The Effect of TheraBand® Corrective Exercise on Co-contraction of Ankle Joint in Men with Genu Valgum during Walking: A Randomized Clinical Trial Study

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Original Article

Abstract

Introduction: Malalignments in the lower limb can affect the biomechanics of human movements such as walking. The ankle joint has a major role in shock absorption, however abnormalities such as genu valgum can disrupt its function. The objective in this study is to investigate the effect of corrective exercise with TheraBand® on the ankle joint co-contraction in patients with genu valgum during walking.

Materials and Methods: 24 male students (20-30 years old) were randomly divided into the two control and experimental groups. Corrective exercises were performed for 8 weeks using TheraBand® for the experimental group. The electrical activity of the selected muscles was recorded by the electromyography (ECG) device (Biometrics Ltd, UK). The statistical analysis was performed using the SPSS software and repeated measures analysis of variance (ANOVA) at the significant level of 0.050.

Results: Findings in the experimental group showed that the general co-contraction of ankle joint increased significantly in the heel contact phase during the post-test phase compared to the pre-test phase (P = 0.044; d = 0.12). Other components did not show any significant differences (P > 0.050).

Conclusion: Generally, increased co-contraction of ankle during the heel contact phase indicated greater ankle joint support after the corrective exercise.

Keywords: Corrective exercise, TheraBand®, Co-contraction, Ankle joint, Genu valgum

Introduction

Walking is one of the basic human needs and skills for movement achieved by children in the first year of life (1). Various factors affect this important activity and cause impaired posture and balance. Postural control is a very important factor in maintaining balance while standing, walking, working, and facing sudden disturbances in life, which is referred to as the ability to maintain balance and orient the body in the environment (2). Postural control is the basis of body movements and is necessary for most daily activities and is influenced by the visual, atrial, and somatosensory systems with the interaction of the central nervous system (CNS) (3).

The results of some studies show that the direction of the lower limb is one of the factors affecting postural control (4-7). In the normal standing position on both feet, the mechanical axis of the lower limb passes through the center of the knee joint (8). Abnormalities in the lower extremities can adversely affect the biomechanics of human movements such as walking, leading to symptoms of instability in the lower extremity joints (9). Since the feet connect the body to the ground, structural deviations, especially in the knee and ankle joints, increase the likelihood of injury to individuals and may prevent them from participating in activities (10). Individuals with genu valgum have a higher risk of developing the disease

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as well as a higher risk of osteoarthritis of the knee in the external compartment in comparison to the healthy people or patients with the genu varus complication (11). This complication reduces the knee adduction torque, knee adductive rotation, and knee flexion compared to the healthy group and patients who suffer from this complication in the inner part of their knees (12). In the genu valgum, the medial supporting ligaments of the knee are stretched, and the progression of these deformities and, consequently, the increase in force on these ligaments may lead to their inefficiency or rupture (13).

According to the results of some studies, lower limb deformities such as genu valgum can also affect the ankle joint and disrupt the main function of this joint, which is to absorb forces during the support phase (14). Any abnormal alignment in the lower limb affects the subtalar joint pronation in the support phase and even impairs the shock absorption mechanism in the plantar fascia (6). Therefore, it is very important to find a way to correct the cruciate ligament complication and prevent its possible risks in patients.

Different methods have been suggested for the treatment of the cruciate ligament complication, one of which being the use of corrective exercises (7). This type of exercise, using Kendall theory, leads to stretching of short muscles and strengthening of weakened muscles (7). TheraBand® is one of the most widely used and available training tools that is also used in corrective training programs (15). TheraBand® is a cheap, portable, and useful tool to increase muscle strength, and does not have the problems of using weights such as common injuries in this type of exercise, including stretching, muscle tears, and joint damage, especially in people with complications (16).

Positive outcomes have been reported for exercise interventions, including appropriate resistance exercises with TheraBand®, to improve strength and the ability to maintain lower limb balance, in addition to lowering overload on the internal parts of knees and preventing the progression of structural damage (15). Various methods have been proposed to evaluate the effectiveness of therapeutic techniques, such as examining the forces acting on the lower limbs or the kinematic study of these exercises. Additionally, it seems appropriate to examine co-contraction of muscles as a method. The proper pattern of muscle activity and simultaneous function of agonist and antagonist muscles around the joints is also of particular biomechanical importance. This is because the muscle cocontraction is one of the factors that play an important role in maintaining joint stability (17). Simultaneous activity of different muscles acting around a joint is called muscular cocontraction (18). In general, there are two types of co-contraction; general cocontraction and directional cocontraction, which examines the ratio of the activity of the agonist and antagonist muscle groups around the joints. Increasing co-contraction increases the loads on the joint (18). Therefore, increasing the amount of general cocontraction, especially in the ankle joint, is very important. Considering the possibility of recording the activity of the tibialis anterior and gastrocnemius muscles and the effective role of these two muscles in the stability of the ankle joint (17), these muscles were evaluated in the present study.

The present study is conducted with the aim to investigate the effect of a course of corrective training with TheraBand® on ankle joint cocontractions in patients with genu valgus while walking. It has been hypothesized that corrective exercise reduces the amount of general cocontraction.

Materials and Methods

This study was a randomized clinical trial conducted at the Health Center of the School of Educational Sciences and Psychology, University of Mohaghegh Ardabili, Ardabil, Iran. The statistical population of the study included people with genu valgus in Ardabil. All male students of University of Mohaghegh Ardabili were surveyed and monitored, and among them, 24 boys with genu valgus were randomly assigned to (putting names in a bag and selecting the members of each group without looking at the names) the two intervention and control groups each as 12 subjects (Figure 1).

A caliper (CA46150, Alton, China) was utilized to measure the increase in the knee valgus. For this purpose, the participants were asked to stand in an anatomical position. Then the distance between the two inner ankles of the feet was measured using the caliper. Then the subjects with genu valgus with an internal ankle distance of 2 to 5 cm (19) were included in the study. The study inclusion criteria included having genu valgus in both legs and no knee injury in the supporting ligaments. Moreover, a history of lower limb fractures, neuromuscular problems, a difference in limb length of more than 5 mm, and the absence of the genu valgus complication were considered as the exclusion criteria. The right leg was identified as the dominant leg of all subjects (16).

It should be noted that research ethics was observed in all stages of the project and consent was obtained from the participants in the study. All study steps were conducted in accordance with the Declaration of Helsinki (DOH) (20).
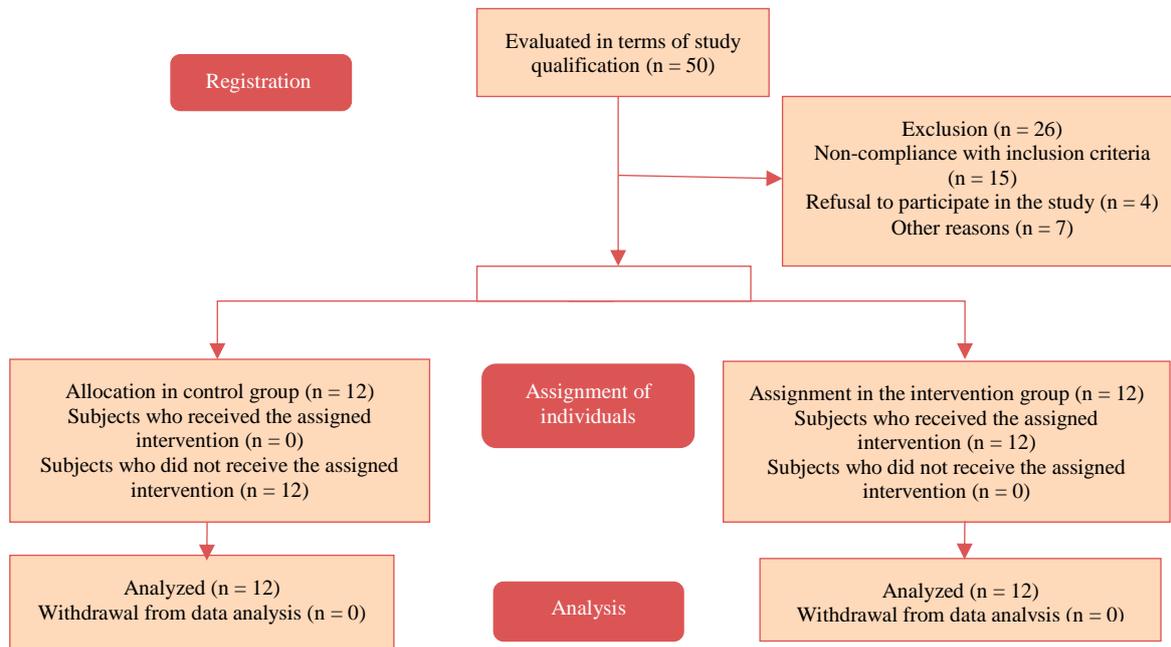
Figure 1. CONSORT chart

The present study obtained an ethics code number IR-ARUMS-REC-1397-091 from Ardabil University of Medical Sciences, Ardabil, Iran and the Iranian Registry of Clinical Trials (IRCT) code IRCT20181223042082N1.

The present study was performed in two stages: pre-test and post-test. The subjects performed the running attempt on the 10-m route of the laboratory after the electrodes were placed on their muscles. Each step was recorded with three correct attempts. An attempt was considered correct in which the electromyography (EMG) signal of all the muscles was recorded correctly. At the beginning of both stages of the test, the participants warmed up for 10 minutes with stretching and jumping movements and performed cooling down after the test.

The correctional exercises were performed for eight weeks and the subjects were engaged in stretching exercises on short muscles for the first two weeks (21). These exercises were performed in four 30-second periods. Then, the subjects performed strengthening the weakened muscles with TheraBand® for six weeks. The corrective exercises were applied to both legs three sessions a week every other day (Saturdays, Mondays, and Wednesdays), with each session lasting 30 to 40 minutes. During the correctional exercises performed by the intervention group, the subjects in the control group did not participate in any exercises and only performed the pre-test and post-test steps.

The electrical activity of tibialis anterior and gastrocnemius medialis muscles was examined using an 8-channel wireless EMG device (Biometrics Ltd, UK) and bipolar surface electrode model Ag/AgCl [circular shape with 11 mm in diameter; center to center distance of 25 mm, input impedance of 100 $M\Omega$, common mode rejection ratio (CMRR) less than 110 dB at 50 to 60 Hz]. 500Hz low-pass and 10Hz high-pass filters, as well as a 60Hz notch filter (to eliminate the utility noise) were used to filter raw EMG data (22). The sampling rate for muscle electrical activity was 1000 Hz. The location of the selected muscles and operations such as shaving the hair of the electrode placement site and cleaning it with alcohol (C_2H_5OH-Ethanol 70%, Kimia Alcohol Company, Iran) were performed according to the Surface EMG for Non-Invasive Assessment of Muscles (SENIAM) recommendation (23). The root mean square (RMS) calculation method was used to obtain the range of electrical activity of muscles. The peak of the muscle activity was recorded as the maximum voluntary isometric contraction (MVIC). For example, the MVIC of the gastrocnemius medialis muscle activity was recorded by asking the subject to stand on one foot (the right foot on which the electrode was placed) and to stand on his toes for 5 seconds. To record the peak activity of the tibialis anterior muscle, the subject placed his foot under a fixed plate and performed dorsiflexion (the heel was

fixed on the ground and the toe moved upward, and in the case of complete contraction without change, the isometric contraction angle was created) and the peak isometric activity of this muscle was recorded. In the next step, all EMG data were analyzed using Biometrics DataLITE (Biometrics Ltd, for Windows, UK) and MATLAB (Math Works® R2016a, for Windows, Natick, USA) software and the data obtained were recorded in Excel software (Microsoft Corp. Released 2016. Microsoft Office for Windows, Redmond, WA, USA). Equation 1 was employed to determine the values of both general and directed co-contraction at different stages of walking (24).

$$\text{Directed cocontraction} = 1 - \frac{\text{Mean activity of antagonist muscles}}{\text{Mean activity of agonist muscles}}$$

Relation 1

Shapiro-Wilk test was used to evaluate the normal data distribution and the possibility of using parametric tests. Data were analyzed using repeated measures analysis of variance (ANOVA) and Bonferroni post hoc test to compare data between the pretest and posttest stages of the two groups in SPSS software (version 21, IBM Corporation, Armonk, NY, USA). P < 0.05 was considered as the significant level. The effect size in the present study was calculated using Cohen's d equation as relation 2 (25).

$$D = (\text{mean1} - \text{mean2})/(\frac{[SD1+SD2]}{2})$$

Relation 2

Results

The demographic information of the participants in the intervention and control groups is presented in table 1.

Given the level of significance obtained, the hypothesis of heterogeneity of variances was rejected and the differences between the groups were not significant.

The mean general and directed ankle joint cocontractions in the intervention and control groups during the pre-test and post-test gait stages are displayed in table 2. Accordingly, the effect of time factor on the general ankle cocontraction in the heel off phase during the post-test had a significant increase compared to the pre-test (P ≤ 0.017). The

effect of group factor on the general cocontraction in the mid stance phase (P ≤ 0.037) and heel off phase (P = 0.046) showed a significant increase in comparison of the two groups.

Additionally, a significant difference was observed in the interaction between time and the general cocontraction group in the heel contact phase (P ≤ 0.024). The results of post hoc test revealed that the general cocontraction during the heel contact phase in the training group had a significant increase of 5.85% during the post-test compared to the pre-test (P ≤ 0.024, d = 0.12). Other components showed no significant difference between the two groups during the post-test compared to the pre-test (P > 0.050).

Discussion

The aim of the present study was to investigate the effects of a correction training course with TheraBand® on ankle joint cocontraction in subjects with genu valgus while walking. The findings in the exercise group showed that the general cocontraction of the ankle joint in the heel contact phase during the pre-test was significantly increased compared to the post-test. The other components did not show any significant differences.

Abnormal knee valgus when walking, especially during the foot-to-ground contact when performing various activities, is associated with some common knee injuries such as supportive ligament injuries such as the anterior cruciate ligament (ACL) (26). Some studies have reported a direct relationship between thigh muscle activity and knee valgus. Thus, the increase in thigh muscle activity led to an increase in knee valgus (27). Moreover, in various studies, the relationship between quadriceps muscle activity (28) or knee muscle activity ratio (29), for instance, the ratio of vastus medialis to vastus lateralis activity and genu valgum has been investigated and the results showed an inverse relationship; so that the decreased activity or contraction ratio led to an increase in knee valgus in movements such as squats. The results of a study by Zeller et al. indicated an increase in rectus femoris activity with an increase in valgus in squat movement (30), which is contrary to other studies (26-28).

Table 1. Demographic information of subjects

Characteristics	Control (n = 12)	Intervention (n = 12)	P value (Levene's test)
Age (year)	23.14 ± 2.96	21.71 ± 2.28	0.343
Height (m)	1.82 ± 0.06	1.76 ± 0.06	0.717
Weight (kg)	80.15 ± 1.50	83.35 ± 1.10	0.388
BMI (kg/m2)	26.30 ± 1.68	26.14 ± 3.33	0.205

BMI: Body mass index
Data are reported as mean ± standard deviation (SD).

Table 2. Mean general and directed ankle cocontraction in both exercise and control groups during pre-test and post-test gait stages

Hase	Co-contraction	Intervention group		Percent change	Control group		Percent change	P		
		Pre-test	Post-test		Pre-test	Post-test		Effect of time factor	Effect of group factor	Effect of group-time interaction
Heel contact	General (MVIC percentage)	33.46 ± 10.00	35.43 ± 22.30	5.85	28.88 ± 10.55	28.99 ± 11.22	0.38	0.664	0.764	0.024[*]
	Dorsiflexor/plantar flexor (ratio)	0.42 ± 0.21	0.37 ± 0.23	11.90	0.40 ± 0.24	0.41 ± 0.20	2.50	0.621	0.763	0.526
Mid stance	General (MVIC Percentage)	32.09 ± 14.08	44.20 ± 17.65	37.73	45.86 ± 28.75	47.97 ± 21.21	4.60	0.090	0.037[*]	0.229
	Dorsiflexor/plantar flexor (ratio)	0.28 ± 0.21	0.37 ± 0.24	32.14	0.27 ± 0.22	0.33 ± 0.24	22.22	0.125	0.491	0.723
Heel off	General (MVIC Percentage)	63.54 ± 25.57	98.21 ± 55.16	54.56	95.65 ± 41.20	99.69 ± 41.06	4.22	0.017[*]	0.046[*]	0.060
	Dorsiflexor/plantar flexor (ratio)	0.19 ± 0.21	0.20 ± 0.24	5.26	0.16 ± 0.14	0.18 ± 0.16	12.50	0.713	0.514	0.844
Oscillation	General (MVIC Percentage)	23.12 ± 8.65	29.25 ± 17.95	26.51	25.47 ± 9.34	29.56 ± 26.67	16.05	0.123	0.704	0.756
	Dorsiflexor/plantar flexor (ratio)	0.45 ± 0.24	0.44 ± 0.32	2.22	0.49 ± 0.20	0.49 ± 0.30	0	0.905	0.413	0.842

[*]Significance at the level of $P < 0.050$
Data are reported as mean ± standard deviation (SD).
MVIC: Maximum voluntary isometric contraction

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The results of the present study suggested an increase in general ankle joint cocontraction in the heel contact phase. The compressive force of the muscles around the ankle joint in the heel contact phase can be more than three times the body weight and up to five times the body weight respectively during walking and in the phase of toe separation from the ground (31). A study reported that the increased simultaneous activity of the agonist and antagonist muscles is controlled by a central interaction mechanism. The increased cocontraction has been introduced as a supportive mechanism in some studies and as a dangerous mechanism in some others. Maintaining the joint balance, providing resistance to the joint rotational movements, and balancing the pressures imposed on the joint surfaces are among the advantages of the increased cocontraction. Cocontraction during dynamic activities such as walking has been defined as an attempt to stabilize the joint and decrease the shear and rotational forces both of which are harmful to the health of the joint cartilage (34). The results of a study suggested that people with genu valgum complication need more activity of the gastrocnemius medialis muscle to maintain their posture compared to healthy individuals; Because compared to the healthy people, in order to control the dynamic posture of the lower extremities, these people need more to control the position of the subtalar and midtarsal joints on the frontal plane (35). Furthermore, in some other studies, it has been clamined that the external hamstring weakness causes internal rotation of the thigh and tibia as well as the occurrence or exacerbation of the genu valgus deformity (36). The increase in the general cocontraction in the ankle joint during the heel contact phase may be a mechanism of protection of this joint against shear forces, which has increased during the increase of the knee valgus.

In a study aimed at investigating the effect of corrective exercises on the components of ground reaction force (GRF) as well as the kinematic characteristics of the older adults with genu valgus during landing movement, Jafarnezhadgero et al. examined 26 elderly men with genu valgus and performed the selected corrective exercises for 14 weeks and achieved significant results. Given their findings, the selected corrective exercises improved the kinematic characteristics of the patients with genu valgus, in addition to improving the GRF components. This improvement led to a reduction in the secondary injuries and the prevention of risks associated with increased valgus angle in the elderly

(4). The increase in the general ankle cocontraction can also prevent secondary injuries due to increased knee valgus. Therefore, it can be concluded that the results of the study by Jafarnezhadgero et al. (4) were in agreement with the findings of the present study. However, no other studies were found in this area. The mechanism of reduction of possible injuries takes place as a result of increasing the general ankle cocontraction and can play an important role in increasing the stability of this joint during daily activities including running and walking (17).

Limitations
One of the most important limitations of the present study was the lack of recording of GRF and also the absence of females in the study.

Recommendations
It is suggested that corrective training interventions using TheraBand®, in addition to individuals with genu valgus, be applied to subjects with the genu valgum complication at the same time and the results be compared. Additionally, it is better to examine females with genu valgum complication and investigate the kinematic variables among them.

Conclusion
According to the results, which showed an increase in the general cocontraction of the ankle joint during the heel contact phase, it can be concluded that corrective exercises have been able to enhance muscle support in this joint during heel contact. In this phase, the ankle joint withstands a high volume of forces and increasing the support of this joint in this phase can increase joint stability and balance in patients with genu valgus.

Authors' Contribution
Farshad Ghorbanlou, AmirAli Jafarnezhadgero, Milad Alipoursarinasirloo, and Amir Letafatkar contributed to the designing, implementing, and analyzing the results, compiling the study, and reading and confirming the final version of the article.

Conflict of Interest

The authors declare that they had no conflict of interest in writing or publishing this article.

References

1. Butler EE, Steele KM, Torburn L, Gamble JG, Rose J. Clinical motion analyses over eight consecutive years in a child with crouch gait: A case report. J Med Case Rep 2016; 10(1): 157.
2. Punakallio A. Balance abilities of workers in physically demanding jobs with special reference to firefighters of different ages [Thesis]. Kuopio, Finland: University of Eastern Finland; 2004.
3. Sundaram B, Doshi M, Pandian J. Postural stability during seven different standing tasks in persons with chronic low back pain - a cross-sectional study. Indian J Physiother Occup Ther 2012; 6(2): 22-7.
4. Jafarnezhadgero A, Madadi-Shad M, McCrum C, Karamanidis K. Effects of corrective training on drop landing ground reaction force characteristics and lower limb kinematics in older adults with genu valgus: A randomized controlled trial. J Aging Phys Act 2019; 27(1): 9-17.
5. Cote KP, Brunet ME, Gansneder BM, Shultz SJ. Effects of pronated and supinated foot postures on static and dynamic postural stability. J Athl Train 2005; 40(1): 41-6.
6. Hunt GC. Examination of lower extremity dysfunction. In: J. Gould J, G. J. Davies GJ, editors. Orthopaedic and Sports Physical Therapy. St. Louis, MO: Mosby; 1990. p. 408–43.
7. Mohammadi V, Letafatkar A, Sadeghi H, Jafarnezhadgero A, Hilfiker R. The effect of motor control training on kinetics variables of patients with non-specific low back pain and movement control impairment: Prospective observational study. J Bodyw Mov Ther 2017; 21(4): 1009-16.
8. Johnson F, Leitl S, Waugh W. The distribution of load across the knee. A comparison of static and dynamic measurements. J Bone Joint Surg Br 1980; 62(3): 346-9.
9. Van Gheluwe B, Kirby KA, Hagman F. Effects of simulated genu valgum and genu varum on ground reaction forces and subtalar joint function during gait. J Am Podiatr Med Assoc 2005; 95(6): 531-41.
10. Dorsey S. Williams, Irene S.McClay, Joseph H, Thomas S.Buchanan. Lower extremity kinematic and kinetic differences in runners with high and low arches. J Appl Biomech 2001; 17(2): 153-63.
11. Felson DT, Niu J, Gross KD, Englund M, Sharma L, Cooke TD, et al. Valgus malalignment is a risk factor for lateral knee osteoarthritis incidence and progression: Findings from the Multicenter Osteoarthritis Study and the Osteoarthritis Initiative. Arthritis Rheum 2013; 65(2): 355-62.
12. Leitch KM, Birmingham TB, Dunning CE, Giffin JR. Changes in valgus and varus alignment neutralize aberrant frontal plane knee moments in patients with unicompartmental knee osteoarthritis. J Biomech 2013; 46(7): 1408-12.
13. Namavarian N, Rezasoltani A, Rekabizadeh M. A study on the function of the knee muscles in genu varum and genu valgum. J Mod Rehabil 2014; 8(3): 1-9. [In Persian].
14. Farahpour N, Jafarnezhad A, Damavandi M, Bakhtiari A, Allard P. Gait ground reaction force characteristics of low back pain patients with pronated foot and able-bodied individuals with and without foot pronation. J Biomech 2016; 49(9): 1705-10.
15. Mikesky AE, Topp R, Wigglesworth JK, Harsha DM, Edwards JE. Efficacy of a home-based training program for older adults using elastic tubing. Eur J Appl Physiol Occup Physiol 1994; 69(4): 316-20.
16. McMaster D, Cronin J, McGuigan M. Forms of variable resistance training. Strength Cond J 2009; 31(1): 50-64.
17. Hubley-Kozey C, Deluzio K, Dunbar M. Muscle co-activation patterns during walking in those with severe knee osteoarthritis. Clin Biomech (Bristol, Avon) 2008; 23(1): 71-80.
18. Lloyd DG, Buchanan TS. Strategies of muscular support of varus and valgus isometric loads at the human knee. J Biomech 2001; 34(10): 1257-67.
19. Rabiei M, Jafarnejhad Gre T, Binabaji H, Hosseininejad E, Anbarian M. Assessment of postural response after sudden perturbation in subjects with genu valgum. J Shahrekord Univ Med Sci 2012; 14(2): 90-100. [In Persian].
20. World Medical Association. World Medical Association Declaration of Helsinki. Ethical principles for medical research involving human subjects. 2004 [Online]. Available from: URL: www.wma.net › what-we-do › medical-ethics › declaration-of-helsinki
21. Becker J. Effectiveness of the StreetStrider as an exercise modality for healthy adults [MSc Thesis]. Madison, WI: University of Wisconsin; 2011.
22. Farahpour N, Jafarnezhadgero A, Allard P, Majlesi M. Muscle activity and kinetics of lower limbs during walking in pronated feet individuals with and without low back pain. J Electromyogr Kinesiol 2018; 39: 35-41.
23. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol 2000; 10(5): 361-74.
24. Heiden TL, Lloyd DG, Ackland TR. Knee joint kinematics, kinetics and muscle co-contraction in knee osteoarthritis patient gait. Clin Biomech (Bristol, Avon) 2009; 24(10): 833-41.
25. Cohen, J. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale, NJ: Lawrence; 1988.

26. Hunt MA, Birmingham TB, Giffin JR, Jenkyn TR. Associations among knee adduction moment, frontal plane ground reaction force, and lever arm during walking in patients with knee osteoarthritis. J Biomech 2006; 39(12): 2213-20.

27. Nguyen AD, Shultz SJ, Schmitz RJ, Luecht RM, Perrin DH. A preliminary multifactorial approach describing the relationships among lower extremity alignment, hip muscle activation, and lower extremity joint excursion. J Athl Train 2011; 46(3): 246-56.

28. Macrum E, Bell DR, Boling M, Lewek M, Padua D. Effect of limiting ankle-dorsiflexion range of motion on lower extremity kinematics and muscle-activation patterns during a squat. J Sport Rehabil 2012; 21(2): 144-50.

29. Markolf KL, Burchfield DM, Shapiro MM, Shepard MF, Finerman GA, Slauterbeck JL. Combined knee loading states that generate high anterior cruciate ligament forces. J Orthop Res 1995; 13(6): 930-5.

30. Zeller BL, McCrory JL, Kibler WB, Uhl TL. Differences in kinematics and electromyographic activity between men and women during the single-legged squat. Am J Sports Med 2003; 31(3): 449-56.

31. Czerniecki JM. Foot and ankle biomechanics in walking and running. A review. Am J Phys Med Rehabil 1988; 67(6): 246-52.

32. De Luca CJ, Erim Z. Common drive in motor units of a synergistic muscle pair. J Neurophysiol 2002; 87(4): 2200-4.

33. Gardinier E. The relationship between muscular co-contraction and dynamic knee stiffness in ACL-deficient non-copers [BSc Thesis]. Newark, DE: University of Delaware; 2009.

34. Setton LA, Mow VC, Howell DS. Mechanical behavior of articular cartilage in shear is altered by transection of the anterior cruciate ligament. J Orthop Res 1995; 13(4): 473-82.

35. Nyland J, Smith S, Beickman K, Armsey T, Caborn DN. Frontal plane knee angle affects dynamic postural control strategy during unilateral stance. Med Sci Sports Exerc 2002; 34(7): 1150-7.

36. Kinakin K. Optimal muscle training: Biomechanics of lifting for maximum growth and strength with DVD. Champaign, IL: Human Kinetics; 2009. p. 49.