Original Article

The effects of intrinsic foot muscles strengthening exercises on foot kinetic parameters in pronated foot subjects during forward jump landing

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Abstract

Background: Pronated foot is one of the most important factors that may lead to musculoskeletal injuries of the lower extremities. Among all treatments for this disorder, intrinsic foot muscles strengthening exercises (IFMSE) have an important role in management of the individuals with pronated foot. Although the effect of the IFMSE is well accepted in this population; however, their impacts on foot kinetic are yet to be clarified. The present study aims to identify the effects of the IFMSE on foot kinetic parameters in pronated foot individuals during forward jump landing. **Materials and Methods:** In this quasi-experimental study, 20 asymptomatic male and female subjects (mean age of 22.65 ± 2.51 years) with pronated foot structures were selected by using a simple non-random sampling method. The ground reaction force (GRF), rate of loading (ROL), and the resultant vector of time to stabilization (RVTTS) were examined during a forward jump landing task by using a force plate before and after six weeks of the IFMSE. **Result:** The findings showed that the following parameters were not significantly change before and after of the IFMSE: GRF (1.97 ± 0.49 vs. 2.03 ± 0.54, *P* =0.667), ROL (.09 ±0.12 vs. 08 ±.12, *P* =.632), and RVTTS (2836.60 ± 1144.62 vs. 2644.35 ± 704.71, *P* =.479). **Conclusion:** In the pronated feet subjects, the IFMSE alone was not capable of changing the kinetic parameters of the foot, or the duration of using these exercises. In this study, six weeks may not be enough to make changes the foot kinetic parameters and therefore these exercises should be used for a longer period of time.

Keywords: Foot kinetic, foot pronation, forward jump landing

Introduction

There are several functional disorders in the foot area, some of which are due to changes in the position of the arch of the foot.[1] One of the most important arches of the sole of the foot is the Medial Longitudinal Arch (MLA), which has played an important role in absorbing the energy of the foot-ground while walking and transferring forces through the foot to the ground.[2] Exacerbated supination and pronation are two important disorders that occur as a result of changes in the amount of MLA, leading to increase of injury during physical activity. Intensified pronation of the foot is characterized by MLA smoothness and midfoot motility.[3]

The intrinsic muscles in the sole play a functional role in stabilizing the foot during balance on one foot. They also support MLA and maintain concavity during walking and similar

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activities. The effects of neuromuscular control on the intrinsic muscles of the sole are essential in order to stabilize the tarsal and metatarsal bones and to adjust the amount and speed of pronation of the foot. This subtle control, in addition to the static control of the MLA, is essential for its dynamic control from the heel strike stage to the toe off stage during the walking cycle. During the walking cycle, complex movements occur in the intertarsal, tarsometatarsal, and metatarsophalangeal joints, where the intrinsic muscles of the sole play an important role in regulating the forces transmitted to the joints and soft tissues in the lower extremities.[4-6]

It is important to pay attention to the anatomy and control of neuromuscular control, intrinsic muscles of the sole and its modulating role in foot function. It is very important to know its promotion strategies.[7] Findings showed that plantar exercises for intrinsic muscles could be capable of increasing the postural stability and self-confidence of people at risk of falling.[8] Lee *et al*.[9] found that intrinsic foot muscles strengthening exercise was significantly more effective over eight weeks than traditional sensory training in improving dynamic balance and ankle stability index in individuals suffered from with instability.

In another study, during a four-week program of intrinsic foot muscles strengthening exercises, a significant reduction in velocity changes and range of motion of the center of pressure was reported by the dynamic balance test, indicating an improvement in postural stability during dynamic activity.[10]

According to the above, the present study was conducted to investigate the effect of intrinsic foot muscles strengthening exercises on foot kinetic parameters in pronated foot subjects during forward jump landing.

Materials and Methods

This quasi-experimental study was performed on people with asymptomatic pronated foot aged 20 to 30 years. Sampling was done non-randomly and individuals with inclusion and exclusion criteria were included in the study. Inclusion criteria included: non-professional athletes, age between 20 and 30 years, BMI between 22 and 25 and foot pronation (MLA angle less than 134 degrees and RL angle more than 9 degrees). Exclusion criteria include: having a history of musculoskeletal injury in the lower extremities during the six months prior to the test, having any arthritic lesions in the lower extremities, having a history of nerve or balance lesions, using psychotropic drugs and alcohol within 48 hrs before the start of the test and the presence of scoliosis and deformity in the knee (varus, valgus, and geno-recurvatum).

Procedure

At first, all the steps of the research were explained to the participants. After confirming and signing the informed consent form and obtaining background information (age, sex, weight, height), the person entered the research process. Then, in order to evaluate the repeatability of the Intra-Tester for all independent and dependent variables, for all 10 subjects, all stages of the experiment were performed three times a day, one hour apart. It should be noted that in each turn, three experiments were performed and then the repeatability between three times in each session was calculated. In addition, the reproducibility of the calculated mean (between three replications) was calculated in three sessions. In the main study, the subject was identified after completing the demographic questionnaire and the dominant foot determination questionnaire.[11-13] For this purpose, the person stood comfortably on both feet so that the distance between the center of the ankle joint was equal to the distance between the two upper anterior iliac spines. In the Medial Longitudinal Arch Angle (MLA) method, one line was drawn from the medial ankle to the protrusion of the navicular bone and the other line was drawn from the navicular protrusion to the inner surface of the head of the first metatarsal bone, and the opening angle between them was measured with a goniometer, which is less than 134 degrees in individuals with intensified pronation. After these measurements, the person was tested if the type of foot structure was confirmed in both methods.

In the next step, the subject was asked to jump forward with his bare feet[14] three times at maximum capacity and land on the force plate while maintaining balance with the dominant foot (Do not open the arms to the sides, do not touch the recessed foot with the ground or do not move the foot with which it landed). If the balance of the person was disturbed during the landing, the experiment was repeated. The person was then asked to jump 60% of the length of their maximum jump (previously marked on the ground) as before, which was considered the main task.

At each jump, kinetic data were recorded by the Kistler force plate device (9286 BA, Kistler-Switzerland) at a frequency of 100 Hz. To get acquainted before the test, the person jumped twice. The jump-landing experiment was repeated three times[15] with a distance of 3 min from each other for each person.

In order to calculate the maximum vertical force of the earth's reaction in this study, first the maximum vertical force recorded by the force plate device (Fz) during landing (Newton) was extracted by examining Fz and then the exact values of the numbers were obtained with a table. Finally, we divided it by the weight of the person (Newton). The result is the maximum vertical force of the Earth's reaction to Newton. To calculate the loading rate, we first divided the maximum vertical force (Fz) (Newton) by the weight of the person (Newton) and divided the result by the time of reaching the maximum force (milliseconds).

$$Average\ loading\ rate = \left[\frac{\frac{peak\ F\ (N)}{body\ Weight\ (N)}}{time\ to\ peak\ F}\right]$$

To calculate the time to reach stability, first the time to reach stability in the anterior-posterior axes (Tx) and internal-external axis (Ty) was calculated. This time was then calculated by the corresponding equation. After calculating the time to reach

stability in each of the anterior-posterior and internal-external axes by the following equation, the time to reach stability after performing the jump-landing task was obtained.[16]

$$TTS = \sqrt{(Tx)^2 + (Ty)^2}$$

The intrinsic foot muscles strengthening exercises were performed according to the method provided by Jam and using some changes.[17]

Statistical analysis

Data were analyzed using SPSS version 23 (SPSS Inc., Chicago, IL) software. Descriptive statistical methods, including dispersion and measure of central tendency, were adopted to describe the variables. The normal distribution of data was assessed by a Shapiro-Wilk test. If the distribution was normal, the outcomes of the studied measurements were evaluated by comparing before-after data using a parametric test of paired t-test. A non-parametric test, the Wilcoxon signed-rank test, was used if the data were not normally distributed. The reliability of the results was assessed through intra-class correlation coefficient (ICC), standard error of measurement (SEM), and minimal detectable change (MDC). Type I error was considered at the 0.05 level.

Ethical considerations

The information of all patients remained confidential. In all stages of the research, all ethics declarations of Helsinki and ethics research committees of the University of Medical Sciences were considered. Code of Ethics: IR. AJUMS. 1396.1082.

Results

In this study, a total of 20 people were included in the study, the mean MLA was 124.5 ± 4.82 and the mean of RL was 11.1 ± 1.29 [Table 1].

The reproducibility of the research variables showed that the ICC coefficient of all variables is between 0.62 and 0.77 and therefore the reproducibility of the variables in this study was considered moderate to good.

Comparison of loading rate before and after intrinsic foot muscles strengthening exercises [Table 2] was examined by Wilcoxon test and the results showed that the loading rate before and after exercise was found to be 0.09 ± 0.12 and 0.08 ± 0.12, respectively (P = 0.632).

The vertical reaction force of the ground before and after training was 1.97 ± 0.49 and 2.03, 0.54, respectively. Examination of the variables before and after training of internal extensor muscles did not show a statistically significant difference (P = 0.667) [Figure 1].

According to Table 2, the comparison of the time to reach maximum stability before and after intrinsic foot muscles strengthening exercises in people with plantar fasciitis was evaluated by paired t-test. The results showed that the time to reach maximum stability before and after these exercises did not differ significantly (0.479) [Figure 1].

Table 1: Demographic findings

Variable	Domain	Minimum	Maximum	Mean
Age (Year)	8	20	28	22.65±2.51
Weight (Kg)	26	55	81	66.25±7.02
Height (Cm)	31	155	186	167±7.56
BMI	2.94	22.03	24.97	23.67±1.1
MLA angle	19	111	130	124.5±4.82
RL angle	5	10	15	11.1±1.29

Table 2: Comparison of loading rates before and after intrinsic foot muscles strengthening exercises

Variable	Text time	Mean	SD	*P*
Vertical force of ground reaction (20 people)	Before workouts	1.97	0.49	0.667
	After training	2.03	0.54	
Loading rate (20 people)	Before workouts	0.12	0.09	0.632
	After training	0.12	0.08	
Time to reach maximum stability	Before workouts	2836.6	1144.62	0.479
	After training	2644.35	704.71	

Discussion

In the present study, the effect of intrinsic foot muscles strengthening exercises on kinetic on foot kinetic parameters in pronated foot subjects during forward jump landing was investigated.

The findings of the present study showed that the vertical force of the ground reaction before and after these exercises were not significantly different. In a similar clinical trial study, it was shown that, as in the present study, strengthening exercises did not have a significant effect on improving intrinsic foot muscles strengthening exercises in people with pronation,[18] but Lee *et al.* investigated the effect of intrinsic foot and tibialis posterior muscles strengthening exercises on the distribution of plantar pressure in adults with flexible flat foot deformities. In this study, 16 young individuals with flat feet were randomly selected in two groups, one group performed strengthening exercises of the intrinsic muscles of the foot and the tibia, and the other group performed only strengthening exercises of the intrinsic muscles of the foot. Their findings demonstrated that strengthening the intrinsic muscles of the foot along with the strengthening the tibialis posterior will be more effective in improving the pressure distribution of the sole of the foot than strengthening the intrinsic muscles alone.[19]

In the present study, a comparison of the loading rate before and after the intrinsic foot muscles strengthening exercises in individuals with foot pronation showed that the loading rate before and after these exercises is not significantly different. In similar study in 2020, strengthening exercise on intrinsic foot

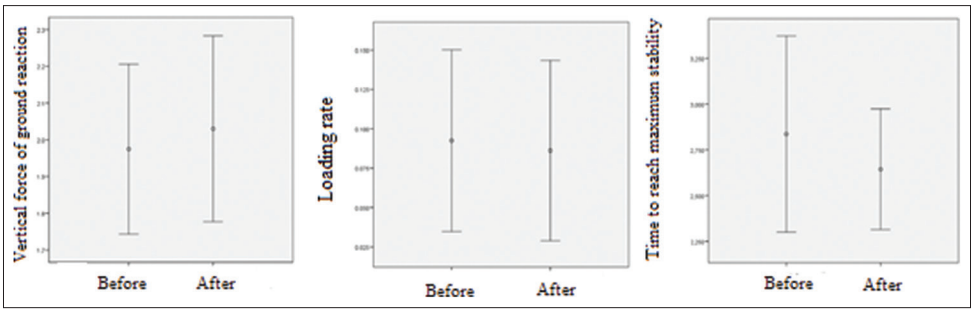

Figure 1: Comparison of vertical ground reaction force, loading rate, and time to reach maximum stability before and after intervention

muscles of the foot before and after exercise did not have a significant effect on the parameters, but in this study the kinetic parameters of the foot were not studied.[18]

Overall, no research was found to be in agreement with the present study regarding the effect of intrinsic foot muscles strengthening exercises on the loading rate. The study by Sulowaska *et al.* was in contrast to the present study in terms of loading rate. A study evaluated the effect of two types of intrinsic foot muscles strengthening exercises on foot position and basic movement patterns in long-distance runners. The researchers selected 35 long-distance runners and divided them into two groups. The first group was trained in Veles Forward Lean and Reverse Tandem Gait exercises and the second group was trained in SF exercises. Both groups performed the exercises for eight weeks and then were evaluated through FMS and FPI tests, which showed acceptable results in FPI of two groups and FMS of the first group. Finally, they stated that strengthening exercises for intrinsic foot muscles had a beneficial effect on functional movement patterns and foot posture.[20,21]

In this study, the results showed that the time to reach maximum stability before and after these exercises is not significantly different. In this regard, various studies have been conducted that the results of studies were not in line with the present study. Various studies have reported that muscle strengthening exercises have a positive effect on stability and balance. The results of the present study contradicted the findings of Moon[22] and Lynn *et al.*[10] In a study, Kim evaluated the effect of intrinsic foot muscles strengthening and supporting insole exercises on improving MLA in people with foot pronation, as well as dynamic balance of the foot and lower limbs. In this study, 14 patients with foot pronation were divided into two groups of intrinsic foot muscles strengthening exercises and support insoles. ND test was used to evaluate the amount of MLA, and Y balance test was used to evaluate the dynamic balance. The researchers concluded that strengthening exercises for the intrinsic foot muscles caused a greater change in ND than supportive insoles, and also showed that the effect of both methods on the dynamic balance of the foot was the same.[21]

The study by Moon *et al.*[22] examined the immediate effect of SF exercise on the dynamic balance of individuals with intensified pronation. In mentioned study, 18 individuals with intensified pronation participated. SF exercises included passive, active auxiliary, and active movements in sitting and standing positions, and the changes were assessed by ND test. The results of this study revealed that SF exercises significantly improved dynamic balance in these individuals.

Lynn *et al.*[10] reported that the intrinsic foot muscles of the sole of the foot have a great effect on the maintenance of MLA, and that the lack of proper performance of these exercises will increase foot pronation and subsequent pathological problems. Therefore, they investigated the effect of two types of SFE and TCE exercises on static balance, dynamics and MLA height index in healthy volunteer students without a history of lower limb injuries and balance disorders. The first experimental group performed SFE exercises and the other group performed TCE exercises for four weeks. Both participants were asked to repeat the exercises 100 times a day. Finally, it was stated that SFE exercises had far greater effects on static and dynamic balance as compared to the TCE exercise ratio.

In the present study, there was no significant difference in the maximum ground reaction force, loading rate and time to reach maximum stability during the jump-landing task before and after strengthening the intrinsic foot muscles, and this was probably due to this. In the present study, the exercises were performed based on the Jam article and the stated standards, and the subjects repeated the exercises for 8 min during the day, but in Lee[19] study, the exercises were performed for 30 min during the day, which is probably low. The duration of the exercises during the day has been one of the reasons for not achieving the desired results. In addition, in the present study, only strengthening exercises of the intrinsic muscles in the therapeutic interventions of people with foot pronation were examined. While in Lee's research, in addition to strengthening the intrinsic muscles of the sole of the foot, strengthening the extrinsic muscles has also been done, and perhaps another reason for not achieving the desired result is lack of other therapeutic interventions such as strengthening the extrinsic muscles of the sole of the foot, because the foot and ankle are a complex set of multiple joints with multiple degrees of freedom that play an important role in static and dynamic activity. The extrinsic and extrinsic muscles of this complex play the role of controlling the deformation of the arch. The stability of this arch as the central core of the foot is a prerequisite for

normal functioning in high-intensity activities such as walking, running, and jump landing.

Many new findings have shown the positive effect of intrinsic exercise on improving the function of the soleus muscles.[10,11,22,23] In the present study, the exercises were performed only on the intrinsic, and extrinsic muscles were not included in the exercises. Also, the subsystems involved in maintaining the stability of the arch were not manipulated. Even the extrinsic muscle exercise instructions emphasize relaxation and inactivation of the extrinsic muscles. Therefore, with this argument, we can answer the lack of significant differences after intrinsic muscles exercise on the kinetics of the lower extremities. It is possible that combination of intrinsic exercises with the extrinsic muscle exercises along with a proper delay period and the reduction of the arch of the foot, may be effectively capable of activating the subsystem of the stability of the foot core.

Therefore, non-observance of the unloading-reloading principle in performing exercises can be considered as a possible reason for lack of significance. Another reason for the insignificance of kinetic variables after intrinsic muscles exercise in individuals with reduced internal longitudinal arch is probably the principle of a specific adaptation to imposed demand (SAID).

The type of exercise applied was only to the intrinsic muscles of the foot and probably did not exert any force on the ankle. Therefore, according to this principle, the lack of significance effect of exercise on the kinetic changes of the foot can be accepted.[24]

In addition, previous researchers have not specifically studied kinetic parameters and only have examined the dynamic balance, fundamental movement patterns and the distribution of plantar pressure, and none of them specifically investigated the kinetic parameters. Another reason for not achieving the desired result is that all previous research has used static tasks, standing, walking, running and maximum drop landing to compare the effect of strengthening the intrinsic muscles in people with foot pronation, while the present study used the forward jump landing exercise, which probably prevented the desired result from being found, because a lot of pressure is applied to the sole of the foot during the forward jump landing. Maintaining balance during forward jump landing is much more difficult than drop landing and other tasks. Exercises may need to be done for longer periods of time during the day or for more weeks.

Conclusion

Intrinsic muscle strengthening exercises alone cannot affect the kinetic changes in individuals with foot pronation. Increasing the duration of strengthening exercises during the day may be effective in strengthening the intrinsic muscles in people with foot pronation. It is suggested that future studies be performed in a larger volume and longer expertise duration, and that the physical factors affecting the improvement of the muscles be examined before and after exercise.

Ethics approval and consent to participate

Patients, who participated in this research, signed the informed consent and had complete clinical data.

Consent for publication

All authors declare that they have consent for publication.

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Nil.

Conflicts of interest

There is no contradiction in the article.

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