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Research article

Footwear and postural changes in the third trimester of pregnancy

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ABSTRACT

Objective: To determine the effects of different heel heights of footwear on gait parameters in normal pregnant women.

Materials and methods: Fifty primigravid women were evaluated at 24th, 28th, 32nd and 36th weeks of gestation in motion analysis laboratory. Anterior pelvic tilting angle, pelvic rotation and plantar flexor moments for flat, 1.5 cm, 3 cm and 4.5 cm heel heights were determined by gait analysis using 3D optical motion capture system (Qualisys AB, Gothenburg, Sweden).

Results: At 24th, 28th, 32nd, and 36th weeks of gestation significantly decreased anterior pelvic tilting and pelvic rotation were detected between 1.5 and 3 cm heel heights. Plantar flexor moment measurements were not significantly different at 24 weeks. However, there were a statistically significant decreases in plantar flexor moment between the flat footwear and both 1.5 cm and 3 cm heel heights throughout at the 28th, 32nd, and 36th weeks of gestation. No significant difference was observed between the flat footwear and 4.5 cm heel heights of footwear for all gestational ages.

Conclusion: Use of 1.5 cm and 3 cm heel heights are associated with less pronounced pelvic tilting, rotation and plantar flexor moments in third trimester pregnancy.

Key words: *Footwear, heel height, postural changes, pelvic tilting, pelvic rotation, plantar flexor moment, motion capture system, pregnancy.*

Introduction

Pregnancy results in a considerable compensation in the structure and the function of the human body to allow normal development and delivery of the fetus [1-2]. As pregnancy progress there is a natural tendency for anterior displacement of the trunk that may be counter balanced by increased activities of gastrocnemius and soleus muscles, extension of hip joints, or posterior displacement of the upper trunk, including increase in lumbosacral angle as well as, lumbar curvature and anterior displacement of the pelvis with simultaneous posterior displacement of the shoulders [3]. Additionally, due to instability and looseness of the joints, the pregnant woman attempts to keep joints locked during locomotion [2]. However, even with the locking of the joints, there is still disturbing features of increased shearing stress applied on lumbosacral area [4].

Characteristic posture and gait associated pregnancy, although transient, are believed to predispose to the development of postural complaints such as back and hip pain [5]. Flat shoes are not advised during pregnancy due to the increased physical strains caused by skeletal changes during pregnancy. To ease back pain during pregnancy American College of Obstetricians and Gynecologists (ACOG) recommends wearing low heeled (but not flat) shoes with good arch support, seeking for correct way to lift objects, and applying heat or cold to the painful area or massaging it [6].

Dananberg and Guiliano reported that shoe inserts appears to provide more effective back pain relief than standard therapies [7]. Also, pregnant woman needs to observe good feet health to prevent pain and discomfort [8].

This study was aimed to determine the effects of different heel heights of footwear on gait parameters in normal pregnant women.

Materials and Methods

Setting and patient selection

This comparative observational study was conducted between late 2007 till early 2009 at the Departments of Obstetrics and Gynecology and Physiotherapy of Kasr El-Aini Hospital, Cairo University, Egypt. Fifty normal primigravid women at 24th week of gestation participated to the study. All patients were selected from the Obstetrics Outpatient Clinic at Kasr El-Eini University Hospital.

Women with diabetes, preeclampsia, varicose veins, twins, polyhydramnios, macrosomic fetuses, musculoskeletal and neuromuscular disorders, deformities, or previous spinal or orthopedic surgery were excluded.

Recording data sheet

Sociodemographic variables and study parameters were recorded by using a custom recording sheet. Weight and height scale was used to measure the height and weight.

Ultrasonographic examination was performed using Voluson 530 3D system (Medison Kretz, Zipf, Austria) using 5.0 MHz transabdominal transducer throughout the study to confirm the gestational age and also assess the presence of exclusion criteria including fetal macrosomia, polyhydramnios, and other congenital abnormalities.

Qualisys (Qualisys AB, Gothenburg, Sweden) gait analysis system was used to record and measure the gait parameters of each pregnant woman while wearing different heel heights of footwear (**Table 1**).

Procedures

Each patient was instructed carefully in each visit for emptying bladder (full bladder may disturb walking pattern), wearing thin, well fitted, comfortable clothes before measurements.

System calibration

At the start, L-shape wand was placed in the middle of the walking path at the force plate form with the x-axis in the walkway direction and then, T-shape wand was moved in x, y and z direction so that, the wand markers were oriented in all three directions of the measurement volume. During this procedure, the operator moved around the measurement volume to allow all cameras to view L-shape and T-shape of the wand during the calibration. Then the operator move the wand in the suggested area of measurement as much as possible so that, all cameras connected to the system can pick up the marker position in various locations, then four reference markers were placed at force plate corners to measure force plate position, The data was captured, tracked and then exported. This procedure took a few minutes.

Gait is cyclic and can be characterized by the timing of foot contact with the ground. An entire sequence of function by one limb is identified as a gait cycle [9].

Application of markers

For each pregnant woman, 20 reflecting dots (markers) according to the system software were placed on special bony landmarks of her body. Two markers were placed on the tip of both acromions, one marker at the 12th thoracic vertebra and another one on the sacrum. Two markers were placed on both anterior superior iliac spines (ASIS), others on both greater trochanters, on the superior surface of the patellae on both sides, over the knee joint line on both sides, over the tibial tuberosities on both sides, over both lateral malleoli, over the dorsum of both feet between bases of the second and third metatarsal bones and two markers one for each heel (posterior of calcaneus) at the same horizontal plane as the toe marker.

Table 1. Gait analysis procedure and parameters used in the study.

Preparation and acquisition of data
- Tracking of the motion data (creating 3D markers trajectories)
- Sorting of the 3D data according to the markers used in the measurement
- Selecting of an appropriate part of the data and export of this selection.
Parameters used in the study
- Kinematic parameters of pelvic motion
Anterior pelvic tilting
Pelvic rotation
- Kinetic parameter
Plantar flexor moment

Measurement

Q tract measurement was started when the patient passed the starting position. She continued walking several meters beyond the volume to allow the Q Trac measurement to be completed and to prevent gait ending effect as slowing her walking speed.

Patients hit the force plate with one foot and the therapist made sure that she did not make any target on it. First procedures were done while the patient was wearing shoes without heel shoes then heel heights were gradually increased to 1.5 cm, 3 cm, and 4.5 cm. All measurements were repeated at 28th, 32nd and 36th weeks of gestation. All data was processed and edited in Q Trac before using in the Q gait software the parameters.

Statistical analysis

Repeated measures ANOVA was used to compare study parameters for different heel heights. *Post hoc* pairwise analyses with Bonferroni corrected p values were performed in significant F test results. Results are presented as mean±standard deviation (SD).

Recording and analysis of data were performed by Microsoft Excel® (Microsoft Corporation, Redmond, WA) and SPSS for Windows (SPSS Inc., Chicago, IL). Statistical significance level was set to 0.05 for all calculations.

Results

Fifty normal primigravid women at 24 weeks of gestation were recruited to study according to the eligibility criteria. Their ages ranged from 20 to 30 years old (25.1±4.6 years), heights ranged from 150 to 170 cm (165.7±1.7) and weights ranged from 54.5 to 89 kg (68.6±8.6), 54 to 90 kg (69.3±7.5), 55 to 91 kg (70.5±8.6) and 56 to 92.5 kg

Table 2. Motion capture parameters with different heel heights.

Motion capture parameters	Heel heights				P value*
	Flat[a]	1.5 cm[b]	3 cm[c]	4.5 cm[d]	
Pelvic tilting (degrees)					
24 wk	4.47±1.18[bcd]	4.18±1.20[ad]	4.02±1.36[ad]	4.68±1.13[abc]	<0.001
28 wk	5.04±1.21[bcd]	4.58±1.06[ad]	4.29±1.33[ad]	5.31±1.26[abc]	<0.001
32 wk	5.68±1.31[c]	5.45±1.24[d]	5.17±1.31[ad]	6.64±1.26[abc]	<0.001
36 wk	7.78±1.66[abc]	6.74±1.39[ad]	6.41±1.51[a]	6.12±1.70[ab]	<0.001
Pelvic rotation (degrees)					
24 wk	10.08±1.86[bcd]	8.81±1.75[ad]	9.04±2.01[ad]	10.63±1.85[abc]	<0.001
28 wk	10.67±1.89[bcd]	9.71±1.99[ad]	9.88±2.26[ad]	11.26±2.18[abc]	<0.001
32 wk	10.91±1.94[cd]	10.51±2.16[d]	9.95±2.10[ad]	11.93±2.11[abc]	<0.001
36 wk	11.52±1.93[c]	11.13±1.58[cd]	10.48±1.83[abd]	11.88±1.81[bc]	<0.001
Plantar flexor moment (N·m/kg)					
24 wk	1.26±0.13	1.25±0.13	1.26±0.13	1.25±0.13	0.35
28 wk	1.30±0.13[c]	1.29±0.12	1.28±0.12[a]	1.29±0.13	0.02
32 wk	1.29±0.10[bc]	1.25±0.12[ad]	1.25±0.12[ad]	1.28±0.12[bc]	<0.001
36 wk	1.27±0.12[ab]	1.24±0.12[a]	1.24±0.11[a]	1.26±0.11	<0.001

Values are expressed as mean ± SD

* Overall P value, repeated measures ANOVA test.

a,b,c,d denotes flat, 1.5 cm, 3 cm, and 4.5 cm heel heights respectively. All values are presented as mean±standard deviation. Superscripts associated with figures shows statistically significant differences in *post hoc* analyses with Bonferroni corrected P values (<0.05).

(71.5±8.7) at 24th, 28th, 32nd, and 36th weeks of gestation, respectively.

There was a statistically significant decrease in anterior pelvic tilting between the flat footwear and both 1.5 cm and 3 cm heel heights of footwear for all measurements. On the contrary there were statistically significant increases between the flat footwear and 4.5 cm heel heights of footwear throughout the gestation (**Table 2, Figure 1**).

Also there was a statistically significant decrease in pelvic rotation between the flat footwear and both 1.5 cm and 3 cm heel heights in all measurements. On the contrary there was a statistically significant increase between the flat footwear and 4.5 cm heel heights of footwear in all measurements (**Table 2, Figure 2**).

Finally differences in plantar flexor moment were not significant at 24th week for different heel heights. There was a statistically significant decrease in plantar flexor moment between the flat footwear and both of 1.5 cm and 3 cm heel heights throughout 28th, 32nd, and 36th weeks of gestation. The difference between the flat footwear and 4.5 cm heel height was not significant in all measurements (**Table 2, Figure 3**).

Discussion

Pregnant women were recommended wearing low heeled (but not flat) shoes during pregnancy. However, there is no specific recommendation about the heel length. Additionally, there was no previous study objectively assessed the effect of heel length on gait parameters during pregnancy. In this study, three different heel lengths were assessed for gait parameters at 24th, 28th, 32nd, and 36th weeks of gestation.

Our results were compatible with previous knowledge that excessive heel length has adverse effects on gait parameters. However, we objectively found that gait parameters most significantly worsened at 4.5 cm and also found that 1.5 to 3.0 cm heel heights associated with optimal changes on gait parameters in all measurements.

The decreased anterior pelvic tilting was observed when footwear of 1.5 cm and 3 cm heel heights can be attributed to the movement of line of gravity (LOG) posteriorly nearly to its normal placement. This resulted in reduced lumbosacral angle and anterior pelvic tilting in comparison to the flat footwear. Wearing 4.5 cm heel height of footwear, there was exaggerated movement of LOG which resulted in increased lumbar lordosis, lumbosacral angle and anterior pelvic tilting.

Foti *et al*. evaluated the flat foot walking of pregnant women and found a significant increase in the anterior pelvic tilting associated with pregnancy that could be explained by the increase in the amount of body mass located in a lower abdomen causing a forward rotating moment that tends to rotate the pelvis forward [10].

Additionally, Bendix *et al*. found that flattening of the lumbar spine and a tendency of pelvis to roll backward in response to wearing high heeled shoes relative to barefoot [11].

Opila-Correia investigated the kinematics of high-heel foot (ranged from 5 cm to 7 cm) gait with consideration for age and experience of wearer. He found that there were significant difference in the way of pelvis, trunk and upper trunk accommodated for footwear to assist in absorbing the greater vertical lordosis of the trunk as younger ages had more anterior pelvic tilt, more posterior upper trunk and an increased trunk lordosis [12].

On the other hand, the results obtained in this study were not compatible with De Lateur and colleagues, who failed to found any significant difference in the back, hip or pel-

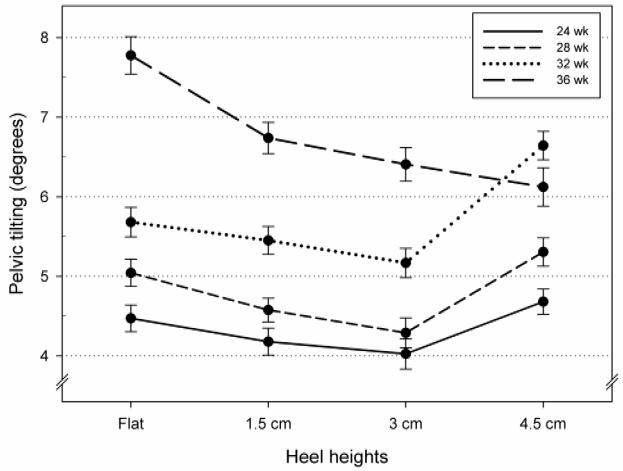

Figure 1. Changes in pelvic tilting in 24th, 28th, 32nd and 36th gestational weeks with different heel heights.

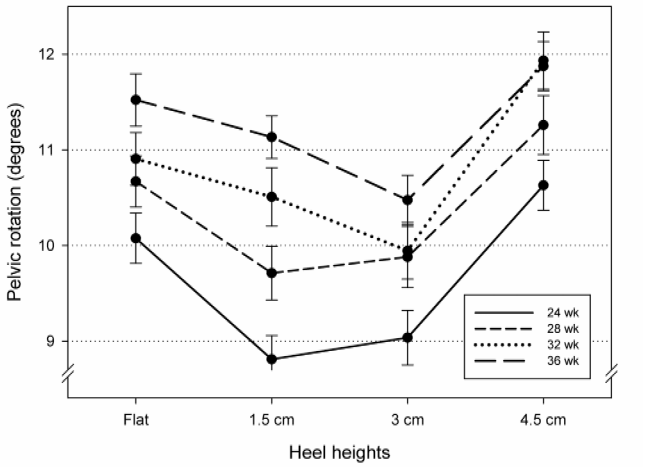

Figure 2. Changes in pelvic rotation in 24th, 28th, 32nd and 36th gestational weeks with different heel heights.

vic tilt angles among subjects who were barefooted, wearing shoes with negative heels or high heels [13].

Snow and Williams, investigated the effect of different heel heights (1.91 cm, 3.81 cm, and 7.62 cm) on the three dimensional kinematics. They found no significant differences or trend among heel heights for pelvic tilt, average lumbar curvature, or range of shoulders and pelvic rotation in the transverse plane [14].

The results of this study revealed that footwear with heel heights of 1.5 cm and 3 cm are the most appropriate heel heights for pregnancy as they are causing minimum change in the anterior pelvic tilting. Footwear with 4.5 cm heel height as well as the flat shoes are not advisable to be worn during pregnancy as they caused maximum change in the anterior pelvic tilting.

In the present study, pelvic rotation was decreased significantly while wearing footwear with 1.5 cm and 3 cm heel heights at 24th, 28th, 32nd, and 36th weeks of gestation. While, with the footwear of 4.5 cm heel height, pelvic rotation increased significantly throughout all measurements.

The results obtained in this study can be explained as wearing medium heels (1.5 cm and 3 cm) effectively lengthen the lower limbs for the initial contact which optimizes the vertical displacement of center of mass (COM) (about 2.5 cm). Also, this decreased displacement of COM resulting in decreased angular displacement which in turn leads to increased linear displacement and smoothness of gait.

Increasing pelvic rotation while wearing flat shoes can be explained by the postural changes occurring during pregnancy. Normally the LOG falls approximately 4 cm anterior to the first sacral segment that is close to the axis of the hips around which pelvic rotation occurs [15].

The increased pelvic rotation observed at heel height of 4.5 cm was in accordance with the findings of Opila-Correia, who found that chronically using high heel women had exaggerated rotation of the pelvis [12].

Furthermore, Foti *et al*. investigated the biomechanical alteration in gait during pregnancy and found that there was a significant increase in hip abduction/adduction power due to increased body mass during pregnancy [10]. Eng and Winter investigated the kinetic analysis of the lower limbs during walking on normal 9 male subjects and they found that the hip power phases were the result of the hip abductor muscles controlling the pelvis, and a small absorption burst during weight acceptance was the result of external rotation which decelerated the forward rotation of the pelvis [16].

In contrast, Opila-Correia investigated the kinematics different heel heights ranged from 0 cm to 2 cm (as low heel) and from 5 cm to 7 cm (as high heel) in nongravid females and he added that pelvic rotation did not significantly differ for different heel heights in both transverse and frontal planes. Also, he explained that the shorter stride length of high heeled gait causes illusion of the exaggerated rotation of the pelvis [17].

In this study, plantar flexor moment showed no significant changes between the different heel heights at the 24th week gestation. In the 28th, 32nd, and 36th weeks of gestation there was a significant decrease of plantar flexor mo-

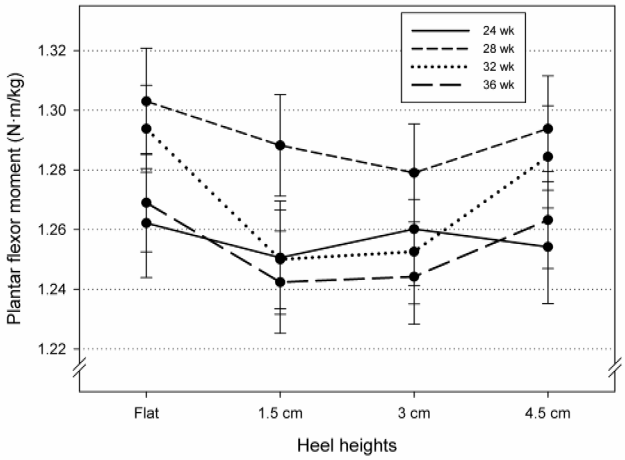

Figure 3. Changes in plantar flexor moments in 24th, 28th, 32nd, and 36th gestational weeks with different heel heights.

ment wearing 1.5 cm and 3 cm heel heights of footwear. On the contrary, there was no significant difference between the flat and 4.5 cm heel heights in all measurements as both have high plantar flexor moment in comparison with 1.5 cm and 3 cm heel heights.

The results of this study showed that there is an increased plantar flexor moment during pregnancy with increasing gestation. There was a natural tendency for anterior displacement of the trunk which may be counter balanced by increased activities of gastrocnemius and soleus muscles. In medium heels (1.5 cm and 3 cm) of footwear, elevating heels move LOG closer to the ankle joint. This generate plantar flexor moment lower than the moment generated in the 4.5 cm heel heights. Elevated heels into a position move the LOG more anteriorly to the ankle joint need more plantar flexor moment to maintain body balance.

Furthermore, Eng and Winter stated that normally during walking, the plantar flexors eccentrically controlled the forward rotation of the leg over the foot (mid stance to terminal stance) and then, concentrically generated a rapid push off [16]. Ebbeling *et al*., found that during the support phase of the gait cycle, the body must attenuate the vertical forces as the foot makes contact with the ground. This is done by eccentric contraction of ankle dorsiflexors during ankle plantar flexion and eccentric contraction of knee extensors during knee flexion [18].

Our results are also in agreement with Ebbeling *et al*. who investigated the effect of different heel heights (1.25 cm, 3.81 cm, 5.08 cm and 7.62 cm) on 15 females and found that the increased heel height placed the foot in a more plantar flexed position at the initiation of support [18]. At the two intermediate heel heights, the ankle reached moderately dorsiflexion while, at the highest heel height the ankle never attained a dorsiflexion, so, dorsiflexors were not able to act eccentrically to attenuate the vertical forces as much as normal during weight acceptance.

Opila-Correia was also found that instability caused by increased plantar flexion of the feet and smaller area of support with high heeled shoes (5 cm to 7 cm) was reflected in a cautious gait style, particularly in inexperienced wearer of high heeled shoes [17].

Snow and Williams showed that the soleus muscle was more powerfully contracted in high heels compared with low heels. Maximum plantar flexion was less in the low and medium heels (1.91 cm and 3.81 cm, respectively) compared with the high heels (7.62 cm) [14].

These results was in disagreement with Esenyel *et al*. who found that walking in high heeled shoes causes a significant reduction in ankle plantar flexor muscles moment, power and work occurred during the stance phase. This reduced plantar flexor muscles moment resulted in a compensatory enhanced hip flexors that assisted in limb advancement during the stance to swing transition [19].

The results suggesting that medium heel heights between 1.5 cm and 3 cm of footwear is the most appropriate to be worn by the pregnant women as these medium heel heights have minimal impact on the pelvis, back and calf muscles. This in addition to antenatal education focusing on postural correction exercises, abdominal exercises and posterior pelvic tilting exercises can help the pregnant women with minimal musculoskeletal discomfort.

Conclusion

In summary, 1.5 cm and 3 cm heel heights are advisable to be worn during pregnancy to help the pregnant women to pass through their pregnancies without or with minimal musculoskeletal discomfort.

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