Comparison of Lower Limb Muscle Activation Patterns in Different Foot Structures using Voluntary Response Index: A Study Protocol

Hosein Kouhzad Mohammadi[1], Khosro Khademi Kalantari[*,2], Sedighe Sadat Naeimi[2], Alireza kbarzadeh Baghban[3], Navid Taheri[4] and Mohammad Pouretezad[1]

[1]*Department of Physical Therapy, Faculty of Rehabilitation Sciences, Ahwaz Jondishapour University of Medical Sciences, Ahwaz, Iran*

[2]*Department of Physical Therapy, Faculty of Rehabilitation Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran*

[3]*Department of Basic Sciences, Faculty of Rehabilitation Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran*

[4]*Department of Physical Therapy, School of Rehabilitation Sciences, Isfahan University of Medical Sciences, Isfahan, Iran*

Abstract: *Background*: Structural foot disorders can widely contribute to lower limb musculoskeletal conditions. Some researchers consider them the origin of overuse injuries in lower limbs. Although their effects on electrical activities of intrinsic and extrinsic foot muscles are well-established, their impact on other lower limb muscle groups are yet to be clarified.

Objectives: This study aims to identify the activation patterns of lower limb muscle groups in various foot structures.

Materials and Methods: In this case control study, 45 asymptomatic male and female subjects with different foot structures (pronated, supinated, and normal) will be selected using non-random sampling. The electrical activities of the gluteus medius, vastus lateralis and medialis, biceps femoris, semitendinosus, and lateral and medial gastrocnemius muscles will be examined during a jump-landing task. Voluntary response index, including magnitude and similarity index, will be subsequently calculated.

Discussion: While several studies have evaluated the activation of lower limb muscles in different foot structures, they have solely focused on foot muscles. In contrast, the present study will assess activation patterns of the global lower limb muscles using the voluntary response index.

Keywords: Voluntary Response Index, Foot, Pronation, Supination, Jumping.

1. BACKGROUND

Excessive supination and pronation are two major disorders resulting from alterations in medial longitudinal arch (MLA) [1]. Supinated foot is identified by increased MLA, midfoot hypomobility, and may not sufficiently adapt to the underlying surface. Consequently, maintaining its postural stability and balance will require increased demand on the surrounding musculoskeletal structures. Moreover, when compared to a normal or pronated foot, a supinated foot relays less plantar sensory information to the upper centers. A pronated foot, on the other hand, is characterized by flattened MLA and midfoot hypermobility. Apparently, stabilizing pronated feet and maintaining them in standing position pose additional demand on the neuromuscular system [1].

*Address correspondence to this author at the Department of Physical Therapy, Faculty of Rehabilitation Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran; Tel: +98-2177561407;
Fax: +98-2177561406; E-mail: khosro_khademi@yahoo.co.uk

Foot function has been proven to largely depend on its shape. Despite their similar anatomical characteristics, feet can have different shapes and biomechanics. A variety of factors including age, gender, race, shoe type, and age at which a person starts wearing shoes can affect MLA shape and form [2].

MLA, an important and vulnerable arch of the foot, plays a vital role in transferring forces through the foot. Since it possesses shock absorption properties and moderates forces transferred to the body [3], both its increase and decrease can predispose a person to injuries during physical activity [2].

The exact contribution of each MLA supporting component in preventing pronation has not been elucidated. However, the bony structure of MLA, especially the navicular bone, has been proposed as a primary stabilizer. The congruency of the MLA is supported by numerous ligaments such as the spring and deltoid ligaments, plantar fascia, and plantar

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aponeurosis. In addition, extrinsic muscles of the foot, e.g. tibialis posterior and anterior, peroneus longus, and peroneus tertius, act as a dynamic stabilizer for the MLA. Electromyographic studies on intrinsic muscles of the foot (including the abductor hallucis, flexor hallucis brevis, flexor digitorum brevis, abductor digiti minimi, and dorsal interossei) have shown the electrical activity of these muscles during walking. Dysfunction of any of these intrinsic MLA supporting muscles can predispose the person to excessive pronation and increase the risk of overuse syndrome [4].

In pronated foot postures, the abductor hallucis and flexor digitorum brevis muscles are highly active to compensate for ligamentous laxity and general hypermobility [5]. On the other hand, as compared with normal state, walking increases the activity of tibialis posterior and anterior muscles but decreases the activity of peroneus longus [6]; in other words, pronation increases the electrical activity of invertor muscles but decreases that of evertor muscles [7]. This difference in the activity of various muscle groups seems to be a neuromuscular adaptation to reduce the pressure exerted on the MLA [6]. Lower rearfoot and forefoot mobility in pronated feet, compared to normal feet, indicates stricter control over the dynamic system [7].

Excessive pronation has been found to cause internal tibial rotation and increases proneness to anterior cruciate ligament (ACL) injury. ACL injury is also believed to have significant relations with increased navicular drop (ND) and anterior pelvic tilt in both genders. In fact, the frequency of ACL rupture is 20 times greater in people with ND > 0.80 cm than in those with ND < 0.63 cm. Similarly, compared to ND < 0.63 cm, 0.63 cm < ND < 0.80 cm increases the risk of ACL rupture 16 fold. Thus, higher ND values are associated with greater risk of ACL rupture [8].

Frontal plane ankle motion is a significant component of the shock absorption mechanism which allows the foot to change from a strong lever into a soft segment with effective shock absorption capability. Kinematic asymmetry of the ankle joint transfers the shock absorption role to higher joints and makes them vulnerable [9]. Excessive pronation of the foot can increase internal tibial rotation which in turn amplifies the strain on the ACL during decelerating activities and ultimately augments the risk of ACL rupture [10].

Comparing leg asymmetry among different groups during challenging activities, such as a jump-landing task, is a method for investigating the theory of leg dominancy [11]. The majority of ACL injuries occur as a result of non-contact mechanisms [12], particularly while landing after jumping [13].

Lee *et al*. [14] have recently introduced the voluntary response index (VRI) as a new technique to evaluate muscles during a particular activity. Unlike the traditional examination of electrical activity of the muscles in which only two muscles are compared at any given time, the new method evaluates all muscles involved in a movement pattern and provides objective, quantitative information about the electrical activity of a number of muscles. The VRI comprises two components: magnitude, which indicates the outcome of overall electrical activity of all muscles in response to a given task, and similarity index (SI), which represents the similarity coefficient of electromyographic activity pattern of muscles when performing a task compared to a prototype pattern obtained from healthy individuals. The VRI technique has been considered in some studies of the shoulder joint [15, 16], cervical spine [17] and spinal cord injury [14, 18]. However, no research has been carried out on foot such as different foot structures.

2. OBJECTIVES

Foot structure is of critical importance in biomechanics and electrical activity of lower limb muscles. However, studies on structural foot disorders have mainly focused on the electrical activity of the muscles of the foot region rather than their utilization pattern based on the VRI. Hence, it is necessary to use the VRI to examine the effects of different foot structures on electrical activity of major lower limb muscles during a challenging task. This study aims to investigate the VRI for seven lower limb muscle activation in different foot structures during a jump-landing task.

3. MATERIALS AND METHODS

3.1. Participants

This case control study will compare individuals with different foot structures (pronated and supinated) with healthy people.

The inclusion criteria will be age 20-30 years and body mass index (BMI) between 22 and 25 kg/m^2. Individuals with professional athletic activities, history of orthopedic and neurological disorders in the past six months, and the use of any substances that affect postural control in the 48 hours prior to tests will be excluded from the study.

Different foot structures will be determined based on the MLA and RL angles. MLA angle will be considered as < 134, 134-150, and > 150 degrees in pronated, normal, and supinated feet, respectively. Moreover, rearfoot to leg (RL) angle will be considered as >9, 3-9, and <3 degrees in pronated, normal, and supinated feet, respectively.

The study protocol has been approved by Shahid Beheshti University of Medical Sciences Ethics Committee, and before the testing, all subjects will be informed of the purpose and the procedure of the study and will sign an informed consent form.

3.2. Sampling Method

A convenience sampling method will be used to select 20-30-year-old, male and female students from the School of Rehabilitation, Shahid Beheshti University of Medical Sciences (Tehran, Iran).

The equation $n = \lambda / \Delta$ was used to get the number of subjects, in which the λ with α = 0.05 and β = 0.2 (power = 0.8) was calculated to 9.64 [19]. Moreover, the Δ was estimated by using a pilot study (5 subjects in each group) and the equation below to 0.7. Finally, the number of subjects was estimated 45 (15 for each group).

$$\Delta = \frac{1}{\delta^2} \sum_{i=1}^{k} (\mu_i - \overline{\mu})^2$$

3.3. Data Collection

3.3.1. Pilot Study

To evaluate the intra-rater reliability of all dependent and independent variables in the methodological study, 10 subjects will be randomly selected regardless of their foot structure type. They will undergo all stages of the test in three sessions and each session includes three trials in a single day and with an hour interval. All the testing procedures will be conducted by an examiner. After assessing the reliability of the three repetitions at each session, the mean values obtained from these repetitions will be calculated and their reliability across the three sessions will also be evaluated. If the statistical tests confirm the reliability of the tests, the main study will be initiated.

3.3.2. Main Study

In the first stage of the main study, the participants' dominant leg will be identified after completing a leg dominance questionnaire [20]. Subsequently, in order to determine the subjects' foot structures, they will be asked to stand in a relaxed position with the distance between their ankle joint centers being equal to the distance between their anterior superior iliac spines. MLA angle measurement will require drawing two lines: one from the medial malleolus to the navicular tubercle and another from the navicular tubercle to the medial surface of the first metatarsal bone head. The obtuse angle formed by these two lines will be then measured using a goniometer. In normal, pronated, and supinated feet, the values will be 134-150, < 134, and > 150 degrees, respectively. The RL angle, on the other hand, will be the acute angle between the lines that bisect calcaneus and the distal third of the calf. RL angles in normal, pronated, and supinated feet will be 3-9, > 9, and < 3 degrees, respectively [21]. Following the measurements, if both methods confirm a particular foot structure, the participant will undergo the main test in two stages:

First, the electrode location will be shaved and cleansed with alcohol. Then, the electromyography (EMG) (Biometrics Data Log, Oxford Ltd, UK) electrodes will be applied parallel to muscle fibers with 2 cm distance in between. The electrodes will be applied over gluteus medius, vastus lateralis, vastus medialis, biceps femoris, semitendinosus, lateral gastrocnemius, and medial gastrocnemius muscles according to the SENIAM protocol [22], (band-pass: 20-500 Hz; sampling rate: 1000 Hz). The foot switch of the EMG system will also be fixed under the subject's heel to detect the ground contact.

Then, the subjects will be asked to jump forward bare foot [23] with both feet and land with dominant foot with maximum effort for three times. The longest jump will be considered as the subject's maximum forward jump and the average EMG_{RMS} of the studied muscles during the test will be taken as maximal voluntary contraction (MVC_{RMS}). Afterward, the participants will again asked to jump as far as 60% of their maximum jump distances (marked previously on the ground) for three times. These jumps will be regarded as the main tasks and the average EMG_{RMS} will be normalized with MVC_{RMS}. In this study, the subjects have to be able to maintain their balances (without opening the arms or touching the ground with their non-dominant foot) during landing. If the subjects be unable to keep balance, the test will be repeated.

In order for familiarization of the subjects, they will practice the jump twice prior to the main test. However, no technical hints about the landing will be provided to avoid the coaching effect [11]. Three repetitions of the jump-landing tests (for both MVC and main tasks) with three-minute intervals will be performed by each subject. Since most injuries tend to occur during the first 40 ms of the landing phase [24], in every test, electromyographic data of the studied muscles will be recorded for 100 ms from the instant of ground contact. The average RMS will be documented as the final value for each subject.

The pronated and supinated groups will be compared with the normal group in terms of the average RMS of each muscle. The RMS values will also be used as response vectors (RV) to calculate the VRI, i.e. both magnitude and SI [14]. The RV of the seven studied muscles in normal feet will be replaced in the following equation to calculate the muscles' magnitude, or prototype response vector (PRV). The RV of pronated and supinated feet will be similarly calculated in the same way and is compared with PRV [14].

$$R_{norm} = \frac{[R_1 R_2 R_3 R_4 R_5 R_6 R_7]}{\sqrt{\sum_i R_i^2}}$$

In the next step, the SI for each group will be calculated using the equation below and the obtained values will be compared [14].

$$SI = \frac{\sum_i (\mathrm{RV}_i \mathrm{PRV}_i)}{|\mathrm{RV}||\mathrm{PRV}|}$$

3.4. Data Analysis

Descriptive statistical methods, including dispersion and central tendency, will be adopted to describe the variables. Shapiro-Wilk test will be applied to check normal distribution of data. The magnitude and SI of the groups and the RMS of all studied muscles will be compared using one-way analysis of variance (ANOVA). Tukey test will be utilized for multiple comparisons of the groups. The reliability of the results will be assessed through intra-class correlation coefficient (ICC), standard error of measurement (SEM), and minimal detectable change (MDC). Type I error will be considered 0.05.

4. DISCUSSION

Structural foot disorders can widely contribute to lower limb musculoskeletal conditions. Some researchers consider them the origin of overuse injuries. Although numerous studies have assessed the patterns of muscular activity in these disorders, they have mainly focused on intrinsic and extrinsic functions of foot muscles and have neglected the functions of other lower limb muscles. Moreover, muscle activation patterns have not been evaluated based on the VRI. The present study will investigate the functions of seven major muscles in lower limb activities during a challenging jump-landing task. It will also examine the activation patterns of the mentioned muscles by calculating the VRI.

The results of this study can be beneficial in understanding lower limb joint injury mechanisms and implementing appropriate interventions to prevent such injuries, especially in the knee, among people with excessive pronation and supination. For instance, if the weakness of particular muscles is detected in a specific foot structure (as compared to normal feet), strengthening the identified muscles or implementation of relevant therapeutic interventions can restore the normal state of the muscles and thus prevent injuries.

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AUTHOR'S CONTRIBUTION

All authors contributed equally.

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