Introduction

Pronation is the inward movement of the foot that occurs during foot landing while running or walking as it rolls to optimally distribute the force of body weight evenly on the foot.[1] The foot rotates approximately 15% of the hump joint in a normal foot and in a standard walk, in which the foot is completely in contact with the ground and is able to bear the entire weight of the body without any problems.[2] Normal pronation is essential for impact absorption and helps keep the foot off the ground evenly from the toes when walking.[3] The arch of the foot has a direct effect on the pronation, and this causes the pronation to deviate from its normal position. In other words, the arch of the foot may cause the foot to rotate inward too much or rotate less than the standard.[4] If the sole of the foot is normal, the pronation of the foot is also normal,

Abstract

Introduction: 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 activities. The intrinsic and extrinsic muscles of this complex play a role in controlling the deformity of the arch; thus, the aim of this study was to investigate the effect of the intrinsic foot muscle-strengthening exercises on knee kinematic parameters in pronated foot subjects during forward jump landing. Methods: This interventional study was performed on students aged 20-30-years old with foot pronation in the School of Rehabilitation. In this study, the kinematic changes of the knee in the frontal, sagittal and transverse plane before and after 6 weeks of strengthening exercises of the intrinsic foot muscles during the forward jump-landing task were examined using a motion analyser. All data analysis was performed offline using a special software program in the MATLAB software environment. Results: Knee angle variables have a normal distribution before and after exercise. The ICC coefficient of all variables was calculated as between 0.44 and 0.71; therefore, the reproducibility of the variables under study in this study was considered moderate to good. The knee angle on the frontal plate was 2.54 ± 2.4 before the exercises and 2.49 ± 2.14 after the exercises, and there was no significant difference between them (P = 0.21). Conclusion: Plantar intrinsic foot muscle-strengthening exercises alone have no effect on the kinematic changes of the knee in people with foot pronation, or the duration of strengthening exercises should be increased during the day to see the effect of strengthening the intrinsic muscles among pronated foot subjects.

Keywords: Intrinsic muscles, kinematic parameters, pronation, sole flatness

Introduction

Pronation is the inward movement of the foot that occurs during foot landing while running or walking as it rolls to optimally distribute the force of body weight evenly on the foot.[1] The foot rotates approximately 15% of the hump joint in a normal foot and in a standard walk, in which the foot is completely in contact with the ground and is able to bear the entire weight of the body without any problems.[2] Normal pronation is essential for impact absorption and helps keep the foot off the ground evenly from the toes when walking.[3] The arch of the foot has a direct effect on the pronation, and this causes the pronation to deviate from its normal position. In other words, the arch of the foot may cause the foot to rotate inward too much or rotate less than the standard.[4] If the sole of the foot is normal, the pronation of the foot is also normal,
indicating that the weight of the foot is evenly distributed on the foot when walking.\textsuperscript{[3]}

For people who have almost or completely flat soles, their feet have too much pronation. On the contrary, too much arch of the foot is associated with less-than-standard pronation or the foot generally rotates outwards.\textsuperscript{[6]} This syndrome causes disorders such as internal rotation and proximity of the femur and tibia, knee iliac and hyperextension, increased Q angle, hip anteverision, lateral pelvic tilt and anterior pelvic tilt, increased lumbar lordosis and compensatory kyphosis.\textsuperscript{[7]} Clinical observations have confirmed that people with excessive pronation syndrome are prone to special injuries such as plantar fasciitis, shin splint, patellofemoral dislocation problems, Achilles tendon inflammation, compression fractures of the lower extremities, anterior cruciate ligament (ACL) and medial collateral ligament (MCL) injuries, patellofemoral pain and ankle sprain.\textsuperscript{[8]} Also, pronation and flat foot insufficiency are risk factors for plantar fasciitis,\textsuperscript{[9]} therefore, people have more dysfunction and are prone to plantar fasciitis.\textsuperscript{[10]} There are conflicting findings regarding ACL injuries that require further investigation, but pronation and flat foot are risk factors for patellofemoral pain syndrome (PFPS), and people with this disorder are more prone to PFPS.\textsuperscript{[11]} Due to the development of the musculoskeletal system, strenuous exercise in young athletes leads to dysfunction in the body.\textsuperscript{[12]} For example, foot pronation syndrome in high-school runners is a risk factor for shin splints. A 5-mm drop in navigation is usually seen in marathon runners. The arched foot is associated with injuries outside the wrist, while the flat foot is associated with knee injuries and soft tissue on the inside of the foot.\textsuperscript{[13]}

The most common injuries seen in runners with flat feet are knee pain, patellar tendonitis, inflammation of the sole of the foot. The risk of knee injuries is higher in women soccer players with foot pronation.\textsuperscript{[14]} Therefore, the aim of the present study was to evaluate the effect of intrinsic foot muscle-strengthening exercises on knee kinematic parameters in pronated foot subjects during forward jump landing.

**Materials and Methods**

This interventional study was performed on students aged 20–30-years old with foot pronation in the Faculty of Rehabilitation, Jundishapur University of Medical Sciences, Ahvaz, Iran. Inclusion criteria were non-professional athletes, age between 20 and 30 years, BMI between 22 and 25 and foot pronation (MLA angle: <134°, RL angle: >9°). Exclusion criteria were having any history of musculoskeletal injury in the lower extremities during the 6 months prior to testing, any lesions of the joint inflammation in the lower extremities, any history of neurological or balance lesions, use of psychotropic drugs and alcohol within 48 h prior to the start of the test and scoliosis and deformity in the knee (varus, valgus and genu recurvatum).

**Sample size**

According to the sample volume estimation formula\textsuperscript{[15]} and pre-test study (pilot) on 10 people, the sample size was estimated to be 20 people in a one-way analysis of variance with the first type error of the test ($\alpha = 0.05$), the second type error ($\beta$ test = 0.2) and power of the test ($\text{power} = 0.8$).

$$n = \frac{(Z_{\alpha} + Z_{\beta})^2 \sigma^2}{\delta^2}$$

**Procedure**

First, all stages of the research were explained to the participants. After confirming and signing the informed company form and obtaining background information (age, sex, weight and height), the person entered the research process. Then, to evaluate the reproducibility of Intra-Tester for all independent and dependent variables (in the methodological study stage) for 10 subjects, all stages of the experiment were performed three times a day with an interval of 1 h from each other. In each turn, three experiments were performed; then, the reproducibility between three times in each session and the calculated average reproducibility (between three repetitions) in three sessions were calculated. Then, the individual characteristics and the dominant foot\textsuperscript{[16]} of the person were determined. For this purpose, the person stood comfortably on both feet so that the distance between the centre 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 inner ankle to the protrusion of the navicular bone and the other line from the navicular protrusion to the inner surface of the metatarsal bone and the opening angle between them was measured with a goniometer. To measure the MLA angle and RL angle, the inside and back of the foot were used for imaging. After specifying the lines mentioned, the angle was measured in imaging software. A motion analyser with seven cameras with a resolution of 1.3 megapixels and a sampling rate of 100 Hz was used (Qualisys, Sweden).

**Marking method**

Subjects were marked by an examiner. A double-sided adhesive was used to fix the markers at specific places on the skin. Markers were placed on the lower limb as follows: a marker on tubercle of the iliac crest (ASIS), a marker on the posterior iliac spine (PSIS), a marker on the femoral groove, a marker on the lateral epicondyle of the femur, a marker on the medial epicondyle of the femur, a marker on the lateral malleolus, a marker on the medial malleolus, a marker on the posterior surface of the calcaneus, a marker on the second metatarsus and a marker on the head of the fifth metatarsus. The subject was then asked to jump forward three times to their maximum ability with both feet barefoot while standing on two legs with the legs shoulder-width apart and then descend while maintaining balance with one foot (dominant foot). If the person’s balance was disturbed during landing, the test was repeated. The individual was then asked to set 60% of
the maximum length of his/her maximum jump,\(^{[13]}\) previously marked on the ground, which was considered the main task. After recording the tests, naming and initial verification of the data were performed in the Motion capture with Qualisys Track Manager (QTM) software. Then, the coordinates of the markers were extracted to determine the three-dimensional kinematics in MATLAB software. Filtering of the coordinates of the markers and calculation of the detailed angles in 3D was done in a program written in MATLAB software for this purpose. To reduce the effect of noise on the coordinates of the markers, a 20-Hz Butterworth low-pass filter was used, and the intrinsic foot muscle-strengthening exercises were performed according to the method provided by Jam via some modifications.\(^{[18]}\)

### Data analysis

Scattering and central inclination indices were used to describe the variables. Shapiro–Wilk test was used to check the normality of data distribution. One-way analysis of variance was used to compare kinematic parameters. Intraclass correlation, coefficient standard error of measurement and minimal detectable change were also used to evaluate the repeatability of variables. All data analysis was performed offline by a special software program written in the MATLAB software environment. The error of the first type of test in this study was considered 0.05.

### Results

In this study, a total of 20 subjects were enrolled, with a mean age of 22.65 ± 2.51 years, mean weight of 66.25 ± 7.02 kg, mean height of 167 ± 7.56 cm, mean BMI of 23.67 ± 1.1, mean MLA of 124.5 ± 4.82 and mean RL angle of 11.1 ± 1.29 [Table 1].

In Table 2, the normal distribution of knee angle variables in the frontal, sagittal and transverse planes before and after exercises was examined based on a single-sample Shapiro–Wilk test. As can be seen, the variables of knee angle before and after exercises have a normal distribution.

The reproducibility of the research variables was examined [Table 3]. As it is clear from the results of the table, the ICC coefficient of all variables was calculated as between 0.44 and 0.71; therefore, the reproducibility of the variables in this study was considered moderate to good.

Figure 1 shows the mean knee angle in the frontal plane before and after intrinsic foot muscle-strengthening exercises. The knee angle on the frontal plane was 2.54 ± 2.4 angle before exercise and 2.49 ± 2.14 after exercise, which was not statistically significant \( (P = 0.21) \).

Comparison of knee angle in the sagittal plane before and after intrinsic foot muscle-strengthening exercises is shown in Figure 2. The knee angle in the sagittal plane was 21.43 ± 4.4 before the exercises and 20.9 ± 4.95 after the exercises; no statistically significant difference was found.

### Discussion

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 activities. Stabilisation changes in this set are associated with changes in the amount of internal longitudinal

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### Table 1: Descriptive statistics of age, weight, height, BMI, MLA angle and RL angle

| Variable       | Number | Domain | Minimum | Maximum | Mean     |
|----------------|--------|--------|---------|---------|---------|
| Age            | 20     | 8      | 20      | 28      | 22.65±2.51 |
| Weight         | 20     | 26     | 55      | 81      | 66.25±7.02 |
| Height         | 20     | 155    | 81      | 186     | 167±7.56   |
| BMI            | 20     | 2.94   | 22.03   | 24.97   | 23.67±1.1  |
| MLA angle      | 20     | 111    | 130     | 124.5±4.82 |
| RL angle       | 20     | 10     | 15      | 11.1±1.29  |

### Table 2: Investigation of normal distribution of knee angle variables, in frontal, sagittal and transverse planes

| Test time | Knee angle on the frontal plane (degree) | Knee angle on the sagittal plane (degree) | Knee angle on the transformer plate (degree) |
|-----------|-----------------------------------------|------------------------------------------|--------------------------------------------|
| Before workouts | Number | 20 | 20 | 20 | The value of Z | 0.92 | 0.955 | 0.953 |
| Probability value | 0.1 | 0.443 | 0.416 |
| After training  | Number | 20 | 20 | 20 | The value of Z | 0.975 | 0.943 | 0.944 |
| Probability value | 0.867 | 0.273 | 0.289 |
Sadeghi, et al.: Intrinsic foot muscles strengthening exercises on knee kinematic in pronated foot

The intrinsic and extrinsic muscles of this complex play a role in controlling the deformity of the arch. Therefore, the aim of this study was to investigate the effect of intrinsic foot muscle-strengthening exercises on foot kinematic parameters in pronated foot subjects during forward jump landing.

In the present study, the mean knee angle in the frontal plane before and after exercises was 2.4 and 1.49, respectively (P = 0.209). The mean knee angle in the sagittal plane before and after exercise was 21.43 and 20.9, respectively (P = 0.616). The mean knee angle on the transversal plane before and after exercise was −3.74 and −4.25 (P = 0.714). No significant difference was found between maximal KFPPA, KSPPA and KTPPA after intrinsic foot muscle-strengthening exercises among pronated foot subjects during forward jump landing (P > 0.05). In this regard, no study was found to be in line with or contrary to the present study. Only Ford's study examined the angle of the knee on the frontal plate in athletes. To maintain stability in the central core of the foot, it is necessary to pay attention to all three subsystems involved in maintaining stability. It is also important to pay attention to the strength of the intrinsic and extrinsic muscles for the active subsystem. In the present study, the exercises were performed only on the intrinsic muscles. The extrinsic muscles were not included in the exercises, and the subsystems involved in maintaining the stability of the arch were not manipulated. Even the intrinsic muscle exercises instructions emphasise relaxation and inactivation of the extrinsic muscles. Therefore, it is possible to answer the lack of effect on the kinematics of adjacent joints, including the knee after the exercise period of intrinsic muscles.

It is possible that simultaneous training of the internal and external muscles, but with a proper delay period, in the treatment program of people with reduced arch of the foot can lead to proper functioning of the active subsystem of the foot core. Therefore, non-observance of the unloading-reloading principle in performing exercises can be considered as a possible reason for the lack of significant difference.

Another reason for the insignificance of the kinematic variables of the knee after the exercises of the intrinsic leg muscles is the principle of specific adaptation to the imposed demand (SAID). There was no force or movement on the knee or even the ankle and leg; thus, the lack of significant effect of exercise on the knee can be accepted.

In addition, forward jump landing is a challenging and ballistic task and puts a lot of force on the soles of the feet and knees, and the knees and ankles may be injured; thus, strengthening the intrinsic muscles of the soles of the feet may not be capable of changing the kinematics of the knee.

Another reason for the lack of significance of knee kinematic variables is the short duration of exercises for people with foot pronation. In addition to the above, because a change in one

| Variable                              | ICC     | SEM    | MDC    | 95% confidence interval for ICC |
|---------------------------------------|---------|--------|--------|--------------------------------|
| MLA angle (degree)                    | 0.711   | 1.114  | 3.089  | 0.18 0.961                     |
| RL angle (degree)                     | 0.688   | 0.636  | 1.765  | 0.144 0.957                    |
| Knee angle on the frontal plane (degree) | 0.662   | 0.454  | 1.259  | 0.108 0.953                    |
| Knee angle on sagittal plane (degree) | 0.561   | 1.249  | 3.464  | -0.014 0.934                  |
| Knee angle on the transversal plane (degree) | 0.441   | 1.367  | 3.791  | -0.125 0.907                  |

Figure 2: Average knee angle on the sagittal plane

Figure 3: Average knee angle on the transverse plate
segment causes a change in the other segments, pronation of the foot causes compensatory internal rotation in the hip joint, adduction in the femur, external rotation and abduction in the tibia and valgus angle increase in the knee, resulting in shortness of the tensor fasciae latae and weakness of the muscles with external rotation and abductor muscles of the hip joint. As a result, strengthening the intrinsic muscles alone may not alter the kinematics of the knee and less force may be applied to the knee joint.[22]

**Conclusion**

Intrinsic muscle strengthening exercises alone have no effect on the kinematic changes of the knee in people with foot pronation, or the duration of strengthening exercises should be increased during the day to see the effect of strengthening the intrinsic muscles among pronated foot subjects.

**Ethics**

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**Consent for publication**

All authors declare that they have consented for publication

**Competing interests**

The authors declare that they have no competing interests.

**Authors’ contributions**

All authors contributed to the design of the study, as well as data collection and analysis, and the writing of the manuscript. All authors read and approved the final manuscript.

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Nil.

**Conflicts of interest**

There are no conflicts of interest.

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