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The relationship between trunk and pelvis kinematics during pregnancy trimesters

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Purpose: Pregnancy is characterized by many musculoskeletal changes that affect daily living activities and walking. The purpose of this study was to examine the effect of pregnancy on pelvic and trunk kinematics, and their relationship during the three pregnancy trimesters. *Methods:* Three-dimensional pelvis and trunk motions were measured using Qualisys Gait Analysis System in the first, second and third trimesters of pregnancy. The maximum anterior pelvic tilt and maximum trunk flexion during stance phase, pelvic tilt, obliquity and rotation, as well as trunk flexion-extension, lateral bending and rotation were measured. *Results:* Repeated-measures analysis of variance showed a significant increase in the maximum anterior pelvic tilt during stance phase ($p = 0.005$), and a significant decrease in the pelvic obliquity ($p = 0.011$), maximum trunk flexion during stance phase ($p = 0.0006$), trunk lateral bending ($p = 0.005$) and trunk rotation ($p = 0.004$). A significant negative correlation was found between maximum anterior pelvic tilt and maximum trunk flexion in the first ($r = -0.72$, $p = 0.008$), second ($r = -0.61$, $p = 0.03$), and third ($r = -0.61$, $p = 0.03$) trimesters of pregnancy. Also, there was a significant positive correlation found between pelvic obliquity and trunk lateral bending in the first ($r = 0.76$, $p = 0.04$), second ($r = 0.59$, $p = 0.04$), and third ($r = 0.59$, $p = 0.04$) trimesters of pregnancy. *Conclusions:* The pregnant women walk with an increased maximum anterior pelvic tilt, a decreased maximum trunk flexion, a decreased pelvic obliquity, as well as a decreased trunk lateral bending and rotation. Pregnancy does not affect the relationship between pelvis and trunk motions.

Key words: *pregnancy, pelvis, motion analysis, trunk*

1. Introduction

Walking is an essential daily activity and it is important to control the weight gain associated with pregnancy [22]. Women experience several changes in the body's physiology, morphology, and hormonal system over 38 to 42 weeks of pregnancy. These changes are increased weight, skeletal alignment changes, increased joint laxity, and change in the center of gravity (CG). These changes affect the body balance and can cause discomfort and pain [2]. When the fetus reaches 40% of the expected final weight, the CG is maximally displaced anteriorly [11]. The increased weight changes trunk's center of mass [16], alters spinal alignment [26] and places a greater demand placed on hip abductor, hip extensor, and ankle plantar flexor muscles during walking [11].

It is well known that hormonal changes occur in women during pregnancy and the level of certain hormones causes the laxity of the ligaments and joints. Laxity in the lumbar spine ligaments, symphysis pubis, and sacroiliac joints may affect mobility of the pelvic girdle, creates some instability at these joints, and leads to muscle strain [26].

Pregnancy leads to a significant decrease in the step length of the gait cycle [3], and a significant increase in the double support time [3], [11]. Other studies showed a significant reduction in the single support time [11], and a significant increase in the step width [13]. Also, there is a significant increase in the base of support [2], [9]. During late pregnancy, there is a significant decrease in speed and cadence [7], [10].

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The angular displacement of the pelvis increases the anterior tilt by approximately 5 degrees [11]. The joints of the lower limb in the sagittal plane show an increase in hip flexion during stance phase [3], [11] an increase of knee flexion during the swing phase, a decrease of knee extension, and a decrease of ankle dorsiflexion and plantarflexion [3]. In the frontal plane, Gilleard [13] found a reduction in the amplitude of the unilateral elevation of the pelvis. There are contradicted results related to the hip joint. Foti et al. [11] found a peak with a greater magnitude in the hip adduction; however, Branco et al. [3] found a decrease in this peak.

Evidence suggests that trunk kinematics relative to the pelvis during daily activities and walking play an important role in the locomotor control [19], and its abnormality results in the development of common conditions such as low back pain [20]. The kinematic pattern of the trunk and pelvis during pregnancy has received little attention in the literature [11], [13], [30]. Also, the relationship or coupling between kinematics of the pelvis and trunk in the different trimesters of pregnancy has not been studied.

Recording trunk and pelvis mechanics and its relationship may provide further insight into the control strategy used by the pregnant women during walking. Also, it may help to identify abnormal mechanics that may relate to low back pain during pregnancy. Therefore, the aim of this study was (1) to examine the three-dimensional kinematics of the pelvis and trunk during pregnancy trimesters, and (2) assess the relationship between the pelvis and trunk motions in different trimesters of pregnancy. It was hypothesized that the motion of the trunk and pelvis and their relation would alter as pregnancy progressed.

2. Materials and methods

2.1. Study subjects

Twenty pregnant women in their 1st trimester, about 12 weeks' gestation (WG), engaged in this study. All pregnant women were right-handed. Women with diabetes, preeclampsia, twins, low back pain, sacroiliac or symphyseal joint pain, cardiac disease, neurological problems, deformities, and previous surgeries at their back or lower limbs were excluded from this study. Ultrasonography was used to calculate the gestational age of each pregnant woman. All pregnant women were instructed about the assessment procedures. A signed agreement was obtained. The Research Ethical Committee of the Faculty of Physical Therapy, Cairo University, Egypt, approved the study.

The participants have undergone evaluation procedure three times by the same examiner; in the first trimester, 12 weeks gestation (WG), the second trimester, 22–24 (WG), and in the third trimester, 34–36 (WG). The average age of participants at the time when the study started was 24±2 years. The body height of females did not change during the whole experiment (160.5 ± 2.2 cm). The body weight was 59.8 ± 4.6 kg in the first trimester.

2.2. Instrumentation

Three-dimensional motion analysis system (Qualisys Company, Gothenburg, Sweden) was used to analyze gait of each pregnant woman. It is valid and reliable [15]. It consisted of six Pro Reflex cameras and a personal computer. The cameras (type 170120; 100–240 V; 50–60 Hz; 230 mA) recorded motion data at a sample rate of 120 Hz. Wand-kit, model number 130440, was used for the calibration of the system and a computer for data processing and analysis with the Q-track software.

Thirteen reflecting spherical markers were placed on special bony landmarks of each woman. Trunk markers were placed on the tip of each acromion, 7th cervical vertebra, 10th thoracic vertebra, and the pelvic markers were placed on the sacrum (S2), and each of the anterior superior iliac spine (ASIS). Other markers were placed on the lateral malleolus, heel and between the second and third metatarsals of each leg. The previous markers placement was performed as described by Tranberg [27]. It showed high intra-repeatability [9]. Although pelvic soft tissue artifact may be a source of error [14], pelvic kinematics are still one of the most reliable measures in the gait analysis with the lowest error in the pelvic rotation and obliquity that is clinically acceptable [25].

2.3. Measurement procedures

After calibration of the motion analysis system, each pregnant woman was asked to walk barefoot three trials at a self-selected speed. A complete gait cycle, from the first to second initial contact of the right leg of each pregnant woman was analyzed. Gait data was processed in the Q-Trac software, in which the Euler angle was employed for the kinematic data [27]. For the calculation of the pelvic and trunk angles, three coordinate systems were used: the pelvic system, the upper trunk system, and the gait progression system.

Pelvic angles were calculated by using the gait progression system as a proximal coordinate system and the pelvic reference system as a distal one. The right and left ASlS markers, and the mid-posterior superior iliac spine (PSIS) marker (sacrum marker) defined the pelvic marker reference frame. The y-axis was a line passing through the right and left ASIS markers, the x-axis was a line passing through the mid-PSIS marker and the midpoint of the line between the ASlSs, and the z-axis was a line perpendicular to the x-y plane at the intersection of the x and y-axes. The gait progression system had its z-axis parallel to the z-axis of the laboratory system (pointing upwards along the vertical axis). However, the y-axis was perpendicular to both the z-axis, as well as the gait progression line. The x-axis was then oriented according to the right-hand rule. The trunk angles were calculated in relation to the pelvic reference frame. The upper trunk system had its origin at the midpoint between the acromion markers (the acromion midpoint). The z-axis was pointing upwards along the line through the 12th marker and the acromion midpoint. The y-axis was pointing to the left along the line going through both acromion markers, and the x-axis was oriented according to the right-hand rule [27]. The motion analysis system assumed the trunk as a rigid segment; it did not measure the thoracic or lumber segment movements.

Pelvis and trunk motions were measured in the sagittal, coronal and transverse planes. The pelvic tilt was measured when the upper pelvis rotated anteriorly and posteriorly. The pelvic obliquity angle was recorded when the lateral pelvis was moving upwards and downward. The pelvic rotation angle was measured when the lateral pelvis was moving forwards and backward. The motion analysis system assumed the trunk as a rigid segment; it did not measure the thoracic or lumber segment movements. It measured the trunk flexion-extension angle when the trunk moved into flexion and extension. The trunk lateral bending was recorded when the trunk bent to the right and left, and the pelvis kept in the neutral position. The trunk rotation was measured when the pelvis moved forward and backward. The values of maximum peaks of the pelvis and trunk curves in the sagittal, coronal and transverse planes were recorded. These peaks included pelvic anterior and posterior tilt, pelvic hike, drop, forward and backward rotation, as well as trunk flexion, extension, right and left lateral bending, forward and backward rotation. Then, pelvis (tilt, obliquity, and rotation) and trunk motions (flexion-extension, lateral bending, and rotation) were calculated. Total range of motion of the previous motions was computed by subtracting the maximum two peaks of each curve [18]. Also, the maximum peak of anterior pelvic tilt and trunk flexion during the double limb support phase were recorded. Data of the three gait cycles selected from the three trials were averaged to calculate the mean values for the angles measured.

2.4. Statistical analysis

Data was analyzed using the Statistical Package for Social Sciences version 13.0 (SPSS Inc., Chicago, IL, USA). Repeated measures analysis of variance (ANOVA) test was used for analysis of the pelvic and trunk kinematic data. If the repeated measures test showed significant results, the Tukey's test was used to determine which trimester mean values were significantly different from each other. Pearson's correlation coefficient was used to assess the correlation between the pelvis and trunk motions in the sagittal, coronal and transverse planes. The level of significance was set at 0.05 for all statistical results.

3. Results

There was a significant increase in the body weight of participants ($p < 0.001$). The mean weight was 59.8 ± 4.6 kg in the first trimester, and 71.8 ± 5.6 kg in the third trimester. It represented an increase of 11.7 kg.

As regards the kinematics of the pelvis and trunk, there were significant changes in the maximum anterior pelvic tilt during stance phase ($p = 0.005$), pelvic obliquity ($p = 0.011$), maximum trunk flexion during stance phase ($p = 0.006$), trunk obliquity ($p = 0.005$) and trunk rotation ($p = 0.004$). However, it showed no significant changes in the pelvic tilt ($p = 0.141$), pelvic rotation ($p = 0.073$) and trunk tilt ($p = 0.132$). Also, it showed no significant change in velocity throughout pregnancy, as shown in Table 1.

The post hoc test for the first and second evaluation (first and second trimester) showed a significant decrease in the maximum trunk flexion during stance phase ($p = 0.002$), and no significant changes ($p > 0.05$) in the pelvic and trunk in coronal and transverse planes, as well as maximum anterior pelvic tilt during stance phase. Moreover, there were no significant changes in

Table 1. Repeated measures analysis of variance (ANOVA) test for pelvic and trunk kinematics during gait in different trimesters of pregnancy

Variables	1st trimester (n = 20) Mean (SD)	2nd trimester (n = 20) Mean (SD)	3rd trimester (n = 20) Mean (SD)	p-value
Velocity	1(0.1)	0.97(0.1)	0.96(0.1)	0.1
Maximum pelvic tilt during stance phase (°)	8.5 (4.9)	10.1 (3.5)	13.8 (5.2)	0.005*
Pelvic tilt (°)	2.9 (1)	2.5 (0.8)	2.7 (0.8)	0.14
Pelvic obliquity (°)	7.5 (2)	6.7 (1.8)	6.3 (1.8)	0.011*
Pelvic rotation (°)	10.8 (3.4)	9.1 (2.4)	8.9 (2.4)	0.07
Maximum trunk flexion during stance phase (°)	22.1 (5.3)	16.2 (5)	14.4 (5.1)	0.0006**
Trunk tilt (°)	4.4 (1.1)	4.1 (1)	3.6 (1.1)	0.13
Trunk obliquity (°)	12.2 (2.6)	11.1 (2.7)	10.4 (2.7)	0.005*
Trunk rotation (°)	15.2 (3.1)	14.1 (2.4)	12.1 (2.8)	0.004*

* – Significant at $p < 0.05$, ** – highly significant at $p < 0.001$.

Table 2. Correlations between pelvic and trunk motions during gait in different trimesters of pregnancy

	First trimester r (p)	Second trimester r (p)	Third trimester r (p)
Maximum pelvic tilt and maximum trunk flexion	–0.72 (0.008)*	–0.61 (0.03)*	–0.61(0.03)*
Pelvic obliquity and trunk obliquity	0.76 (0.004)*	0.59 (0.04)*	0.59(0.04)*
Pelvic rotation and trunk rotation	0.18 (0.56)	0.07 (0.82)	0.40(0.19)

r – Pearson's correlation coefficient, * – significant difference ($p < 0.05$).

all pelvic and trunk kinematic data between the second and third trimester ($p > 0.05$).

Comparing the first trimester to the third trimester, the pregnant women showed significant changes in the pelvic and trunk kinematics. There was a significant increase in the maximum anterior pelvic tilt during stance phase (p = 0.019), and a significant decrease in the pelvic obliquity (p = 0.022), maximum trunk flexion (p = 0.002), trunk obliquity (p = 0.007) and trunk rotation (p = 0.003). However, there was no significant change in the pelvic and trunk tilt ($p > 0.05$).

As regards correlation, there was a significant negative correlation between maximum anterior pelvic tilt and maximum trunk flexion in the first trimester (r = –0.72; p = 0.008), second trimester (r = –0.61; p = 0.03), and third trimester (r = –0.61; p = 0.03). There was a significant positive correlation between pelvic and trunk obliquity in the first trimester (r = 0.76; p = 0.004), second trimester (r = 0.59; p = 0.04), and third trimester (r = 0.59; p = 0.04). However, there was no correlation between the pelvic and trunk rotation in the different trimesters of pregnancy ($p > 0.05$), as shown in Table 2.

4. Discussion

This study was conducted to evaluate changes in the pelvic and trunk kinematics and their relationships during different trimesters of pregnancy. The results of the current study revealed that there is a decrease in the maximum trunk flexion during stance phase between the first and second trimester. Moreover, there was an increase in the maximum anterior pelvic tilt during stance phase, and a decrease in the pelvic obliquity, pelvic rotation, and maximum trunk flexion during stance phase, trunk lateral bending, and trunk rotation, when comparing the first trimester with the third trimester. The increase in the anterior pelvic tilt was consistent with the findings of Foti et al. [11], who reported the same finding in the third trimester of pregnancy.

The lower trunk has significantly greater rates of change than all other body segments during the second and third trimester of pregnancy [16]. The increased maximum anterior pelvic tilt during pregnancy is attributed to the increased mass in the anterior lower part of the trunk and the increased moment arm, which represents the distance between the center of the spine motion and center of gravity of forward abdominal mass [6] that produces high forward moment resulting in an increase of maximum anterior pelvic tilt.

The negative relationship between maximum trunk flexion and anterior pelvic tilt in different trimesters of pregnancy reflects the adaptation of the trunk angle to that of the pelvis in the sagittal plane. Decreased maximum trunk flexion during the stance phase may help the pregnant woman to keep the CG fall within the base of the support for maximizing her balance during walking. The decreased maximum trunk flexion may be attributed to increases in body mass and width, as well as changes in mass distribution about the trunk [11].

The non-pregnant women walk with the trunk bends anteriorly from the heel strike to the double limb support phase to enhance forward progression [5]. Reduced trunk flexion indicates that the pregnant women may exhibit extended trunk posture, which leads to decreased forward progression during walking. Extended trunk posture may control the shift of CG and thus decrease the force the erector spinae must develop to oppose the anterior moment of the abdominal mass [16]. The previous finding is in agreement with the findings of McCrory et al. [24], who reported an increase in the thorax extension at heel strike in the second and third trimesters of pregnancy. Moreover, the extended thorax would result in a greater anterior pelvic tilt during locomotion.

In the coronal plane, the pelvic obliquity and trunk lateral bending significantly decreased throughout pregnancy. Decreased pelvic obliquity may be attributed to the growth of the gravid uterus, which expands out of the pelvis superiorly, anteriorly and laterally after 12 WG [6]. Normal body kinematics depends on the smooth trunk-pelvic coordination [19]. Although the pregnant women showed a restriction in the kinematics of the pelvis and trunk in the frontal plane, the coupling between the trunk and pelvic kinematics in the frontal plane was not affected. Trunk obliquity significantly related to pelvic obliquity in different trimesters of pregnancy. This result was supported by the findings of Whittle and Levine [28], who reported a strong relationship between the trunk lateral bending and pelvic obliquity in non-pregnant women.

Pelvic obliquity has previously been identified as a determinant of gait. It plays an important role in the shock absorption during gait [12] and keeps the whole body balance [21]. It has been reported that reduced pelvic obliquity may be associated with increased stance-phase knee flexion, to avoid an increase in the vertical ground reaction force in non-pregnant subjects [18]. However, McCrory et al. [23] reported no change in the ground reaction force during pregnancy. The decrease in the pelvic obliquity can be attributed to the significant increase in the base of support during walking in pregnant women [2]. Although step width increases, pelvic width also increases; thus, the ratio of the base of support to pelvic width remains constant [11].

In the transverse plane, the pregnant women showed a decrease in trunk rotation ROM, and a trend toward a decrease in the pelvic rotation as pregnancy progressed. Reduced pelvis motions in the coronal and transverse planes agreed with the findings of Gilleard [13]. Furthermore, reduced pelvic rotation agreed with the finding of the study of Wu et al. [30], who compared the pregnant women with nulligravida. They reported a decrease in the thoracolumbar motion in the transverse plane. Regarding the step length; however not studied, previous literature reported a decrease in the step length during pregnancy [1], [13], which may have a cause of a decreased trunk and pelvic rotation. However, it is also possible the converse is true that the reduced trunk and pelvic rotation may result in a reduced stride length.

Control of the trunk is important for posture and balance because the upper body mass constitutes two-thirds of the body mass [29]. It is suggested that reduced trunk motions may be useful for the pregnant women to maximize their stability. However, combined trunk and pelvic motions restriction could affect the locomotor activities. This restriction can explain why the pregnant women find some difficulties in performing some daily living activities, which require trunk and pelvis movements [17].

There are conflicting results of changes in gait velocity during pregnancy [13], [24], [30]. In the present study, gait velocity showed no significant change as pregnancy progressed, and this finding agreed with the longitudinal study conducted by Gilleard [13]. Evidence showed that the walking speed affects the trunk motions relative to the pelvis [8]. Thus, the decreased trunk motions observed in the present study may be attributed to other factors related to pregnancy that need further investigations and not to changes in the velocity.

Lastly, there are some limitations of this study. First, there was no control group of non-pregnant women to determine if there are changes in the first trimester of pregnancy compared with non-pregnant peers. Second, pelvic soft tissue artifact due to increased abdominal circumference may be a source of error [14] and affect the results of the present study. However, the pregnant women with excessive adipose tissue that obscured the ASIS markers were excluded from the present study to reduce this error. Third, the motion analysis system assumed the trunk as one segment and did not provide data about segmental movements such as the thoracic or lumbar segment. Finally, this study examined only the kinematics of the trunk and pelvis without consideration of spatiotemporal gait parameters such as stride length, kinetics analysis or the relationship between kinematics and kinetics changes during the pregnancy trimesters.

Further studies are warranted to investigate the factors underlying the reported changes in trunk and pelvic motions during pregnancy. Future work is needed to investigate the effect of pelvic soft tissue artifact on pelvic and lower extremities kinematics using different markers setup for the pelvic region during pregnancy. Moreover, longitudinal studies are needed to determine changes in gait after childbirth for identifying if the pregnant women return to the non-pregnant state or there may be residual changes in trunk and pelvic motions after pregnancy. More research is needed to explore the relationship between extended posture, erector spinae muscle electromyographic activities and low back pain.

5. Conclusions

Pregnancy leads to changes in pelvis and trunk motions, which were prominent in the third trimester. The pregnant women showed less maximum trunk flexion, increased maximum anterior pelvic tilting; and less trunk rotation and lateral bending. Pregnancy does not affect the relationship between pelvis and trunk motions in the sagittal and frontal planes.

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Conflict of interest statement

There are no financial and personal relationships with other people or organization, which may lead to a conflict of interest.

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