# Influence of second-degree flatfoot on spinal and pelvic mechanics in young females

*Neveen Abdel-Raoof, Dalia Kamel, Sayed Tantawy*

***Objective:*** *To investigate the effect of bilateral flexible second-degree flatfoot on pelvic and spinal mechanics in young females.*
***Methods:*** *A case control trial was conducted at the Faculty of Physical Therapy, Cairo University, on 60 female participants who were assigned into two groups. Group A (the control group) included 31 healthy subjects, and group B (the study group) included 29 subjects with bilateral flexible second-degree of flatfoot deformity. For each subject in both groups, using lateral weight-bearing radiographs, foot assessments were performed bilaterally to measure the talus–first metatarsal angle. Using the formetric-II device, 3D assessments of the pelvis were performed on the frontal and sagittal planes in addition to lumbar and thoracic curvatures on the sagittal plane. Outcome measures were pelvic inclination, pelvic tilt, and lumbar lordotic and thoracic kyphotic angles.*
***Results:*** *There was a significant difference in pelvic inclination and in lumbar and thoracic angles (P=0.012, 0.009, and 0.028) respectively between both groups. There was no significant difference between both groups in pelvic tilt (P=0.688).*
***Conclusion:*** *Subjects with bilateral flexible second-degree flatfoot demonstrated increased pelvic inclination, lumbar lordotic and thoracic kyphotic angles than normal subjects. Foot assessments should be performed as an essential part of the evaluation of female patients with spine and pelvic problems. Bilateral flexible second-degree flatfoot may act as a predictor for pelvic organs prolapse in their later lives.*

Key words: ■ Flatfoot ■ Pelvic mechanics ■ Pelvic tilt ■ Pelvic inclination ■ Spinal curvatures ■ Pelvic organ prolapse

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Acquired adult flatfoot deformity (AAFD) is a common and often debilitating chronic foot and ankle condition (Stephen and Sheldon, 2006). Out of the total population, 60% have normal arches, 20% have a cavus or high-arched foot, and 20% have a planus or low-arched foot (Williams and McClay, 2000). Foot arches serve several purposes: they protect the nerves, blood vessels, and muscles on the plantar surface of the foot from compression during weight bearing; they help the foot to absorb shock during impact with the ground; and they store mechanical energy then release it to improve the efficiency of locomotion (Oatis, 2004).

Flat-arched feet have been associated with altered foot function, prolonged calcaneal eversion, increased tibial internal rotation, and increased forefoot abduction (Williams et al, 2001; Tweed et al, 2008; Levinger et al, 2010). Therefore, changes in lower limb posture may lead to postural alterations of the pelvic and spinal alignment (Botte, 1981; Rothbart and Estabrook, 1988; Levine and Whittle, 1996; Legaye et al, 1998; Gurney, 2002; Aebi, 2005; Khamis and Yizhar, 2007; Pinto et al, 2008). These postural alterations result from the additional stress placed on all of the joints, ligaments and muscles involved in maintaining upright posture (McPartland et al, 1997). The bilateral presence of excessive calcaneal eversion also generates internal rotation of the hips and, consequently, may lead to increased pelvic anteversion (Khamis and Yizhar, 2007) and the presence of lumbar hyperlordosis (Levine and Whittle, 1996). Therefore, these biomechanical faults can adversely affect any of the joints and structures of the foot–ankle complex, the lower extremity, the pelvis, and the spine (Kuhn et al, 1999).

In the literature, there is no documented evidence describing the effect of bilateral flexible second-degree flatfoot on pelvic and spinal alignment that subsequently may lead to pelvic organ prolapse later in life. However, previous researchers reported the effect of induced foot pronation on the posture of the pelvis (Khamis and Yizhar, 2007; Pinto et al, 2008) and the lumbar spine in healthy subjects (Duval et al, 2010). In addition, other researchers reported a relationship between spinal curvature alteration and pelvic organ prolapse (Mattox et al, 2000; Manizheh and Alizadeh, 2007). Therefore, the present study's objective was to investigate the effects of bilateral flexible second-degree flatfoot on all of the pelvic postures, and on lumbar and thoracic posture in one analysis.

## METHODS

### Data collection

Out of 377 female students volunteers from the Physical Therapy Faculty, Cairo University, 100 were recruited for this study. Inclusion criteria for participants were a body mass index (BMI) of 18.5–24.9 Kg/m$^2$, age ranging between 17–21 years old, and bilateral second-degree flexible flatfeet (see *Figure 1*).

Exclusion criteria were subjects with a BMI above 24.9 Kg/m$^2$, a leg length discrepancy (Fann, 2001), traumatic conditions and/or surgery, and a neurological deficit of the lower limbs, pelvis, or the spinal column.

This study took place during the period of March to December 2011. The study was approved by the Institutional Ethics Committee of the Faculty of Physical Therapy, Cairo University, and all subjects signed a consent form.

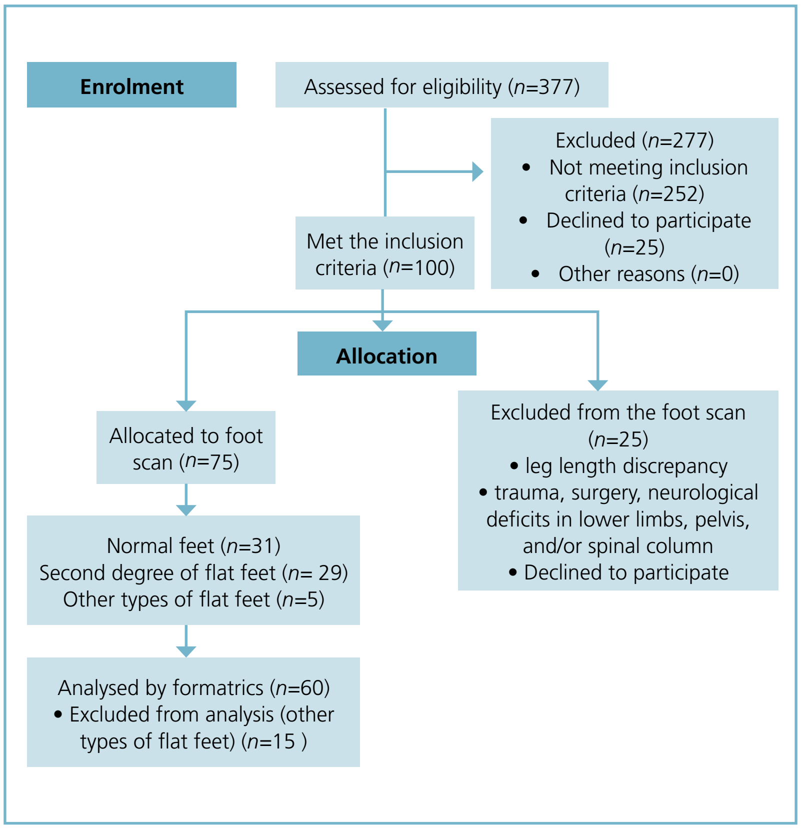


***Figure 1. Methodology flow chart***

### Instrumentation

**1. X-ray apparatus**

This study used a Philips view forum 2003 x-ray device to confirm the results of the physical examination and assess foot anatomy through lateral weight-bearing radiographs of each participant's feet. The x-ray radiographs were used to confirm the study group's bilateral second-degree flat feet and the control group's normal feet arches.

**2. Optical three-dimensional spine analysis and posture measurement system**

This study used a Rasterstereographic System Formetric 3D® (Diers International GmbH, Schlangenbad, Germany) (*Figure 2*) as it is a reliable method for three-dimensional back, and pelvis shape analysis, and for reconstruction of spinal deformities without using ionizing radiation or any markers (Hackenberg et al, 2003). This study used rasterstereography to measure pelvic posture in the sagittal and frontal planes, and lumbar lordosis and thoracic kyphosis angles in the sagittal plane.

***Figure 2. The formetric II** AQ: do you have a higher resolution jpeg of this picture?*

### Procedures: Assessment of foot type

**1) Physical examination**

Initial selection of the subjects within both groups involved performing a physical examina-


*Figure 3a. Normal talus–first metatarsal angle*


*Figure 3b. The talus–first metatarsal angle in flatfoot*

tion, which included:

- Observation
- Differentiation between flexible and rigid flat feet.

The observation involved the authors obsers-erving the foot with the participants standing and while they were ambulating. The author checked the position of heels, the medial arches, and the position of the forefeet and the subtalar joint. The participants' medial arches were measured as they stood barefoot on both feet with the subtalar joint in its neutral position. Neutral position of the subtalar joint was defined as equal palpation of the medial and lateral aspects of the head of talus in relation to the navicular (Nielsen et al, 2009) (AQ: could you specify what you mean by 'equal'?). Palpation was used to locate the navicular tuberosity, and then the perpendicular distance between the floor and the navicular tuberosity was measured with a ruler. Moul (1998) defines the normal navicular height using this measurement method as a range from 7.3 to 9.0 mm; therefore, participants with measurements below this range were considered to have low medial arches. The authors observed the participants in standing and walking, looking for evidence of flat feet through the following signs: heel valgus, low medial arches, and, commonly, forefoot abduction and supination. In this study, the authors observed that the subtalar joint of people with flat feet is commonly in an over-pronated position in stance and the over pronation may be even more visible while walking.

Second-degree flexible flatfoot is characterised by a change in the contour of the foot, with depression of the longitudinal arch and prominence of the navicular bone (Cailliet, 1997). Observation of the subjects with normal feet arches revealed normal heel position and normal arch height.

Differenting between flexible and rigid flat feet among the participants with flat feet involved the authors using the single heel raise test. Each participant was asked to stand on their tiptoes on one foot then repeat the same procedure for the other foot. Participants were noted as having flexible flat feet if their arch re-appeared and their calcaneus demonstrated normal inversion when viewed from behind (Vora and Haddad, 2003).

**2) Radiographic evaluation**

Following the physical examination, the authors obtained lateral weight-bearing x-ray radiographs of each participant's feet in both groups to detect whether or not participants had normal or flat feet and to determine the degree of severity of their flatfoot deformity. Each subject had an x-ray radiograph image taken once for each foot.

The degree of flatfoot was determined through measuring the talus–first metatarsal angle on a lateral weight-bearing radiograph (see *Figures 3a* and 3*b*). The x-rays were mounted on the viewing box, which was lighted maximally. The angle is formed between the long axis of the talus and first metatarsal. The authors marked the line connecting the points defining the angle on the x-rays with the x-ray pencil. They used the ruler to draw straight lines joining the points. The angles were then measured with a goniometer and recorded. The calculated angle measurement was 0° in the normal foot (control group), 0–15° in participants with mild or first-degree deformities, 15–30° in participants with moderate or second-degree deformity (study group), and greater than 30° in cases of severe deformity or third-degree flatfoot (Chi et al, 1999).

## Procedures: Assessment of pelvic and spine alignment

The assessment was undertaken for both the control and the study groups using the 3D measurement system, Formetric II. Each subject stood with bare feet in a neutral, upright posture, 2 metres in front of the 3D scanning system (photo camera) with the skin of their trunk bare. The patient's back surface (including buttocks) was also completely bare to avoid disturbing image structures. Participants were asked to bind up their hair so that the neck, in particular the vertebral prominence, was uncovered. The instrument's height was adjusted according to the participant's height to ensure the relevant parts of their back were in the centre of the control monitor. A multitude of light sections were projected onto the patient's back from a different direction than that of the optical measurement unit, thereby compiling shape information along the section line.

The best moment for capturing the image was when the participant exhaled slightly. Each participant was first asked to breathe normally. The moment of exhalation was observed on the control monitor. The researchers then asked the patient to stop breathing for a few seconds while they captured the participant's image. The scanning time was very short (40 ms) to eliminate movement artifacts. (AQ: did you have to dispose of any images for this reason? If so, what proportion?)

The automatic anatomical landmark localisation, noted the prominent vertebrae (AQ: do you mean one prominent vertebra [if so, which one] or a few vertebrae?) and the iliac spine, and this formed the basis of an automatic reconstruction of the sagittal back and pelvic shape. It provided a set of shape parameters characterising the back profile (Hackenberg et al, 2003). The formetric II system analysed the back and pelvic surface form in a sophisticated, anatomic way with no need for manual fixation of markers on the vertebrae. Anatomical landmarks, and vertebral position and rotation were automically detected by the reconstructed high-resolution surface, anatomical, and pathological model (AQ: could you clarify this phrase in green? Do you mean the Formetric II reconstructed the pathological and non-pathological models?). The resulting model showed the complete form and the data from the spine and pelvis it had examined.



## The outcome measures

The following parameters were calculated and recorded: pelvic inclination, pelvic tilt, lordotic angle (max), and kyphotic angle (max).

## Statistical analysis

The authors used SPSS 14.0 for Windows Integrated Student Version (SPSS Inc., Chicago, IL, USA) for statistical analysis. An unpaired t-test was used to compare the variables between the two groups at baseline with the $P$ value set at 5%. A statistical power analysis suggested that sample sizes above 25 subjects per group were required to achieve more than 80% power.

# RESULTS

The participants' demographic characteristics in the study group, which consisted of 29 females with bilateral flexible second degree of flatfoot, were an average age of 24.06 years old (± 3.75), height 163.23 cm (± 9.11), weight 64.5 kg (± 8.34), and BMI 24.1 kg/m$^2$ (± 0.6). The characteristics of the 31 normal females participating in the control group were an average age 24.5 years old (± 3.48), height 163.63 Cm (± 9.43), weight 65 kg (± 7.87), and BMI 24.17 kg/m$^2$ (± 0.59), normal feet, and an absence of musculoskeletal abnormalities.

*Table1* shows the variables measured by the formetric II, and the means and standard deviations for each dependent variable.

## Pelvic inclination (sagittal plane)

While the control group showed maximum and minimum values as 27° and 8.3° respectively, the

**Table 1. Outcome measures of different variables for the control and study groups**

| Variables | Control group | Study group | *P* value |
|---|---|---|---|
| Pelvic inclination (in sagittal plane) | 17.993 ± 5.0 | 21.623 ± 5.776 | 0.012 |
| Pelvic tilt (in frontal plane) | 1.766 ± 4.987 | 1.20 ± 5.862 | 0.688 |
| Lordotic angle | 44.400 ± 7.902 | 49.3663 ± 6.408 | 0.009 |
| Kyphotic angle | 51.300 ± 5.831 | 54.800 ± 6.244 | 0.029 |

study group scored maximum pelvic inclination of 30.8° and a minimum value of 10°. Bilateral flexible second-degree flatfoot caused significant changes in pelvic inclination in comparison to the control group, producing a significant anterior pelvic inclination (*P*= 0.012).

### Pelvic tilt (frontal plane)

Maximum and minimum values in the study group were 11° and -9° respectively, while in the control group, the maximum value was 9° and minimum angle was -9°. Bilateral flexible second-degree flatfoot did not produce changes in pelvic tilt. There was no significant difference between the two groups (*P*=0.688).

### Lordotic and kyphotic angles (sagittal plane)

The bilateral flexible second-degree flatfoot group showed maximum values for the lumbar and kyphotic curves of 60° and 63° respectively, and minimum values of 40° and 44°. For the control group, it showed maximum angles of 56° and 64° respectively for lumbar and kyphotic curves. The minimum values for the same group were 25° and 41° respectively. The study group showed significant changes in lordotic and kyphotic angles in comparison to the control group, producing a significant increase in lordotic angle (*P*=0.009) and a significant increase in kyphotic angle (*P*=0.029).

## DISCUSSION

Results of pelvic mechanics showed that subjects with bilateral flexible second-degree flatfoot had an anterior pelvic inclination greater than healthy subjects, while pelvic tilt did not differ between the two groups.

The significant change in pelvic alignment towards anterior tilt observed in the bilateral flexible second degree of flatfoot group can be attributed to the presence of foot pronation and calcaneal eversion.

Flatfoot generates an internal rotation of the tibia and femur and consequently at the hip joint, (Botte, 1981; Khamis and Yizhar, 2007). This internal rotation may make the head of femur move posteriorly, which consequently shifts the pelvis posteriorly. In order to regain postural balance, the trunk moves anteriorly to shift the centre of mass anteriorly and this forces the pelvis to tilt anteriorly in the sagittal plane. In addition, tension in the iliopsoas muscle and hip joint capsule as a result of hip internal rotation produced anterior pelvic tilt (Botte, 1981; Pinto et al, 2008). Furthermore, internal rotation of the hip joint brought the greater trochanter forward and outward, chronically stretching the piriformis muscle that inserts into the apex of the trochanter. The Piriformis muscle's origin is at the anterolateral aspect of the sacrum; therefore, the sacrum may be pulled into an antero-inferior position leading to anterior pelvic tilt in the sagittal plane (Schafer, 2000).

The alteration in foot mechanics will cause alteration in whole body mechanics, including in the pelvis. These body alterations can occur even when foot alteration is temporary as Khamis and Yizhar (2007) reported. Their healthy subjects wore medially tilted wedges and Khamis and Yizhar (2007) reported that this induced bilateral hyper-pronation of subjects' feet, which led to increased anterior pelvic inclination. Furthermore, unilateral and bilateral use of medially-tilted wedges produced an increase of calcaneal eversion and consequently caused anterior pelvic inclination. Pinto et al (2008) reported that bilaterally-increased foot pronation did not generate any change in pelvic alignment in the frontal plane while only unilateral-increased foot pronation would significantly increase pelvic tilt in the frontal plane.

The results of the current study disagreed with the results of Duval et al (2010), who reported that artificially-induced foot pronation did not have a relationship with pelvic tilt. The difference in results possibly occurred due to methodological differences. Duval et al, 2010 used markers attached to body segments to detect changes in the alignment and these markers may be affected by movement of the skin and soft tissues and thus increase the artifacts of movement, while in the current study used the formetic II, which does not require markers attached to the body. Furthermore, this study contradicted the results of Duval et al (2010), which were caused by immediate increase of calcaneal eversion or foot pronation that enabled the healthy subjects to use short-term compensatory mechanisms to prevent a change in pelvic posture. However, the participants in the current study with bilateral flexible second-degree flatfoot showed signs of excess pronation for an extended period of time and thus may develop compensatory mechanisms. These compensatory mechanisms reported in this study may have lead to a change in pelvic alignment in the sagittal plane as long-term tissue adaptations may allow greater postural changes to occur (Mueller and Maluf, 2008).

Previous studies (Botte, 1981; Cibulka, 1999; Kuhn et al, 1999; Fann, 2001; Gurney, 2002; Pinto et al, 2008) showed that unilateral increases of foot eversion position generate a lateral pelvic tilt due to ipsilateral lower limb shortening. This lateral pelvic tilt led to a functional limb length difference between the two lower limbs, resulting in a pelvic obliquity in the frontal plane. The results of the current study revealed that participants with bilateral flexible second-degree flatfoot showed no change in pelvic tilt in the frontal plane compared with normal subjects. This may be due to the presence of bilateral pronation of both feet, which may have no effect on pelvic alignment in frontal plane.

The lordotic and kyphotic angles in the present study revealed that both angles were higher in participants with bilateral flexible second-degree flatfoot than in normal subjects. These results can be attributed to the anatomical relationship between the pelvis and lumbar spine; the pelvic alignment affected the lumbar spine posture especially in standing position (Legaye et al, 1998). Therefore, changes in pelvic inclination affected the degree of lumbar lordosis (Egund et al, 1978; Levine and Whittle, 1996) and thus, anterior pelvic tilt may lead to the presence of hyperlordosis (Legaye et al, 1998; Levine and Whittle, 1996). In addition, increased lumbo-sacral junction angle is a common finding in patients with pronation of the foot and associated internal rotation of the lower extremity (Innes, 1993).

Although muscle changes were not investigated in this study, the authors propose that the increase in lumbar lordosis they report in this paper is a mechanical disadvantage to the abdominal muscles through increasing their length. This causes abdominal muscle weakness over time, which allows a further increase in lumbar lordosis angle. Furthermore, the shortening of the erector spinae, quadrates lumborum and iliopsoas muscles act to accentuate the lumbar lordosis. In addition, the kyphotic angle also increases as a compensatory mechanism for lumbar hyperlordosis to maintain the posture (Kelly, 2005 AQ: Could you give an alternative, peer-reviewed journal reference here?). Schafer (2000) reported that the biomechanical effects of pronation could be witnessed as high in the body as the occiput.

Bilateral flexible second-degree flatfoot has an impact on different body parts, such as the spinal curvatures. The alterations in the spinal curvatures themselves have effects on the trunk area either internally or externally. The relation between spinal curvature and pelvic organ prolapse is that normal spinal curvature appears to protect the pelvic cavity from direct upper abdominal forces. Variations in spinal curvature may alter these vector forces and possibly potentiate the development of pelvic organ prolapse (Mattox et al, 2000). Furthermore, the stage of prolapse Mattox et al (2000) reported was higher in cases with increased spinal curvatures compared to controls (OK?). These observations underline the importance of taking into account the abnormal changes in spine curvature of patients when investigating risk factors for development of pelvic organs prolapse (Fann, 2000). We hypothesise that if there is alteration within all the aforementioned areas, females may be vulnerable to developing genital (AQ: do you mean pelvic organ?) prolapse later in their lives.

## Clinical message

More attention should be paid to evaluating the patient's whole posture rather than focussing only on the symptomatic area. Postural foot alterations can produce and maintain far-reaching effects both in the spine and the pelvis. Postural foot alterations may act as a predictor of pelvic organ prolapse as it is a risk factor in young unmarried/nulliparous females. When these changes are overlooked, symptoms referred to other parts of the body continue because their cause, being in the feet, has failed to be properly diagnosed and treated.

## CONCLUSION

This study provided evidence for the effects of bilateral flexible second-degree flatfoot on pelvic mechanics and spinal curvatures. It revealed that subjects with bilateral flexible second-degree flatfoot had an increase of anterior pelvic tilt, and increased lumbar and thoracic curvatures compared to healthy subjects. We recommend further research to assess the biomechanic foot alterations in females who have developed pelvic organ prolapse. IJTR

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Conflicts of interest: None.

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## KEY POINTS

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