC Inc, 1201 Main St, Bowdoin, ME 04287.
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