

EFFECTS OF FOOT MUSCLE EXERCISE ON HARD AND ELASTIC SURFACES IN PERSONS WITH LOW-ARCHED FEET

Orrachon Sukprasert, Thidamas Jongrak, Jadsada Seelaprom, Nongnuch Taesawat, Asama Komolkul, Sompiya Somthavil* and Onuma Boonyarom

Received: February 22, 2021; Revised: May 25, 2021; Accepted: June 16, 2021

Abstract

This study examines the effects that functional intrinsic foot muscle exercises for six weeks can have on the hard and elastic surfaces of the arch of the foot in persons with low-arched feet. The 33 participants were all student volunteers aged between 18 and 23 years old. The arch of the foot was measured with the longitudinal arch angle and the functional foot stability was measured using the Balance Error Scoring System. The participants were divided into three groups of 11: control group, exercise on hard surfaces group and exercise on elastic surfaces group. The results showed significant differences ($p < 0.05$) in the arch of both feet between the control and the exercise groups. However, there was no significant difference ($p > 0.05$) in the arch of both feet between the exercise groups. The stability of both feet was not significantly different ($p > 0.05$) between any groups.

Keywords: Elastic surface, Foot muscle exercise, Hard surface, Low-arched feet

Introduction

The feet are structures of the body that play an important role in life. They support the entire weight of the human body when it is vertical while both stationary and moving. The feet consist of bones and muscles comprising the arch of the foot, which allows the feet to support many times the weight of the body and helps to stabilize it. Thus, the intrinsic foot muscles are very important in maintaining the shape and arch of the foot (Hrysomallis, 2007). According to a study by Kelly *et al.* (2014), the muscles in the soles of the foot contribute to the stability of the body during push-off when walking;

therefore, these muscles should be exercised to increase or maintain their strength and flexibility. There are many forms of exercise for intrinsic foot muscles, including the short-foot exercise, which is a method that helps stimulate the muscles in the soles of the feet along the arch. Kim and Kim (2016) found that the short-foot exercise was more effective at improving flatfoot conditions than applying arch support insoles. The authors also found that the capacity to control foot posture and longitudinal arch stiffness (Kelly *et al.*, 2014) and performing corrective exercises can improve

Department of Rehabilitation and Movement Sciences, Faculty of Sports Science, Kasetsart University, Nakhon Pathom, 73140, Thailand. Tel. 08-1596-2234; Fax. 0-3435-5258; E-mail: sompiya.s@ku.th

* Corresponding author

navicular height, which means increasing the arch of the foot (Kolooli, 2014); however, the short-foot exercise emphasizes the contraction of the muscles in the sole of the foot. There are many types of training for flatfoot conditions (Jung *et al.*, 2011; Fourchet and McKeon, 2015; Sivachandiran and Kumar, 2016), such as neuromuscular training in the soles of the feet using electrical stimulation, which helps to reduce the collapsing of the arch while in motion, and foot core control training along with other movements, which affects the strength and ability of the muscles in the soles of the feet and helps to prevent the collapsing of the medial arch while moving (Fourchet and McKeon, 2015). Moreover, integrating foot core control skills training during moving activities is a practice the intrinsic foot muscles require, as they use a variety of physical activities to affect the ability to control the feet. Fritz and Peikenkamp (2003) indicated that carrying out a weight-bearing activity on a flexible surface can help reduce the pressure between the foot and the floor, Mientjes and Shorten (2003) found that changing the curvature of the feet affects the impact between the feet and the floor. Aragao *et al.* (2011) found that using a trampoline for exercise can improve foot function in athletes with instability of the ankle and improve balance control in the elderly. The literature reviewed did not explore exercising on different surfaces to study the effects of foot arches and functional foot stability in people with low-arch feet. The purpose of this study was to study the effects of functional intrinsic foot muscle exercises on hard and elastic surfaces on the foot arches of persons with low-arch feet. It was expected that the effects of exercising on hard and elastic surfaces can increase the foot's arch and improve functional foot stability, which helps to prevent or reduce foot posture problems and foot instability in the future.

Materials and Methods

Participants

The participants were 33 Kasetsart University students from Kamphaeng Saen Campus, aged 18-23 due to the prevalence of flatfoot in Thai students during that age is more than 50% (Tantaopas *et al.*, 2018). The sample size was determined based on a previous study (Namsawang *et al.*, 2019). The inclusion criteria were 1) Flexible, flat feet determined by testing the collapse of the medial longitudinal arch (Atik and Ozyurek, 2014) and using the Hubscher maneuver (Jack test) (Lee *et al.*, 2005; Pandey *et al.*, 2013; Atik and Ozyurek, 2014); 2) No current history of illness affecting vision, balance, or movement ability; 3) No problems with

pain, injuries, or foot surgery within the last 6 months; and 4) Ability to follow the researchers's instructions or explanations. Participants also signed a consent form for participating in the research and could request to withdraw from participation in the study at any time

Flexible Flat Foot Screening

The Collapse of the Medial Longitudinal Arch Testing

Atik and Ozyurek (2014) is conducted by having the participant stand up straight, look straight forward, and bear weight on the feet while the examiner observes the medial longitudinal arch collapsing. Then, the participant is asked to raise up on their tiptoes (tiptoe test); the arch forms again when weight-bearing forces on the feet are relieved. If this arch can be observed, it is considered to be a flexible flatfoot condition.

The Hubscher Maneuver (Jack Test)

Lee *et al.* (2005); Pandey *et al.* (2013); Atik and Ozyurek (2014) is conducted by having the participant stand up straight, look straight forward, and bear weight on both feet. The examiner uses their fingers to push the participant's big toe to a fully extended position and observes the medial arch of the foot. If the medial longitudinal arch is raised, it is considered to be a flexible flatfoot condition, as shown in Figure 1(a) and Figure 1(b).

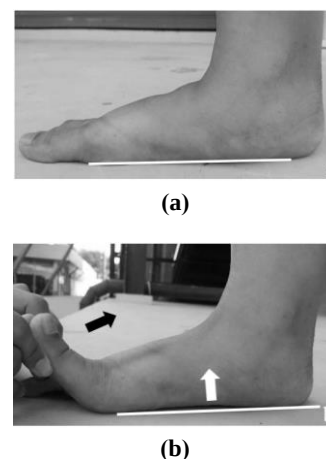


Figure 1. The Hubscher maneuver method of flexible flatfoot screening.

The Foot Arch and Functional Foot Stability Measurement

Before starting the exercise program, participants were divided into 3 groups with the Longitudinal Arch Angle (LAA) and the counting Balance Error data criteria: the control group, the

hard-surface-exercise group, and the elastic-surface-exercise group. The testing methods were as follows.

Foot Arch Measurement using the Longitudinal Arch Angle (LAA) Method.

McPoil and Cornwall (2005); Nilsson *et al.* (2012). The participant stands up with the test foot limb weigh on step and looks straight forward. The examiner marks 3 points at the center of the medial malleolus, navicular tuberosity, and head of the first metatarsal (Figure 2a) using a skin marker (Edding 8020, Germany), draws a line between the navicular tuberosity and the 1st metatarsal head, and draws another line between the navicular tuberosity and the center of the medial malleolus. The examiner uses a goniometer (Mahidol University, Thailand) to measure the angle: the axis is on the navicular tuberosity, the stationary arm is on the navicular tuberosity and the 1st metatarsal head line, and the moving arm is on the navicular tuberosity and the center of the medial malleolus line (Figure 2b). Measurements are taken 3 times on the same foot, data is recorded in degree units, and then the other foot is measured

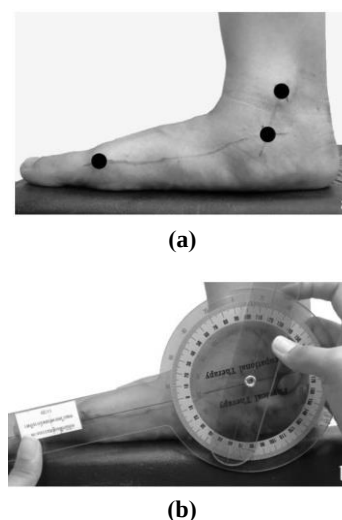


Figure 2. Longitudinal arch angle (LAA).

(balance errors) was counted and recorded. The BE criteria were lifting the hands off the hips, opening the eyes, hip abduction of more than 30°, hip flexion of more than 30°, lifting of the forefoot or heel of the weight-bearing foot, remaining out of the proper testing position for more than 5 seconds, and placing the non-weight-bearing foot on the ground (Djun and Tan, 2015). If the participant made a mistake according to the BE criteria for any items, it was counted as one BE, and if multiple mistakes (more than 1 of the BE criteria) were made at the same time, only one BE was counted. The average was calculated by taking measurements 3 times. If the BEs were less than 2, foot stability was

Functional Foot Stability Measurement using the Counting Balance Error (BE) Method.

In order Djun and Tan (2015) to ascertain the functional stability of the feet, the participants were asked to stand on the test foot and bend the other knee to approximately 90° with their eyes closed and their hands on their iliac crests for 20 seconds, timed using a stopwatch (Casio, HS-70W, China). The test was performed 3 times per foot. The number of BEs

Table 1. Functional intrinsic foot muscle exercise program.

Week	Exercises			
	Warm up and cool down Static stretch: hamstrings, quadriceps, gastrocnemius, intrinsic muscles of foot (30 sec/each) 3 min Dynamic stretch: forward & backward bends (30 sec/each), clench & unclench (30 sec/each), high knees (15 sec/side) 2 min Aerobic: high knee 1 min Rest time: 30 sec/set, 1 min/exercise			
1	Toes lifting and short foot 10 reps/set, 3 sets	Heel raise with both leg standing (Figure 3a) 10 reps, hold 15 sec/rep	Toe raise with both leg standing (Figure 3b) 5 reps, hold 15 sec/rep	Lightly jump with both legs 10 reps/set, 3 sets
2	Heel raise with both leg standing 10 reps, hold 30 sec/rep	Toe raise with both leg standing 5 reps, hold 30 sec/rep	One leg standing (Eyes opened) 5 reps/side, hold 15 sec/rep	One leg standing (Eyes closed) 5 reps/side, hold 15 sec/rep
3	One leg standing (Eyes closed) 5 reps/side, hold 30 sec/rep	Heel raise with one leg standing 10 reps/side, hold 15 sec/rep	Switch leg 5 reps/side, 3 sets	Heel raise and toe raise with both leg standing 10 reps/set, 3 sets
4	Lightly jump with both legs 15 reps/set, 3 sets	Switch leg 10 reps/side, 3 sets	Heel raise and toe raise with one leg standing 10 reps/side, 3 sets	Squat 10 reps/set, 3 sets
5	Squat 15 reps/set, 3 sets	Backward lunge 10 reps/side, 3 sets	Move opening and closing legs 10 reps/set, 3 sets	Heel raise and toe raise with both leg standing 15 reps/side, 3 sets
6	Move opening and closing legs 15 reps/set, 3 sets	Backward lunge 15 reps/side, 3 sets	Switch leg 15 reps/side, 3 sets	Heel raise and toe raise with one leg standing 15 reps/set, 3 sets

Modified from Diracoglu *et al.*, 2005; Sivachandiran and Kumar, 2016; Kanchanasamut and Praneet, 2017.

demonstrated; however, if the BEs were more than 3, there was no stability of that foot.

The participants were divided into 3 groups of 11 participants per group. The first group was the control group; participants in this group lived normal daily lives, but avoided activities or exercises that pose a risk of injury. The second group exercised on a hard surface, and the third group exercised on an elastic surface, which was a trampoline (Contrix, Germany). The second and third groups participated in a functional intrinsic foot muscle exercise program (Table 1), which was performed in 3 sessions per week for a period of 6 weeks, with its intensity increasing weekly. After the participants practiced for 6 weeks, they were tested for foot arches (LAA measurement) and functional foot stability (counting BEs); the data were further analyzed for statistical results.

In this research, the examiner of the LAA measurement tested for the intratester reliability using intraclass correlation coefficient (ICC) statistics, and found that the reliability of the examiner's repeat measurement was high (ICC=0.998).

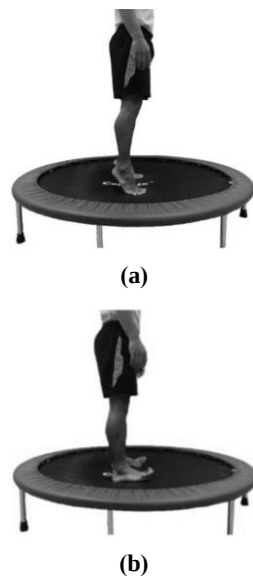


Figure 3. Example of functional intrinsic foot muscle exercise.

Statistical Analysis

Descriptive statistical analysis was used to describe participants' characteristics as mean and standard deviations (mean±SD). One-way analysis of variance (ANOVA) was used to test the differences in foot arches and functional foot stability between the groups at baseline and at 6 weeks post-intervention; the Scheffe method was used for comparison after ANOVA testing. Statistical significance was set at $p<0.05$ for all statistical analysis tests.

Results and Discussion

For all 33 participants from the 3 groups, the mean and standard deviation (mean±SD) of age was 18.94 ± 1.25 years, weight was 67.72 ± 11.61 kg, height was 1.69 ± 0.10 m, and body mass index (BMI) was 23.77 ± 3.44 kg/m². For each group, means and standard deviations of the participants' characteristics are shown in Table 2.

At baseline, the means and standard deviations of the LAAs of the left and right feet of the control group were $120.24\pm4.25^\circ$ and $122.85\pm4.99^\circ$, respectively; the hard-surface-exercise group's were $119.51\pm5.50^\circ$ and $122.52\pm4.30^\circ$, respectively; and the elastic-surface-exercise group's were $120.18\pm4.64^\circ$ and $122.15\pm4.03^\circ$, respectively. The comparison of the foot arch differences between the control group, the hard-surface-exercise group, and the elastic-surface-exercise group showed that there was no significant difference between the arches of the left and right feet at the baseline at the $p<0.05$ significance level, as shown in Table 3. In terms of the functional stability of the feet measured by counting the number of BEs for the left and right feet, the means and standard deviations of the control group were found to be 2.67 ± 1.59 errors and 3.06 ± 1.64 errors, respectively; the hard-surface-exercise group's were 3.12 ± 1.43 errors and 2.63 ± 1.34 errors, respectively; and the elastic-surface-exercise group's were 2.90 ± 2.11 errors and 2.69 ± 1.87 errors, respectively. Comparing the functional foot stability between the three groups revealed that there was no significant difference in

Table 2. Characteristics of the participants for each group.

Variables	CG	HSG	ESG	<i>p</i>
	mean±SD	mean±SD	mean±SD	
Age (years)	19.82±1.47	18.45±0.69	18.55±1.04	0.012*
Height (m)	1.70±0.12	1.72±0.10	1.65±0.07	0.231
Weight (kg)	71.36±13.87	69.91±8.64	61.89±10.35	0.118
BMI (kg/m ²)	24.80±4.07	23.75±3.36	22.75±2.79	0.392

CG=control group; HSG=hard-surface-exercise group; ESG=elastic-surface-exercise group; BMI=body mass index; * Statistically significant at $p<0.05$.

functional foot stability before the exercise program at the $p<0.05$ significance level, as shown in Table 3.

At 6 weeks, the means and standard deviations of the LAAs of the left and right feet in the control group were $120.48\pm4.56^\circ$ and $121.54\pm4.39^\circ$, respectively; the hard-surface-exercise group's were $126.02\pm4.22^\circ$ and $129.18\pm3.45^\circ$, respectively; and the elastic-surface-exercise group's were $127.06\pm3.62^\circ$ and $128.81\pm3.69^\circ$, respectively. Comparing the foot arch differences between the three groups revealed that after attending the 6-week exercise program, there was at least a significant difference between the $p<0.05$ significance levels, as shown in Table 4. The LAAs at baseline and 6 weeks were $119.51\pm5.50^\circ$ and $126.02\pm4.22^\circ$ of the left foot and $122.52\pm4.30^\circ$ and $129.18\pm3.45^\circ$ of the right foot in the hard-surface-exercise group, and the elastic-surface-exercise group, the LAAs at baseline and 6 weeks were $120.18\pm4.64^\circ$ and $127.06\pm3.62^\circ$ of the left foot and $122.15\pm4.03^\circ$ and $128.81\pm3.69^\circ$ of the right foot. In terms of the functional stability of the feet measured by counting the numbers of

BEs for the left and right feet, the means and standard deviation of the control group were found to be 2.51 ± 1.13 errors and 2.06 ± 1.26 errors, respectively; the hard-surface-exercise group's were 2.09 ± 1.25 errors and 1.66 ± 1.00 errors, respectively; and the elastic-surface-exercise group's were 1.60 ± 1.15 errors and 1.81 ± 1.79 errors, respectively. Comparing the functional foot stability between the three groups revealed that there was no significant difference in functional foot stability at 6 weeks after the exercise program at the $p<0.05$ significance level, as shown in Table 4.

A post-hoc test used in ANOVA, Scheffe's method, indicated that in terms of the foot arch determined by measuring the LAAs of the left and right feet, comparing the control group and the hard-surface-exercise group, and comparing the control group and the elastic-surface-exercise group, there were significant differences at the $p<0.05$ significance level. Both of the exercise groups had more value than the control group. However, the foot arches of the exercise groups were not

Table 3. The means and standard deviations of the longitudinal arch angles and the balance errors are shown at baseline.

Variables	CG (N=11)	HSG (N=11)	ESG (N=11)	p
	mean $\pm$ SD	mean $\pm$ SD	mean $\pm$ SD	
LAA left side ($^\circ$)	120.24 $\pm$ 4.25	119.51 $\pm$ 5.50	120.18 $\pm$ 4.64	0.927
LAA right side ($^\circ$)	122.85 $\pm$ 4.99	122.52 $\pm$ 4.30	122.15 $\pm$ 4.03	0.935
BEs left side (errors)	2.67 $\pm$ 1.59	3.12 $\pm$ 1.43	2.90 $\pm$ 2.11	0.849
BEs right side (errors)	3.06 $\pm$ 1.64	2.63 $\pm$ 1.34	2.69 $\pm$ 1.87	0.805

LAA=longitudinal arch angle; BEs=balance errors; CG=control group; HSG=hard-surface-exercise group; ESG=elastic-surface-exercise group.

Table 4. The means and standard deviations of the longitudinal arch angles and the balance errors are shown at 6 weeks.

Variables	CG (N=11)	HSG (N=11)	ESG (N=11)	p
	mean $\pm$ SD	mean $\pm$ SD	mean $\pm$ SD	
LAA left side ($^\circ$)	120.48 $\pm$ 4.56	126.02 $\pm$ 4.22	127.06 $\pm$ 3.62	0.002*
LAA right side ($^\circ$)	121.54 $\pm$ 4.39	129.18 $\pm$ 3.45	128.81 $\pm$ 3.69	0.000*
BEs left side (errors)	2.51 $\pm$ 1.13	2.09 $\pm$ 1.25	1.60 $\pm$ 1.15	0.214
BEs right side (errors)	2.06 $\pm$ 1.26	1.66 $\pm$ 1.00	1.81 $\pm$ 1.79	0.803

LAA=longitudinal arch angle; BEs=balance errors; CG=control group; HSG=hard-surface-exercise group; ESG=elastic-surface-exercise group; * Statistically significant at $p<0.05$.

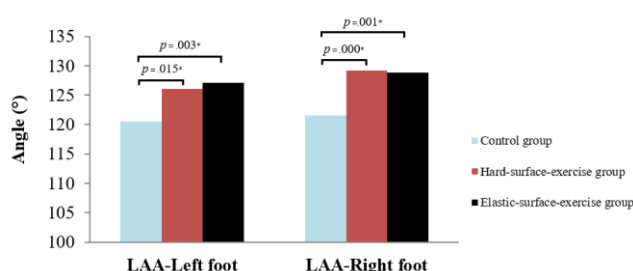


Figure 4. Post-hoc test (Scheffe's method) of the arch of the left and the right feet at a 6 week exercise program.

significantly different at the $p < 0.05$ significance level, as shown in Figure 4.

The purpose of this study was to study the effects of functional intrinsic foot muscle exercises on hard and elastic surfaces on the foot arches of persons with low-arch feet. The results of the study show that a 6-week exercise program was found to improve flatfoot conditions through changes in the LAA. In this study, the functional intrinsic foot muscle exercise program consisted of both targeting the intrinsic foot muscles and integrating lower limb functional exercises, such as squats, lunges, and light jumping. This combination engages the other joints of the lower extremities which primarily control the foot's position. Exercise of the hip joint with assistance from the knee and hip joints is emphasized frequently by unwelcome responses in these joints to abnormal stresses in the foot (Elftman, 1969) and due to the effect of flat feet reportedly leading to decreased muscle activity in the abductor hallucis, medial gastrocnemius, tibialis anterior, and vastus medialis (Jung *et al.*, 2011; Kodithuwakku Arachchige *et al.*, 2019). It is also the case that flatfoot conditions cause the leg and foot muscles to be more fatigable and can cause cramps and pain due to overuse (Gray and Basmajian, 1968); for this reason, functional intrinsic foot muscle exercises affect the changes in the foot arches. Moreover, Welte *et al.* (2018) reported novel evidence for an interplay between the windlass and arch-spring mechanisms that aid in the regulation of energy storage within the foot. Windlass functions also modify the shape of the foot, in accordance with Okamura *et al.*, 2019, who found that the windlass mechanism occurs during the tiptoe or heel-raising motions. While on tiptoe, tension will occur at the plantar fascia to pull the heel bone, therefore causing the arch to be lifted up. Increasing the intensity of this form of exercise can be used as another way to help develop a foot structure that can result in higher arches, as demonstrated in the research of Sulowska *et al.* (2016); Zhao *et al.* (2016). In this study, the hard-surface-exercise group and the elastic-surface-exercise group had more mean angles than the control group after the 6-week exercise program; for the hard-surface-exercise group, the LAAs of the left and right feet were $126.02 \pm 4.22^\circ$ and $129.18 \pm 3.45^\circ$, respectively, and for the elastic-surface-exercise group, the LAAs of the left and right feet were $127.06 \pm 3.62^\circ$ and $128.81 \pm 3.69^\circ$, respectively. This was an increase to almost within maximal normal values, which were in the range of $131\text{--}152^\circ$ (Nilsson *et al.*, 2012), but still not in the normal range maybe from short time.

This study shows that exercise on different surfaces does not affect the changes in the foot arch

in different ways; therefore, in terms of application, both forms of exercise can be used. Exercising on an elastic surface can be an alternative way to exercise the intrinsic foot muscles and foot muscles for people with musculoskeletal problems, as the surface is not rigid, which can help reduce the pressure between the foot and the floor (Fritz and Peikenkamp, 2003; Tessutti *et al.*, 2012).

In assessing the functional stability of the foot by counting the number of BEs of the left and right feet between the three groups, significant differences were not found at the significance level of $p < 0.05$, as shown in Table 4. It was found that the average functional stability of the feet after the 6-week exercise program decreased as the number of errors decreased, which shows that the functional stability of both feet tended to increase, especially in the exercise groups, but not with significant differences between those groups. This is due to the effect of changing the center of pressure within the feet by shifting medially because the longitudinal arch height is reduced in flat feet (Han *et al.*, 2011), affects the body's center of mass (Gefen, 2001), and causes a decrease in proprioception and activity of muscle spindles and tendon sensory mechanisms in flat-arch conditions (Tahmasebi *et al.*, 2015). Moreover, only a 6-week-long exercise program was evaluated in this study; hence, future studies related to functional foot stability measurements are recommended to use an exercise program longer than 6 weeks.

Conclusions

From the results of testing functional intrinsic foot muscle exercises on hard and elastic surfaces on foot arches of persons with low-arch feet, it was found that the foot arches of participants exercising on both hard and elastic surfaces for 6 weeks increased significantly when compared with the non-exercising control group. This shows that the functional intrinsic foot muscle exercises resulted in increasing the foot arches of people with low-arch feet. Therefore, it is an optional form of exercise for people with low-arch feet who want to increase their arches to help prevent or reduce problems that may arise from having flat feet.

Acknowledgment

The authors would like to thank the Faculty of Sports Science for providing the equipment and place for use within this study.

References

- Aragao, F. A., Karamanidis, K., Vaz, M. A., and Arampatzis, A. (2011). Mini-trampoline exercise related to mechanisms of dynamic stability improves the ability to regain balance in elderly. *J. Electromyogr. Kinesiol.*, 21(3):512-518.
- Atik, A. and Ozyurek, S. (2014). Flexible flatfoot. *North. Clin. Istanbul.*, 1(1):57-64.
- Diracoglu, D., Aydin, R., Baskent, A., and Celik, A. (2005). Effects of kinesthesia and balance exercises in knee osteoarthritis. *J. Clin. Rheumatol.*, 11(6):303-310.
- Djun, M. H. T. and Tan, J. C. C. (2015). The effect of taping on foot structure, functional foot stability and running gait patterns of the foot. *J. Sports. Sci.*, 3:11-21.
- Elftman, H. (1969). Dynamic structure of the human foot. *Artif. Limbs.*, 13(1):49-58.
- Fourchet, F. and McKeon, P. (2015). Foot core strengthening: an update about the intrinsic foot muscles recruitment. *Br. J. Sports. Med.*, 49(S1):A6.
- Fritz, M. and Peikenkamp, K. (2003). Simulation of the influence of sports surfaces on vertical ground reaction forces during landing. *Med. Biol. Eng. Comput.*, 41(1):11-17.
- Gefen, A. (2001). Simulations of foot stability during gait characteristic of ankle dorsiflexor weakness in the elderly. *IEEE. Trans. Neural. Syst. Rehabil. Eng.*, 9(4):333-337.
- Gray, E. G. and Basmajian, J. V. (1968). Electromyography and cinematography of leg and foot ("normal" and flat) during walking. *Anat. Rec.*, 161(1):1-15.
- Han, J., Koo, H., Jung, J., Kim, Y., and Lee, J. (2011). Differences in plantar foot pressure and cop between flat and normal feet during walking. *J. Phys. Ther. Sci.*, 23(4):683-685.
- Hrysomallis, C. (2007). Relationship between balance ability, training and sports injury risk. *Sports. Med.*, 37(6):547-556.
- Jung, D. Y., Kim, M. H., Koh, E. K., Kwon, O. Y., Cynn, H. S., and Lee, W. H. (2011). A comparison in the muscle activity of the abductor hallucis and the medial longitudinal arch angle during toe curl and short foot exercises. *Phys. Ther. Sport.*, 12(1):30-35.
- Kanchanasamut, W. and Pensri, P. (2017). Effects of weight-bearing exercise on a mini-trampoline on foot mobility, plantar pressure and sensation of diabetic neuropathic feet; a preliminary study. *Diabet. Foot. Ankle.*, 8(1):1,287,239.
- Kelly, L. A., Cresswell, A. G., Racinais, S., Whiteley, R., and Lichtwark, G. (2014). Intrinsic foot muscles have the capacity to control deformation of the longitudinal arch. *J. R. Soc. Interface.*, 11(93):20,131,188.
- Kim, E. K. and Kim, J. S. (2016). The effects of short foot exercises and arch support insoles on improvement in the medial longitudinal arch and dynamic balance of flexible flatfoot patients. *J. Phys. Ther. Sci.*, 28(11):3,136-3,139.
- Kodithuwakku Arachchige, S. N. K., Chander, H., and Knight, A. (2019). Flatfeet: biomechanical implications, assessment and management. *Foot.*, 38:81-85.
- Koolooli, M. (2014). The effects of 8 weeks corrective exercise program on the navicular height of teens with flat feet. *Asian. J. Multidiscip. Stud.*, 2(5):96-99.
- Lee, M. S., Vanore, J. V., Thomas, J. L., Catanzariti, A. R., Kogler, G., Kravitz, S. R., Miller, S. J., Gassen, S. C. (2005). Diagnosis and treatment of adult flatfoot. *J. Foot. Ankle. Surg.*, 44(2):78-113.
- McPoil, T. G. and Cornwall, M. W. (2005). Use of the longitudinal arch angle to predict dynamic foot posture in walking. *J. Am. Podiatr. Med. Assoc.*, 95(2):114-120.
- Mientjes, M. and Shorten, M. (2003). Effects of surface modulus and curvature on plantar pressure distribution beneath the heel. *Proceedings of the 6th International Society of Biomechanics Symposium on Footwear Biomechanics; 2003; Queenstown, New Zealand*, np.
- Namsawang, J., Eungpinichpong, W., Vichiansiri, R., and Rattanathongkom, S. (2019). Effects of the short foot exercise with neuromuscular electrical stimulation on navicular height in flexible flatfoot in Thailand: a randomized controlled trial. *J. Prev. Med. Public. Health.*, 52(4):250-257.
- Nilsson, M. K., Friis, R., Michaelsen, M. S., Jakobsen, P. A., and Nielsen, R. O. (2012). Classification of the height and flexibility of the medial longitudinal arch of the foot. *J. Foot. Ankle. Res.*, 5:3.
- Okamura, K., Kanai, S., Fukuda, K., Tanaka, S., Ono, T., and Oki, S. (2019). The effect of additional activation of the plantar intrinsic foot muscles on foot kinematics in flat-footed subjects. *Foot.*, 38:19-23.
- Pandey, S., Pal, C. P., Kumar, D., and Singh, P. (2013). Flatfoot in Indian population. *J. Orthop. Surg. (Hong Kong).*, 21(1):32-3.
- Sivachandiran, S. and Kumar, G. V. (2016). Effect of corrective exercises programme among athletes with flat feet on foot alignment factors. *Int. J. Phys. Educ. Sports Health.*, 3(6):193-196.
- Sulowska, I., Oleksy, Ł., Mika, A., Bylina, D., and Sołtan, J. (2016). The influence of plantar short foot muscle exercises on foot posture and fundamental movement patterns in long-distance runners, a non-randomized, non-blinded clinical trial. *PLoS. One.*, 11(6):e0157917.
- Tahmasebi, R., Karimi, M. T., Satvati, B., and Fatoye, F. (2015). Evaluation of standing stability in individuals with flatfeet. *Foot. Ankle. Spec.*, 8(3):168-174.
- Tantaopas, W., Jitchanvichai, J., Laisiroengrai, T., Jenjai, N., Julphakee, T., Theera-Umporn, N., Vaseenon, T., Phuackchantuck, R., Harnsiriwattanakit, K., and Sudwan, P. (2018). Prevalence and associated factors of flatfoot in third-year medical students at Chiang Mai University. *Chula. Med. J.*, 62(3):627-637.
- Tessutti, V., Ribeiro, A. P., Trombini-Souza, F., and Sacco, I. C. N. (2012). Attenuation of foot pressure during running on four different surfaces: asphalt, concrete, rubber, and natural grass. *J. Sports. Sci.*, 30(14):1,545-1,550.
- Welte, L., Kelly, L., Lichtwark, G., and Rainbow, M. (2018). Influence of the windlass mechanism on arch-spring mechanics during dynamic foot arch deformation. *J. R. Soc. Interface.*, 15(145):20,180,270.
- Zhao, X., Tsujimoto, T., Kim, B., Katayama, Y., Wakaba, K., Wang, Z., and Tanaka, K. (2016). Effects of increasing physical activity on foot structure and ankle muscle strength in adults with obesity. *J. Phys. Ther. Sci.*, 28(8):2,332-2,336.