Assessment of the contraction speed of the dorsal and plantar flexor muscles of the foot in young women after inversion ankle sprain, against the background of the results of the control group

Filip Georgiew¹, Wiesław Chwał¹, Ewa Otfinowska¹, Łukasz Rydzik², Jakub Florek⁴

¹Department of Physiotherapy, University of Applied Sciences in Tarnów, Poland
²Institute of Biomedical Sciences, University of Physical Education, Kraków, Poland
³Institute of Sports Sciences, University of Physical Education, 31-571 Kraków, Poland
⁴Department of Orthopaedics and Traumatology, Rydygier Hospital Brzesko, Poland
*Correspondence: wieslaw.chwala@awf.krakow.pl

Abstract

Background: The complex structure of the ankle joint makes it particularly vulnerable to injuries, among which the most common is an inversion sprain of the ankle joint, posing a significant clinical problem. The aim of this study was to assess the impact of ankle sprain on the speed capabilities of the plantar flexor and dorsal flexor muscles of the feet in a group of women. Methods: The study involved 42 young women. The experimental group consisted of 21 women who had suffered an inversion sprain of the ankle joint, while the control group comprised 21 women without an injury to the ankle joint. Participants were assessed for the contraction speed of the plantar and dorsal flexor muscles of the foot, and the results were presented in the form of Maximum Gradient of Force Development (MGFD) values. Results: Statistically significant differences were observed in MGFD values for the dorsal flexors of the dominant limb in the control group compared with the corresponding index for the affected and unaffected limb in the experimental group (p<0.05). Conclusions: A significantly higher MGFD value was noted in the control group compared to the experimental group for the dorsal flexor muscles of the foot.

Key words: Ankle Sprain, Plantar Flexor Muscles, Dorsal Flexor Muscles, Maximum Gradient of Force Development (MGFD), Women’s Health

Introduction

The intricate structure of the ankle joint makes it particularly prone to injuries, the most common of which is an inversion sprain, presenting a significant clinical challenge (1–3). Many sprains lead to chronic complaints, impairing the ability to perform physical activities or work, thus reducing the quality of life (4). According to statistical data, 10% to 30% of all sports injuries are ankle joint injuries, and sprains of this joint constitute up to 70% of all injuries, with about 85% being inversion sprains of the ankle joint (5,6). During an inversion sprain of the ankle joint, the anterior talofibular ligament (ATFL) is most commonly damaged (accounting for 85% of all ankle ligament injuries) (7).

One significant factor that may influence both the frequency and severity of an ankle sprain is the reaction time of the peroneal muscles, which is related to the speed of recruitment of motor units in the ankle muscles (4,8). In biomechanical research related to sports and physiotherapy, muscle speed characteristics are used as a clinical indicator (9). The characteristics of these variables provide information about the dynamic capabilities of a muscle, related to the speed of recruitment of motor units, which determines the muscle’s contraction speed (9,10). The efficiency of this mechanism can effectively counteract the significant moments of force accompanying the mechanism of inversion sprain and protect the joint from injury. The lack of significant reports on this topic was the premise for empirically verifying this hypothesis.

The aim of the study was to assess the speed capabilities of the plantar flexor and dorsal flexor muscles of the feet in young women after an inversion sprain of the ankle joint in comparison with a control group.

Material and Methods

Participants

The study involved 42 young women. The experimental group consisted of 21 women who had experienced an inversion sprain of the ankle joint, while the control group comprised 21 women without an injury to the ankle joint.
without any injury to the ankle joint. Characteristics of individuals from both the experimental and control groups qualified for the study are presented in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Experimental Group n=21</th>
<th>Control Group n=21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age [years]</td>
<td>21.4±0.4</td>
<td>21.1±0.3</td>
</tr>
<tr>
<td>Body Mass [kg]</td>
<td>61.3±5.3</td>
<td>58.3±5.6</td>
</tr>
<tr>
<td>Body Height [m]</td>
<td>1.64±0.04</td>
<td>1.62±0.05</td>
</tr>
<tr>
<td>BMI [kg/m²]</td>
<td>21.86±1.9</td>
<td>21.93±2.1</td>
</tr>
</tbody>
</table>

The inclusion criteria for the experimental group were as follows: a history of an inversion sprain of the ankle joint in one lower limb, occurring no earlier than one year prior to the study, and individual consent from participants to measure the speed capabilities of the dorsal and plantar flexor muscles of the feet. The exclusion criterion was a history of other orthopedic injuries, congenital defects, or neurological disorders in the lower limbs that could affect the results of the planned measurements. Information regarding qualification and exclusion from the study was obtained based on a conducted survey.

Studies in the control group were conducted among women who met the qualification criteria: no history of injuries in the ankle joint area or other lower limb joints, no neurological disorders, orthopedic diseases, or congenital defects in the lower limbs that could affect the results of the planned measurements.

The study received approval number 21/2022 from the Thematic Team for the Ethics of Physiotherapy Research at the National Chamber of Physiotherapists. The initial procedure for examining qualified individuals in both groups included measuring body mass and height and declaring the dominant limb. Subsequently, tests were conducted to assess the speed capabilities of the dorsal and plantar flexors of the feet at a specially constructed measurement station.

**Measurement Method**

The measurement station consisted of an adjustable seat, stabilizing straps, and a ZPS4-U force measurement set on a stabilizing frame, appropriately connected and configured with a computer equipped with the MAX measurement program version v. 6.0 "JBA STANIAK." Before the study, each participant performed a 5-minute standard warm-up of the lower limbs, focusing on the muscle groups involved in the experiment. The women were informed about the purpose and course of the study and were also instructed about the possibility of withdrawing from the study. The participant took a seated position on the measurement station with a 90-degree angle between the torso and thigh, thigh and lower leg, and lower leg and foot. After proper setting and adjusting the seat height, the hip, knee, and ankle joints were stabilized with straps to prevent movement in the joints and eliminate the involvement of other muscles serving the remaining lower limb joints. A non-extendable, adjustable strap was placed on the forefoot. An electronic dynamometer was mounted between the foot and the frame of the measurement station on the strap. The dynamometer’s tendon was set perpendicular to the axis of rotation in the ankle joint. Each measurement was preceded by system calibration, involving the determination of the zero level of dynamometer tension, taking into account its own weight and mounting system.

The measurement was performed under static conditions, in isometric contraction of the plantar and dorsal flexors of the feet, after assuming the measuring position and stabilizing the foot from the heel bone side (Figure 1).

During the measurement of the speed capabilities of the dorsal and plantar flexors of the feet, the task for the study participants was to perform the dorsiflexion and plantarflexion movements as quickly as possible with each foot. Measurements were taken five times for the dorsal and plantar flexors of both feet (affected and unaffected in the experimental group and right and left in the control group) at a frequency of 1000 Hz, with short 2-second breaks to relax the muscles before each subsequent measurement. The measurements were brief and painless for the study participants.
Assessment of the contraction speed of the dorsal and plantar flexor muscles of the foot in young women after inversion ankle sprain, against the background of the results of the control group

participants. Since the feet were immobilized during the measurement, the result was a graph showing the rate of force development over time during isometric contraction, illustrating the speed of recruitment of motor units in the muscles while achieving maximum force (Figure 2). After the muscle was quickly tensed, it was immediately relaxed.

Subsequently, a graph of the derivative of force over time obtained during each contraction was generated, and the highest values were read. The average value of the force derivative from all five trials was selected for analysis. The results were presented in the form of the Maximum Gradient of Force Development (MGFD) according to equation (1).

\[ MGFD = \max \frac{dF}{dt} \tag{1} \]

where: MGFD – Maximum Gradient of Force Development, \( \max \frac{dF}{dt} \) - aximum value of the derivative of force over time.

Figure 2. Measurement Graph of Maximum Gradient of Force Development (MGFD)

**Statistical Analysis Methods**

The obtained study results were archived and then subjected to statistical analysis using Statistica software version 12. The normal distribution of the variables in the control and experimental groups was examined using the Shapiro-Wilk test. The Levene’s test was used to assess the equality of variances in the groups. For variables meeting the assumption of normal distribution of individual results in the groups and homogeneity of variances, a one-way analysis of variance (ANOVA) with post hoc Tukey’s test was used to determine the significance of differences between means (11).

**Results**

The presented study compared the MGFD values of the dorsal and plantar flexors of the foot in the experimental and control groups. The results of individuals who had experienced an inversion sprain of the ankle joint were analysed and compared with those of individuals without injuries in the lower limbs. The variables were characterized by a normal distribution of individual results and no differences in variances (Table 2, Figure 3).

Table 2. Descriptive Statistics for MGFD Values in the Experimental and Control Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>( \bar{x} \pm SD ) [Ns(^2)]</th>
<th>Max [Ns(^2)]</th>
<th>Min [Ns(^2)]</th>
<th>V [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>EX_MGFD_ZPS_Z</td>
<td>1 890±654</td>
<td>3508</td>
<td>792</td>
<td>35</td>
</tr>
<tr>
<td>EX_MGFD_ZPS_NZ</td>
<td>2 115±919</td>
<td>4212</td>
<td>961</td>
<td>43</td>
</tr>
<tr>
<td>EX_MGFD_ZGS_Z</td>
<td>1 947±669</td>
<td>2941</td>
<td>824</td>
<td>34</td>
</tr>
<tr>
<td>EX_MGFD_ZGS_NZ</td>
<td>1 937±834</td>
<td>4180</td>
<td>1007</td>
<td>43</td>
</tr>
<tr>
<td>CO_MGFD_ZPS_P</td>
<td>2439±1163</td>
<td>5972</td>
<td>1044</td>
<td>48</td>
</tr>
<tr>
<td>CO_MGFD_ZGS_L</td>
<td>2072±743</td>
<td>3516</td>
<td>1143</td>
<td>36</td>
</tr>
</tbody>
</table>
Discussion

According to Fuller, lateral ankle sprains are caused by an increased supination moment in the subtalar joint. This is due to the ground reaction force at the initial contact of the foot with the ground, as well as when the center of pressure on the sole of the foot shifts medially relative to the axis of the subtalar joint, resulting in a greater lever arm along the axis of the subtalar joint (12).

Wright et al. demonstrated that an increased plantar flexion angle at foot contact with the ground increases the risk of lateral sprains. Contact of the foot with the ground during rolling over the forefoot increases the lever arm between the axis of the ankle joint and the rotational torque of the joint (13).

Delayed reaction time of the peroneal muscles also contributes to lateral ankle sprains. According to research by Ashton-Miller et al., ankle sprain occurred within 40 milliseconds as the vertical ground reaction force peaked during landing from a jump (14). The peroneal muscles initiate the pronation movement, which counters the supination movement of the joint. In individuals without ankle injury, the reaction time of the peroneal muscles was about 50 ms. However, the evertor moment after reflex response was generated after 135 ms, and active eversion after 180 ms. It is suggested that the muscle reflex may not be fast enough to counteract the sudden supination movement of the foot (5). Therefore, rapid recruitment of the dorsal flexor muscles of the foot may, along with their strength capabilities (15), be an important factor in protecting the joint from injury (16).

In intragroup comparisons, the average maximum force development gradient (MGFD) values in the experimental group were higher for the plantar flexors of the unaffected limb, by about 12% compared to the affected limb. The speed of motor unit recruitment in the experimental group for dorsal flexors was practically at the same level for both the affected and unaffected limbs.

In the control group, symmetrical average MGFD values were noted comparing the contraction speed of plantar flexors of the right and left lower limbs, with differences not exceeding 3%. Within the dorsal flexors, MGFD level differences were clearly higher, reaching 18% between the right and left lower limbs. None of the noted differences in intragroup comparisons were statistically significant at the level of $p<0.05$.

In intergroup comparisons, the highest MGFD values were observed for the dorsal flexor muscles of the right lower limb in the control group. A significant difference ($p<0.001$) was noted between the maximum force development gradient for the dorsal flexors of the right dominant lower limb in the control group and the corresponding muscles of the affected and unaffected limbs in the experimental group. The difference between the average MGFD values was about 24%. The left lower limb in the control group achieved higher MGFD values for the dorsal flexors of the foot by only about 7%, and the noted differences were not statistically significant at $p<0.05$.

Comparing the contraction speed of plantar flexor muscles of the feet in the experimental and control groups, differences were noted within the range of 5-10%, but they were not significant at $p<0.05$. The highest MGFD value was recorded in the experimental group for the unaffected limb.

The significantly higher MGFD value of the dorsal flexors of the foot in the dominant limb of the control group compared to the affected and unaffected limbs in the experimental group by about 24% may indicate a predisposition of those in the experimental group to inversion sprain injuries. No similar differences were noted for this index in the plantar flexors. Therefore, measuring the contraction speed of the dorsal flexors may be an appropriate diagnostic pathway to assess the risk of inversion sprain injuries.
The literature lacks reports on studies concerning the maximum force development gradient of the ankle joint muscles. Studies on the speed capabilities of the plantar and dorsal flexor muscles are very limited. It seems necessary to create a normative database for this index, which may increase diagnostic effectiveness and indicate the risk of sprain. Such a database could be used in physiotherapy and sports biomechanics to assess the speed capabilities of human muscles and indicate directions for potential therapy. Measurement results can also help in selecting methods and means of physiotherapy and muscle training aimed at protecting the musculoskeletal system to avoid future similar injuries.

**Conclusions**

1. A significantly higher MGFD value was noted in the control group compared to the experimental group for the dorsal flexor muscles of the foot.
2. No significant differences in the MGFD index were noted in both groups for the plantar flexor muscles of the feet.
3. No significant differences were also noted in comparisons between antagonistic muscle groups in both studied groups.
4. Measurements of muscle contraction speed can be one of the effective elements in the diagnostics of the risks of inversion ankle sprains.


**Conflicts of Interest:** The authors declare no conflict of interest.

**Funding:** Scientific work financed by the University of Applied Sciences in Tarnow, contract no PWSZ/PRWR-s/0700-9/PN-U/2019: BAD-009/2019

**Institutional Review Board Statement:** The study received approval number 21/2022 from the Thematic Team for the Ethics of Physiotherapy Research at the National Chamber of Physiotherapists.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in this study.

**Data Availability Statement:** The data used in this study will be made available upon reasonable request by the author.

**References**