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Original Article

Core muscles' endurance in flexible flatfeet: A cross - sectional study

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Abstract

Objective: Flexible flatfoot is a common deformity in adults that has been thought to be a causative factor of a lot of lower limb injuries and back pain. Core muscles act as stabilizers for the trunk and weak core places a person at greater risk of low back pain and lower limb injuries. We aimed to compare the core muscles' endurance between individuals with and without flatfeet. **Methods**: Thirty subjects with bilateral flexible flatfeet (study group) were compared with thirty healthy subjects (control group). Navicular drop test was used to evaluate the medial longitudinal arch. Modified back extensors, modified flexion and lateral muscles' endurance tests were used to evaluate the endurance of the core muscles. **Results**: The lateral muscles' endurance time in the flatfeet group was found to be significantly lower than that of the healthy group on both sides (p=0.0001). However, no significant difference was found in the trunk flexors' (p=0.15) and trunk extensors' (p=0.27) endurance time between both groups. **Conclusions**: Impairment of the lateral core muscles' endurance was observed in subjects with bilateral flexible flatfeet which may predispose to low back pain and other lower limb injuries in those subjects.

Keywords: Core Muscles, Endurance, Flexible Flatfeet, Pes Planus, Pronated Feet

Introduction

Flexible flatfoot is a common deformity affecting adults[1] characterized by collapse in the medial arch, abduction of the forefoot, internal rotation and plantar flexion of the talus and calcaneal eversion[2]. Pes planus, hypermobile flatfoot, pronated foot are synonyms usually used to describe flatfoot[3]. The prevalence of flexible flatfoot ranges from 2% to 23% in the United State population[4]. Lauterbach et al.[5] found a prevalence of 17% in men and 20% in women in the Boston area.

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While the feet are supporting the body weight, the instability resulting from a flatfoot could cause pathomechanical problems as well as a compensating action in the closed kinematic chain of the lower extremity[6]. Researchers supported the presence of a distal to proximal kinematic chain in healthy subjects, where induced flatfeet (using wedges or sandals) led to immediate shank and thigh medial rotation, anterior pelvic tilting[7-10] and increased lumbar lordosis and thoracic kyphosis[11]. The altered pelvic posture was suggested to increase the strain on muscles of the hip and pelvis, including piriformis, iliopsoas and gluteal muscles[12]. In addition, lumbar hyperlordosis could result in an increased stress on the facet joints which has been associated to the occurrence of low back pain (LBP)[13].

It is theorized that biomechanical foot disorders such as flatfoot affect the entire lower extremity kinetic chain system and the spine causing LBP[14,15]. Also, the concept of "anatomy trains" suggested that any tension at a particular part of an "anatomy train" may result in detrimental effects on the other parts of the corresponding fascial line[16]. Some evidence support that flatfoot has been associated with mechanical

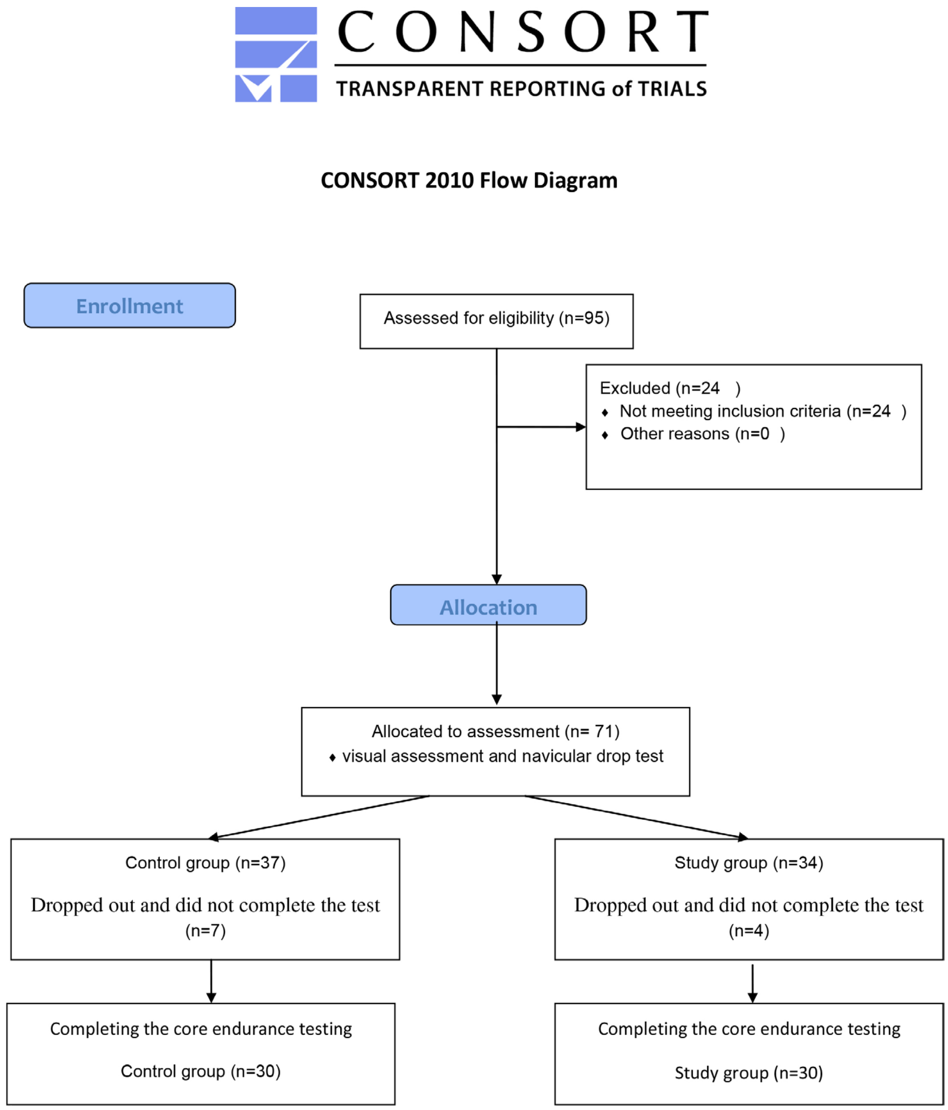

Figure 1. Consort 2010 flow diagram.

LBP[15]. The core (trunk, pelvis, and hip) muscles considered the center of the kinetic chain and their dysfunction could disrupt the kinetic chain of motion and it has been associated with lower limb injuries and LBP[17].

Despite this strong theoretical basis linking foot function to biomechanical dysfunction of the lower limb and trunk, limited studies had investigated the effects of foot misalignments on the muscular performance of the trunk and hip. Smaller eccentric hip extensors' torque was found in flatfoot subjects when compared to the control group[18]. Javdaneh et al.[19] showed that isometric strength of hip abductors and external rotators and quadriceps muscles had decreased significantly in subjects with flatfoot. In addition, Zahran et al.[20] showed a significant decrease in the isokinetic concentric strength of the hip flexors, extensors, internal rotators, and external rotators in subjects with flatfeet compared to subjects with normal feet alignment. However, no significant difference was observed between groups regarding concentric strength of trunk flexors and extensors. Despite endurance tests were found to be the most reliable measurements for assessing the core[21], to our knowledge, there is no study that has assessed endurance of core muscles in subjects with flatfeet. So the aim of this study was to compare the core muscles' endurance between individuals with and without bilateral flexible flatfeet. We hypothesized that there would be a significant reduction in the endurance time of core muscles in subjects with flexible flatfeet compared with those without flexible flatfeet which in turn could predispose to lower limb injuries and LBP.

Materials and methods

A case-control comparison was conducted from January 2017 to September 2018 at faculty of physical therapy, Cairo University. The Ethics Committee of the Faculty of Physical Therapy, Cairo University, Egypt approved this study (No: P.T.REC/012/001437) and all participants have signed a written consent. Participants were recruited from the university through local advertising. Ninety-five students and physical therapy practitioners were intended by the assessor. Twenty-four subjects were excluded because they did not fulfill the inclusion criteria. Seventy-one were assessed with the navicular drop test (NDT) and allocated into two groups (study group=34 and control group=37). Eleven subjects dropped out and did not complete the test (study group=4 and control group=7). Finally, 60 subjects were included in the study and underwent both the NDT and the core endurance test (30 subjects in each group).

A flowchart is presented in Figure 1. Sixty subjects (aged 20-26years) of both genders participated in this study and were enrolled in 2 groups: a group of subjects with bilateral flexible flatfeet (n=30; 24 female, 6 male), and a group of subjects with normal feet alignment (n=30; 25 female, 5 male). Subjects were included in the study group if, on visual assessment, they had a normal medial longitudinal arch (MLA) in sitting and they had 10 mm difference or more on the NDT for both feet. Subjects were included in the control group if they had less than 10 mm difference on the NDT for both feet. Subjects were excluded from the study if they have history of surgery or congenital deformity in lower extremities or trunk, injury to the lower extremities or back in the previous 6 months, chronic back pain, pregnancy, regular practice of physical activity or sport participation, or neuromuscular damage of the spine and lower extremities.

Sample size calculation

Sample size calculation was performed based on the primary outcome (trunk flexors' endurance time). Sample size calculation was performed using G*POWER statistical software (version 3.1.9.4; Franz Faul, Universitat Kiel, Germany) [œ=0.05, ß=0.2 and effect size=0.8] and revealed that the appropriate sample size for each group was N=26.

Assessment of foot posture

Navicular drop test was used to assess the MLA as described by Brody[22]. The NDT was shown to have a high intra- and inter-tester reliability[23]. It has moderately to well-correlation with the x-rays[24]. ND of 10 mm or more were considered abnormal and a sign of reduced MLA while a drop of less than 10 mm were considered normal[25,26].

The participants were placed in a sitting position with knee in 90° flexion, ankle in a neutral position and feet flat on a firm surface. A dot was drawn over the most prominent point of the navicular tuberosity then an index card was aligned perpendicular to the medial side of the foot. A mark was placed on the index card at the level of the dot on the navicular tuberosity. The subject was asked to assume a normal bilateral weight bearing stance and another mark was placed on the card at the level of the navicular tuberosity. A ruler was used to measure the distance between the two marks on the card (measured in mm). All assessments were performed by one experienced examiner. The measurements were repeated three times and an average was calculated. ND was measured for both feet in both the study and control groups.

Assessment of core muscles

The most reliable measurements of the core were the endurance test with flexibility tests the second most reliable, followed by strength, motor control, and functional assessments, respectively. It had a moderate to very high reliability (0.66-0.96)[21]. Assessment for trunk flexion and extension was made using a modified testing method which was proved to be valid and reliable[27].

1. Modified back extensors test

According to Reiman et al.[27] participants were positioned prone with the iliac crests at the edge of the plinth. Their upper trunk kept out of the plinth by pushing with their extended arms on a chair directly below him. A clinician stabilized the participant over the middle of the participant's posterior knees. At the initiation of the test, the upper limbs would be lifted off the chair and crossed over the chest. Participants were instructed to maintain the horizontal position for as long as they can once testing commenced.

Time was measured by another clinician (using a stopwatch) from the instant the participant assumed the horizontal position until the participant visually deviated from the horizontal plane.

2. Modified flexion endurance test

According to Reiman et al.[27] participants lied supine, with hips and knees flexed to 90°, trunk inclined at 60° resting on a prefabricated wedge. A clinician held the participants' feet for stabilization. Participants placed their hands crossed over the shoulders. They were instructed to maintain this position for as long as possible after the wedge was moved back 10 cm. Time was measured (using a stopwatch) from the instant the wedge was moved back until the participant visually reestablished contact with the wedge.

3. Lateral muscles test

According to McGill[28] participant was instructed to lie in full side bridge position, place one elbow flexed 90° below the shoulder. The legs were extended in line with the trunk, with one foot positioned in front of the other. The other hand was placed on the opposite shoulder. The test was started when participant lifting the hips off the mat to create a straight line from the shoulders to the feet and stopped when the patient

Table 1. Descriptive statistics and t-test for both groups.

Variables	Study group	Control group	t- value	p-value
	$\bar{X} \pm SD$	$\bar{X} \pm SD$		
Age (years)	22.46 ± 1.54	23.13 ± 1.63	-1.62	0.11
Weight (kg)	66.03 ± 11.77	64.56 ± 9.65	0.52	0.6
Height (cm)	162.80 ± 7.08	162.73 ± 8.30	0.03	0.97
BMI (kg/m²)	24.97 ± 4.60	24.40 ± 3.40	0.53	0.59

$\bar{X}$: Mean; SD: Standard deviation; t-value: Unpaired t value; p-value: Probability value.

Table 2. The frequency distribution and chi squared test for comparison of sex distribution between study and control groups.

Gender	Study group	Control group	x^2	p-value
Females	24 (80%)	25 (83%)	0.11	0.73
Males	6 (20%)	5 (17%)		

x^2 : Chi squared value; p value: Probability value.

Table 3. Paired t-test for comparison of mean value of navicular drop between Right and Left sides in both groups.

Navicular drop (mm)	Right side	Left side	t- value	p-value
	$\bar{X} \pm SD$	$\bar{X} \pm SD$		
Study group	12.00 ± 1.98	12.03 ± 1.92	-0.076	0.94
Control group	5.40 ± 2.02	5.03 ± 1.37	1.173	0.25

$\bar{X}$: Mean; SD: Standard deviation; t value: paired t-value; P-value: Probability value.

was no longer able to maintain the position.

The order of testing was randomly determined. About 5-minute rest was allowed between each test. To ensure adequate stabilization, the clinician providing stabilization was determined to weigh more than the subject being tested. Before testing, all subjects were encouraged to maintain the testing position as long as they can. No encouragement was allowed during testing, and the instructions were kept standardized during the whole testing procedure.

Statistical analysis

Descriptive statistics and unpaired t-test were used to compare mean age, weight, height, BMI between both groups. Chi squared test was used for sex distribution comparison between both groups. Paired t-test was conducted for comparison of ND between right and left sides in both groups. Unpaired t-test was used for comparison of right and left ND between both groups and Right/Left ND difference between the study and control groups. MANOVA test was conducted for comparison of trunk muscles' endurance time between both groups. The level of significance for all statistical tests was set at ($p<0.05$). All statistical tests were performed through the statistical package for social studies (SPSS) version 19 for windows (IBM SPSS, Chicago, IL, USA).

Results

No significant difference was found between both groups regarding the mean age, weight, height, or BMI ($p>0.05$) (Table 1). Chi squared test revealed no significant difference between study and control groups in sex distribution ($p=0.73$) (Table 2). A significant increase was found in the ND of the study group in comparison with the control group in both sides ($p=0.0001$) (Table 4). However, no significant difference was found between both groups regarding the difference between right and left ND ($p=0.078$) (Table 4). Also, the difference between right and left ND was not statistically significant neither for the study group ($p=0.94$) nor for the control group ($p=0.25$) (Table 3).

MANOVA test revealed no significant difference in the trunk flexors' endurance time between both groups ($p=0.15$). Also, there was no significant difference in the trunk extensors' endurance time between the study and control groups ($p=0.27$). However, the right lateral muscles' endurance time was found to be significantly lower in the flatfeet group than that of control group ($p=0.0001$).

Table 4. Comparison of mean value of navicular drop, Right / Left navicular drop differences and endurance time of trunk flexors, extensors and lateral musculatures between both groups.

Variables	Study group	Control group	p-value
	$\bar{X}$ ±SD	$\bar{X}$ ±SD	
Navicular drop of Right side (mm)	12.00 ± 1.98	5.40 ± 2.02	0.0001
Navicular drop of Left side (mm)	12.03 ± 1.92	5.03 ± 1.37	0.0001
Right / Left navicular drop difference (mm)	1.50 ± 0.86	1.08 ± 0.83	0.078
Endurance time of trunk flexors (sec)	76.70 ± 18.41	83.06 ± 15.55	0.15
Endurance time of trunk extensors (sec)	66.13 ± 16.66	70.30 ± 12.45	0.27
Endurance time of Right lateral muscles (sec)	30.90 ± 8.05	42.86 ± 12.70	0.0001
Endurance time of Left lateral muscles (sec)	33.93 ± 9.09	43.76 ± 9.88	0.0001

$\bar{X}$: Mean; SD: Standard deviation; P value: Probability value.

Similarly, the left lateral muscles' endurance time was fund to be significantly lower in the flatfeet group than that of control group (p=0.0001) (Table 4).

Discussion

It was hypothesized that muscular endurance is more important than muscle strength for proper lumbar stabilization, because only a small percentage of maximum muscular force is used to stabilize the spine during daily activities. Strength seems to have little, or very weak, relationship with low back health[28]. Endurance time was significantly lower in LBP patients compared with healthy elderly individuals[29]. Decreased trunk extensor muscle endurance has been shown to be predictive of future LBP in a non-athletic population[30] and seems to have a strong association with the risk of LBP[31]. So, the purpose of this study was to investigate the difference of core muscles' endurance between individuals with and without flatfeet. Although there are two theories that could explain the relationship between flatfoot and lumbopelvic impairments (a "ground up" approach and a "top down" approach), the current study consider the ground up chain as our participants had flatfeet early in their life (known from the history) and they didn't report any back pain up till the time of the study. The results revealed that the endurance of lateral core muscles in subjects with flatfeet was significantly reduced compared with those of normal feet alignment. However, no significant difference was observed in the trunk flexors' and extensors' endurance time between the study and control groups.

Two systematic reviews concluded that the role of foot posture as a contributor to the abnormal biomechanics of the lumbopelvic area is not sufficiently investigated. There is a little evidence to support that foot alignment, particularly flatfoot, is associated with LBP. The suggested mechanisms for this finding are based on either pathomechanical changes or altered muscular activity in the lumbar and pelvic area[15,32]. We hypothesized that endurance of the core muscles in individuals with flatfeet could be reduced which in turn can lead to LBP. This is partially supported by our findings.

The main finding of the current study is the significant reduction of the lateral core endurance time in flatfeet subjects. When the MLA was collapsed, the ability to absorb impacts and the sense of balance will decrease so that stability decreased during walking or running leading to reduced endurance[33,34]. Reduced endurance of the lateral muscles without affection of the anteroposterior muscles somewhat support this theoretical explanation.

The reduced lateral core endurance could be explained by the weakness of hip abductors observed in flatfeet subjects[35,19]. The hip abductors act to stabilize the pelvis, so that prevent pelvic drop during single leg stance (Trendelenburg sign). Hip abduction weakness could result in an increased firing of the lateral trunk stabilizer[17]. The increased firing could probably cause muscle fatigue over time. According to Myers[16], there is a fascial connection, named the "lateral line" that connects the foot with the tensor fasciae latae and the gluteus medius.

The impaired lateral core endurance observed in this study could also be supported by the altered muscular activities acting on the frontal plane observed by Taeho and Jinyong[36]. Flatfoot group had significantly lower muscle activity of posterior fiber of gluteus medius than the normal foot group in stance phase. Also, the flatfoot group had significantly higher muscle activity of foot invertors and lower activity of the foot evertors[37].

In cases of asymmetrical pronation, the functional shortening of the leg[10] is linked to pelvic tilt[8] and subsequent lumbar scoliosis[38]. The majority of our participants (flatfeet and control) have Right/Left differences in the ND, but this difference was not statistically significant for the same group or between both groups. However, in flatfeet this may cause asymmetrical pronation which could lead to pelvic tilt and subsequent functional scoliosis. This may in turn lead to lateral muscle imbalance which could explain the impairment of lateral core muscles.

Furthermore, our findings came into agreement with Betsch et al.[39] and Yi[40]. They found that induced pronation led to significant changes of the pelvic tilt but didn't cause any changes in trunk alignment in the sagittal plane (kyphotic and lordotic angles). Changing pelvic posture in the frontal plane could affect mainly the lateral muscles of the trunk. In addition, the non significant changes of the lumbar posture in the sagittal plane could mechanically explain the non significant changes in the trunk flexors and extensors' endurance. Similarily, Duval et al.[41] described no significant relationship between flatfoot and lumbar lordosis. This was in line with our results in which the flatfoot had no effect on the muscles acting on the sagittal plane.

The non significant difference in the endurance time of the trunk flexors and extensors were in agreement with the finding of Zahran et al.[20] who didn't find a significant difference in lumbar flexors' and extensors' concentric peak torques between the flatfeet and control groups. Also, they are similar to the study of Ntousis et al.[42] that revealed no effect of induced pronation on the EMG activity of the rectus abdominis and latissimus dorsi.

In contrast, Cobb et al.[43] have observed that subjects with forefoot varus (with greater ND measures) presented impaired anteroposterior (AP) postural stability compared with those with aligned forefoot; however, there was no difference in the mediolateral (ML) stability between groups. As core endurance and balance seems to be positively correlated[44], this is controversy to the current study.

Cobb and colleague[43] observed higher ML postural sway scores in varus group; however, they did not reach a statistical significance. This was somewhat unexpected because varus is primarily a frontal-plane foot posture; so the largest difference was expected in frontal-plane stability. The authors explained the somewhat unexpected finding of the study by several factors. The number of subjects in the study (study group 20, control group 12) may have limited the power of the study to reveal statistically significant ML differences. Another explanation is that it is possible that individuals compensate with increased sagittal plane motion during single-limb stance due to the greater length of the foot in relation to its width, and because the muscles controlling AP motion are stronger than those controlling ML motion.

It can be concluded that there is a significant reduction of the endurance of the lateral core muscles without significant difference in the trunk flexors and extensors between individuals with flat-arched foot compared to healthy subjects. It is recommended that assessment and rehabilitation of these muscles should be added to the treatment program in those subjects.

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Author contributions

Faten F Elataar performed the search experiments and wrote the manuscript, Salwa F Abdelmajeed, Nasef MN Abdellatif and Maha M Mohammed designed the experiments and reviewed the manuscript. All authors read and approved the final version.

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