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Investigation of the impact levels of pregnancy on balance

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Abstract

Introduction: Pregnancy is accompanied by progressive biomechanical and physiological adaptations that may impair postural balance and increase the risk of musculoskeletal disorders.

Objectives: This study aimed to investigate the effects of pregnancy on postural balance, medial longitudinal arch height, and lumbar lordosis in pregnant women.

Methods: In this cross-sectional study, 64 healthy pregnant women attending obstetrics and gynecology outpatient clinics were recruited and classified according to gestational trimester (first, second, and third). Demographic characteristics, parity, the Berg Balance Scale (BBS), the Y Balance Test (YBT), the Navicular Drop Test (NDT), and lumbar lordosis angle were assessed.

Results: No significant differences were observed among the trimester groups in age, height, weight, body mass index, or YBT performance ($p > 0.017$). Parity and gestational week differed significantly between groups ($p < 0.017$). Women in the third trimester demonstrated significantly greater navicular drop and lumbar lordosis angles, together with lower BBS scores, than those in the first and second trimesters ($p < 0.017$). Multiple linear regression analysis revealed that gestational week and parity were significant predictors of navicular drop ($R^2 = 0.70$, $p < 0.001$). To maintain an overall alpha level of 0.05 during multiple group comparisons, a Bonferroni correction was applied, setting the level of significance at $p < 0.017$.

Conclusion: Advancing pregnancy, particularly during the third trimester, is associated with impaired postural balance, increased navicular drops, and greater lumbar lordosis. These findings highlight the importance of routine assessment of balance and musculoskeletal adaptations during antenatal care to facilitate early identification of women at increased risk of functional impairment and to guide targeted preventive interventions.

Keywords: Foot arch; Lordosis; Postural balance; Pregnancy; Trimester

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1. Introduction

Pregnancy is characterized by profound physiological, hormonal, and biomechanical adaptations that enable fetal growth while simultaneously altering maternal musculoskeletal function. Progressive increases in body mass, enlargement of the uterus, and redistribution of body weight result in substantial changes in posture, gait, and movement strategies throughout gestation.[1,2] Although these adaptations are considered physiological, they may compromise postural stability, increase the mechanical demands on the musculoskeletal system, and contribute to a greater risk of falls and pregnancy-related musculoskeletal disorders.[3,4]

Maintaining postural balance depends on the central nervous system's continuous integration of visual, vestibular, and somatosensory information to generate appropriate motor responses that keep the body's center of mass within the base of support.[5] During pregnancy, this finely coordinated system is challenged by progressive anatomical and biomechanical alterations. As gestation advances, anterior displacement of the center of mass caused by fetal growth and maternal weight gain requires compensatory postural adjustments to preserve stability.[6] These adaptations include increased lumbar lordosis, anterior pelvic tilt, altered trunk alignment, and modifications in lower-extremity joint kinematics, all of which influence balance control and movement efficiency.[1,7]

In addition to mechanical changes, hormonal adaptations contribute substantially to altered postural control during pregnancy. Increased concentrations of relaxin, estrogen, and progesterone promote ligamentous laxity and joint hypermobility, particularly in the pelvis, to facilitate childbirth.[3,8] However, these hormonal effects are not restricted to the pelvic region. Increased ligament laxity throughout the lower extremities may reduce passive joint stability and alter proprioceptive input, thereby impairing neuromuscular control mechanisms responsible for maintaining postural equilibrium.[1] Simultaneously, stretching and weakening of the abdominal musculature reduce trunk stability and further increase dependence on compensatory postural strategies.[9]

Pregnancy-related biomechanical adaptations also affect foot structure and function. Increased body weight combined with ligamentous laxity can lead to progressive flattening of the medial longitudinal arch, increased foot pronation, and greater navicular drop during the later stages of pregnancy.[10,11] These alterations modify plantar pressure distribution and may compromise the quality of somatosensory feedback originating from the foot, which represents one of the primary sensory interfaces responsible for postural regulation.[12,13] Because efficient balance control relies heavily on accurate plantar sensory input, structural changes in the foot may contribute to decreased postural stability beyond the direct effects of increased body mass alone.

Lumbar alignment also appears to play an important role in pregnancy-related balance alterations. Increased lumbar lordosis develops as a compensatory mechanism to offset anterior displacement of the center of mass and maintain upright posture.[1,14] Although this adaptation reduces the forward bending moment, excessive lumbar curvature increases compressive loading across the lumbar spine and sacroiliac joints while modifying trunk muscle activation patterns.[1] These biomechanical changes may impair postural control and partly explain the high prevalence of low back pain, pelvic girdle pain, and functional limitations reported during pregnancy.[14]

The clinical importance of these adaptations extends beyond musculoskeletal discomfort. Falls during pregnancy represent a significant public health concern because they may adversely affect both maternal and fetal health. Previous studies have reported that approximately one in four pregnant women experiences at least one fall during pregnancy, with a considerable proportion resulting in injury requiring medical attention.[3,15] More recent epidemiological evidence continues to identify impaired balance as an important contributor to fall risk during pregnancy, particularly during the third trimester when biomechanical demands reach their maximum.[3,16] Consequently, identifying modifiable factors associated with balance impairment has become increasingly important for optimizing prenatal care and preventing pregnancy-related complications.

Despite growing evidence that pregnancy affects postural stability, several limitations remain within the current literature. A recent systematic review has highlighted considerable heterogeneity in study designs, assessment protocols, and outcome measures, resulting in inconsistent findings regarding postural adaptations across pregnancy.[17] Many previous studies have primarily relied on laboratory-based stabilometric assessments using force platforms, whereas relatively few have combined clinically applicable functional balance tests with musculoskeletal parameters that may explain balance impairment. Furthermore, most investigations have evaluated lumbar posture, foot morphology, or postural balance independently rather than exploring their complex interactions across different stages of gestation.[1,17] Although pregnancy-related changes in spinal alignment, foot biomechanics, and postural control have each been described, the combined influence of lumbar lordosis, medial longitudinal arch alterations,

gestational age, body mass index (BMI), and parity on functional balance remains insufficiently understood.[14,18]

Addressing these gaps may improve understanding of the mechanisms underlying postural instability during pregnancy and facilitate the development of targeted preventive rehabilitation strategies. Identifying the clinical factors most strongly associated with balance impairment may also support early screening of women at increased risk of falls and musculoskeletal dysfunction during antenatal care. Therefore, the present study aimed to investigate trimester-related changes in postural balance among healthy pregnant women and to examine the associations of lumbar lordosis angle, navicular drop, gestational week, BMI, and parity with functional balance performance. We hypothesized that advancing gestational age, particularly during the third trimester, would be associated with increased lumbar lordosis, greater navicular drops, and impaired postural balance.

2. Materials and methods

This cross-sectional study was conducted to investigate the effects of pregnancy on postural balance and pregnancy-related musculoskeletal adaptations. Specifically, the study examined whether functional balance performance differed across pregnancy trimesters and explored the associations of lumbar lordosis angle, navicular drop, BMI, gestational age, and parity with balance outcomes.

2.1. Participants

A total of 64 healthy pregnant women were recruited from the obstetrics and gynecology outpatient clinics of Near East University Hospital and Kyrenia University Hospital in Northern Cyprus via convenience sampling. Women aged between 18 and 35 years who were in the first, second, or third trimester, had a singleton pregnancy, and had no rigid foot deformity were eligible to participate. Participants were excluded if they had a twin or multiple pregnancy, were at risk of preterm birth, were unable to stand independently for prolonged periods, had any diagnosed musculoskeletal, neurological, vestibular, or systemic disorder that could affect balance, including gestational diabetes mellitus, preeclampsia, and anemia, or declined to participate. Data collection was conducted between December 2020 and February 2021, following ethics approval granted on November 26, 2020.

We stratified participants into first (up to 13 weeks and 6 days), second (14–26 weeks and 6 days), and third (27 weeks and above) trimester groups to allow clinically meaningful, stage-specific comparisons of physiological and biomechanical adaptations that are known to vary across gestation.[14,19,20]

The study protocol received approval from the Scientific Research Ethics Committee of Near East University (Approval No. YDU/2020/85-1191; November 26, 2020). All participants provided written informed consent before enrollment. The research was conducted in accordance with the ethical principles set forth in the World Medical Association Declaration of Helsinki. The necessary sample size was calculated with G*Power (version 3.1.9.4, Heinrich-Heine-Universität Düsseldorf, Germany), using parameters informed by prior studies that assessed postural balance during pregnancy.[1,21] For a one-way analysis of variance comparing three groups, assuming a medium effect size ($f = 0.40$), an alpha level of 0.05, and a power ($1-\beta$) of 0.80, the minimum total sample size was calculated as 60 participants (20 per trimester). A total of 77 pregnant women were screened for eligibility. Of these, 13 were excluded: nine did not meet the inclusion criteria due to multiple pregnancy ($n = 3$), at-risk pregnancy ($n = 4$), or gestational diabetes mellitus ($n = 2$), and four declined to participate. The study included 64 healthy pregnant women (first trimester, $n = 22$; second trimester, $n = 22$; third trimester, $n = 20$), ensuring sufficient statistical power for the planned comparisons and regression analyses (Figure 1).

2.2. Procedure

All assessments were performed during a single testing session at the participating hospitals. Before data collection, participants received a standardized explanation of the study procedures and testing protocol. Demographic characteristics, including age, height, body weight, BMI, gestational week, and parity, were recorded.

Following demographic assessment, participants underwent evaluation of functional balance using the Berg Balance Scale (BBS) and the Y Balance Test (YBT). Foot posture was assessed using the Navicular Drop Test (NDT), and sagittal spinal alignment was evaluated by measuring the lumbar lordosis angle. All measurements were performed by the same experienced physiotherapist using standardized assessment procedures to ensure consistency throughout the study.

The BBS and YBT scores were considered the primary indicators of postural balance, whereas lumbar lordosis angle and NDT measurements were included as biomechanical variables potentially associated with balance performance. Gestational age, BMI, and parity were also incorporated into the statistical analyses as potential explanatory variables.

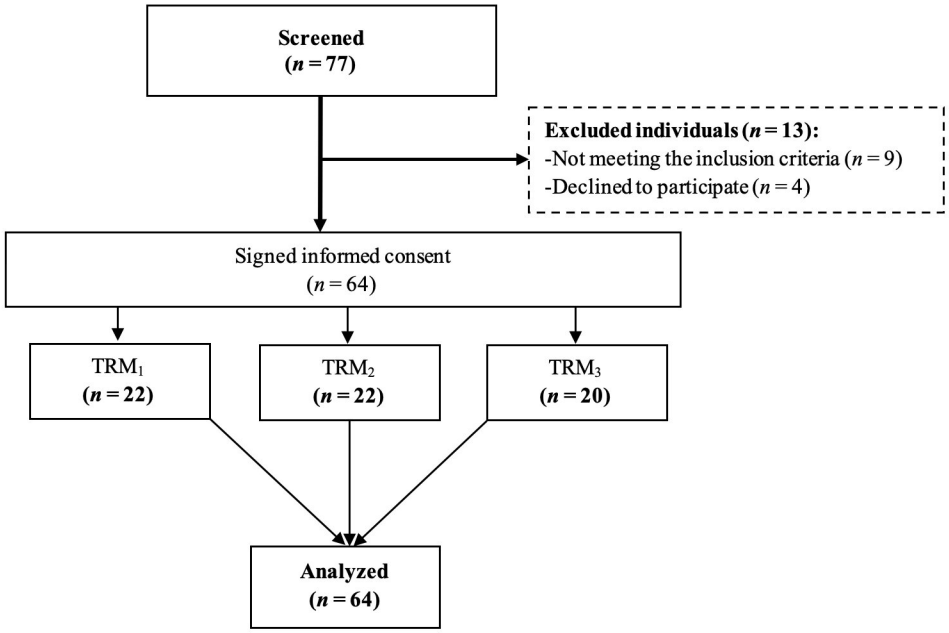


Figure 1. Flow chart of the individuals included in the study
Abbreviation: TRM: Trimester.

2.3. Data collection tools

2.3.1. Balance assessment

The YBT and the BBS were used to assess balance. Functional balance was first evaluated using the BBS, a 14-item validated instrument designed to measure both static and dynamic balance through common activities of daily living.[22] The clinician monitored participants while they completed tasks of increasing difficulty, from unsupported sitting to single-leg standing. Each task was rated on a 5-point scale (0–4), with higher scores denoting better, more independent performance. The maximum total score of 56 represented optimal balance, while scores approaching 36 indicated an increased risk of falls.

Following the BBS, dynamic balance was quantified using the YBT. To prepare the testing area, three 150-cm measuring tapes were fixed to the floor at standardized angles. While staying balanced on one leg at the grid's center, participants used their other foot to reach as far as they could in three specific directions: anterior, posteromedial, and posterolateral.[23] After a standardized warm-up and 5–6 minutes of rest, participants performed three trials in each direction for both limbs while keeping their hands on their hips. A trial was repeated if the participant failed to maintain balance, removed their hands from their hips, or could not return to the starting position. Using a standard measuring tape, researchers determined lower limb length by measuring the distance from the anterior superior iliac spine to the ipsilateral medial malleolus. Reach distances were normalized to lower limb length by dividing the reach distance (cm) by leg length (cm) and multiplying by 100.

2.3.2. Medial longitudinal arch measurement

Foot posture and medial longitudinal arch integrity were assessed using the NDT. This test quantifies foot pronation by calculating the difference in the height of the navicular tubercle between a non-weight-bearing sitting position (hip and knee at 90°) and a bilateral weight-bearing standing position.[24] The height of the navicular tuberosity from the floor was measured in mm in both positions, and the difference provided a clinical indication of the medial longitudinal arch height and dynamic foot deformation.

2.3.3. Evaluation of lumbar lordosis

Standing lumbar lordosis was measured using a smartphone-based digital inclinometer application (Clinometer; version 4.9.4, Apple Inc., USA), following the clinical technical protocol validated by Salamh and Kolber.[25] Participants were instructed to stand in a comfortable, neutral upright position with their arms resting alongside the body. To ensure accurate instrument placement, the spinous processes of the twelfth thoracic (T12) and first sacral (S1) vertebrae were identified by palpation and used as anatomical landmarks. The T12

landmark was located by palpating the twelfth rib and tracing it medially to the corresponding spinous process, whereas the S1 landmark was identified by locating the iliac crests to estimate the L4–L5 level and then palpating caudally to the sacral region. Following palpation, both landmarks were marked on the participant's skin. The smartphone-based inclinometry protocol described by Salamh and Kolber[25] has demonstrated excellent inter-rater reliability (intraclass correlation coefficient = 0.96; 95% confidence interval [CI]: 0.92–0.98), good intra-rater reliability (intraclass correlation coefficient = 0.81; 95% CI: 0.61–0.91), and a minimal detectable change of 7°, supporting its clinical utility for assessing standing lumbar lordosis.

The smartphone was positioned directly over each marked landmark with the power-button side of the device contacting the skin (Figure 2). Inclination measurements were obtained at the superior (T12–L1) and inferior (S1–S2) regions. The lumbar lordosis angle was calculated as the sum of the inclination angles recorded at these two anatomical landmarks.[25] All measurements were performed by a single experienced physiotherapist to ensure consistency in landmark identification, device positioning, and measurement procedures.[26]



Figure 2. Measurement technique with iPhone inclinometer placed at L5–S1 (inset shows T12–L1 placement)

2.4. Data analysis

The Statistical Package for Social Sciences (SPSS 27.0, IBM, United States) was utilized for the statistical analysis. To evaluate whether the data followed a normal distribution, the Shapiro–Wilk test was applied alongside a visual review of histograms. For continuous variables, descriptive statistics were reported as mean ($\bar{X}$) and standard deviation (SD).

To compare demographic characteristics, balance performance (YBT and BBS scores), navicular drop, and lumbar lordosis angles among the three trimester groups, a one-way analysis of variance was utilized for normally distributed data. To identify specific group differences following any statistically significant main effects, post-hoc pairwise comparisons were performed with a Bonferroni correction applied. Due to multiple comparisons among the three groups, the significance threshold for these analyses was adjusted to $p < 0.017$.

A multiple linear regression model was constructed to identify significant predictors of foot posture, with the NDT score as the dependent variable. A backward elimination procedure included lumbar lordosis angle, BMI, parity, and gestational age as candidate predictors (entry $p < 0.05$; removal $p > 0.10$). Prior to fitting the model, we performed standard diagnostic checks to verify regression assumptions: multicollinearity was assessed using variance inflation factors (all <2.0), residual normality was examined using the Shapiro–Wilk test and Q–Q plots, homoscedasticity was evaluated by plotting standardized residuals versus fitted values and tested with the Breusch–Pagan test, and influential observations were assessed with Cook's distance (no observations exceeded 1.0). Where necessary, model robustness was confirmed by re-running analyses after removal of potential influential points; results were unchanged. Standardized regression coefficients (β), standard errors (SE), *t*-statistics, 95% CI, the *F*-statistic, and R^2 are reported for the final model. Statistical significance was set at $p < 0.05$.

3. Results

Table 1 summarizes the participants' demographic and obstetric characteristics. Comparisons between the trimester groups revealed no statistically significant differences regarding height, weight, age, or BMI ($p > 0.017$). A significant difference in parity (birth count) was observed between the TRM_1 and TRM_2 groups ($p_1 = 0.01$), whereas no significant differences were found between the TRM_2 and TRM_3 ($p_2 = 0.12$) or between the TRM_1 and TRM_3 ($p_3 = 0.04$) groups after Bonferroni adjustment.

Table 2 presents the results for functional and dynamic balance. Across all trimesters, none of the YBT reached directions showed any statistically significant differences ($p > 0.017$). However, functional balance assessed via the BBS showed a significant decline between the TRM_1 and

Table 1. Demographic and obstetric characteristics of the participants according to trimester

Characteristics	TRM_1 ($\bar{X}$ ± SD)	TRM_2 ($\bar{X}$ ± SD)	TRM_3 ($\bar{X}$ ± SD)	p_1 (TRM_{1-2})	p_2 (TRM_{2-3})	p_3 (TRM_{1-3})
Age	29.75 ± 5.00	32.35 ± 4.41	30.21 ± 3.95	0.08	0.13	0.74
Weight (kg)	69.80 ± 10.93	70.45 ± 10.97	72.79 ± 9.54	0.89	0.47	0.36
Height (cm)	164.75 ± 4.60	163.85 ± 3.94	164.00 ± 5.44	0.56	0.88	0.45
BMI (kg/cm^2)	25.79 ± 4.54	26.20 ± 3.56	27.21 ± 3.48	0.74	0.40	0.24
Parity	1.05 ± 0.84	1.70 ± 0.84	1.42 ± 2.47	0.01[a]	0.12	0.04

Notes: [a]Bonferroni-adjusted statistical significance was set at $p < 0.017$; p values were derived from one-way analysis of variance with Bonferroni post-hoc pairwise comparisons.
Abbreviations: BMI: Body mass index; SD: Standard deviation; TRM: Trimester.

Table 2. Comparison of dynamic balance performance across trimesters using the YBT and BBS

YBT sub-tests	TRM_1 ($\bar{X}$ ± SD)	TRM_2 ($\bar{X}$ ± SD)	TRM_3 ($\bar{X}$ ± SD)	p_1 (TRM_{1-2})	p_2 (TRM_{2-3})	p_3 (TRM_{1-3})
ANT-right (cm)	41.10 ± 2.63	37.35 ± 2.63	39.10 ± 2.40	0.32	0.62	0.58
ANT-left (cm)	41.88 ± 2.84	40.15 ± 2.84	40.60 ± 2.59	0.67	0.90	0.74
PM-right (cm)	46.88 ± 2.30	47.13 ± 2.30	45.63 ± 2.10	0.94	0.63	0.69
PM-left (cm)	45.73 ± 2.80	52.00 ± 2.80	47.00 ± 2.55	0.12	0.19	0.74
PL-right (cm)	59.87 ± 2.40	62.02 ± 2.40	64.85 ± 2.19	0.53	0.39	0.13
PL-left (cm)	59.97 ± 2.70	60.30 ± 2.70	64.24 ± 2.47	0.93	0.29	0.25
BBS total	54.70 ± 2.87	52.50 ± 4.12	51.13 ± 5.47	0.13	0.31	0.01[a]

Notes: [a]Bonferroni-adjusted statistical significance was set at $p < 0.017$; p values were derived from one-way analysis of variance with Bonferroni post-hoc pairwise comparisons.
Abbreviations: ANT: Anterior; BBS: Berg Balance Scale; PL: Posterolateral; PM: Posteromedial; SD: Standard deviation; TRM: Trimester; YBT: Y Balance Test.

TRM_3 groups ($p_3 = 0.01$), while no significant differences were observed between TRM_1 and TRM_2 ($p_1 = 0.13$) or TRM_2 and TRM_3 groups ($p_2 = 0.31$) (Table 2).

Regarding foot arch characteristics, the NDT results revealed that the NDT values in the TRM_3 group were significantly higher than those in both the TRM_1 and TRM_2 groups ($p_2 < 0.01$, $p_3 < 0.01$), indicating a more pronounced drop in the navicular height during the late stages of pregnancy. In contrast, no statistically significant difference was observed between the TRM_1 and TRM_2 groups ($p_1 = 0.02$), as the value did not meet the Bonferroni-adjusted significance threshold of $p < 0.017$ (Figure 3).

The analysis of lumbar lordosis demonstrated that the lordosis angles were similar between the TRM_1 and TRM_2 groups (33.30 ± 6.57° and 33.55 ± 10.81°, respectively), with no statistically significant difference ($p_1 = 0.93$). In contrast, the TRM_3 group exhibited a significantly greater lumbar lordosis angle (45.96 ± 7.41°) than both the TRM_1 ($p_3 < 0.01$) and TRM_2 ($p_2 < 0.01$) groups, indicating a marked increase in lumbar lordosis during the third trimester of pregnancy (Figure 4).

To identify the factors associated with navicular drop, a backward multiple linear regression analysis was performed including lumbar lordosis angle, BMI, parity, and gestational age as candidate predictors. Variables were entered at $p < 0.05$ and removed at $p > 0.10$. During the backward elimination procedure, lumbar lordosis angle and BMI were excluded from the final model, whereas parity and gestational age remained significant predictors of navicular drop. The final regression model was statistically significant ($F_{(2,61)} = 46.55$, $p < 0.01$) and explained 70% of the variance in navicular drop ($R^2 = 0.70$). Gestational

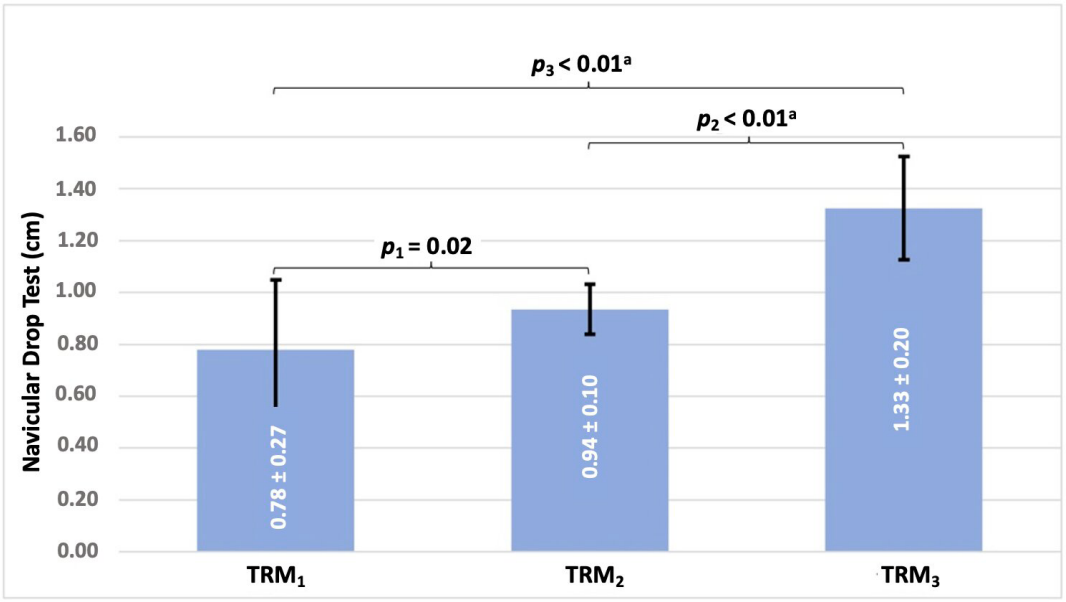


Figure 3. Comparison of navicular drop values among trimester groups
Note: [a]Bonferroni-adjusted statistical significance was set at $p < 0.017$.
Abbreviation: TRM: Trimester.

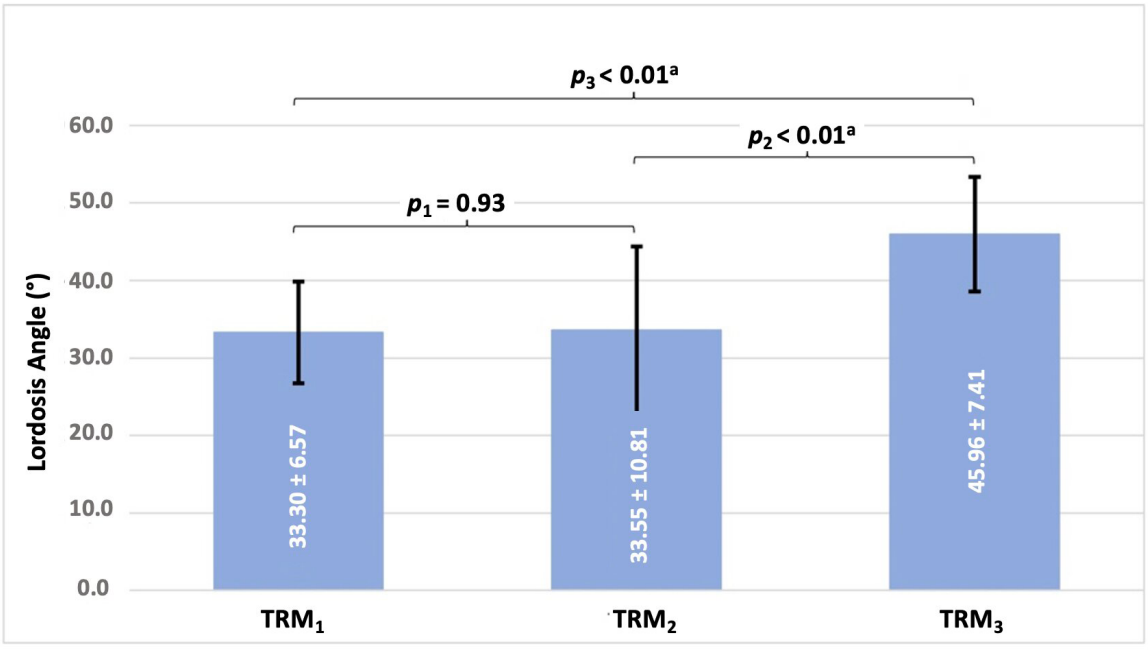


Figure 4. Comparison of lumbar lordosis angles among trimester groups
Note: [a]Bonferroni-adjusted statistical significance was set at $p < 0.017$.
Abbreviation: TRM: Trimester.

age was the strongest positive predictor (β = 0.811, $p < 0.01$), whereas parity demonstrated a modest negative association with navicular drop (β = −0.164, $p = 0.043$). Variance inflation factors were all below 2.0, indicating no significant multicollinearity among the predictors in the final model (Table 3).

Table 3. Backward multiple linear regression analysis of factors associated with navicular drop

Predictor	β	SE	R^2	*t*	*p*	95% CI	VIF
Parity	−0.164	0.079	0.14	−2.062	**0.04***	−0.322–−0.005	1.12
Gestational age	0.811	0.079	0.70	10.213	**<0.01***	0.652–0.960	1.12

Notes: *$p < 0.05$; predictor p-values were obtained from a backward multiple linear regression model (entry $p < 0.05$; removal $p > 0.10$).
Abbreviations: β: Standardized regression coefficient; CI: Confidence interval; SE: Standard error; VIF: Variance inflation factor.

4. Discussion

The present study investigated whether balance, foot posture, and lumbar sagittal alignment differ across the first (TRM_1), second (TRM_2), and third (TRM_3) trimesters of pregnancy, and whether selected maternal characteristics predict navicular drop. The main findings can be summarized as follows. First, demographic variables such as age and BMI were comparable across trimester groups, whereas gestational age differed as expected and parity differed only between the first- and second-trimester groups after Bonferroni adjustment. Second, foot posture and lumbar alignment changed primarily in late pregnancy: navicular drop and lumbar lordosis were both significantly greater in the third trimester than in the first and second trimesters. Third, functional balance, as assessed by the BBS, declined significantly between the first and third trimesters, whereas no between-group differences were observed in any direction of the YBT. Finally, in the regression model, gestational age emerged as the strongest predictor of navicular drop, while parity also remained a significant predictor; in contrast, lumbar lordosis angle and BMI did not contribute independently to the final model. Taken together, these findings suggest that late pregnancy is characterized by clinically relevant changes in foot posture, spinal curvature, and functional balance, but that dynamic reach performance may be preserved through compensatory strategies.

Maternal age did not differ significantly among the three trimester groups and, importantly, the mean ages of all groups remained below the threshold usually associated with advanced maternal age. This is relevant because adverse obstetric outcomes have been reported more frequently in older pregnant women, including higher rates of hypertensive disorders, gestational diabetes, fetal growth restriction, preterm birth, and other complications.[27,28] In the present sample, however, the relatively homogeneous age distribution and the absence of high-risk pregnancies likely reduced the potential influence of maternal age on postural or balance-related outcomes. In addition, although maternal age is clearly important in obstetrics, there is still limited direct evidence that age, within a relatively young and healthy pregnant sample, independently drives trimester-related changes in balance or foot posture. Our findings therefore suggest that, under uncomplicated conditions, gestational progression rather than chronological age is more relevant to postural adaptation.

Similarly, BMI was not significantly different across trimesters and did not independently predict navicular drop in the final regression model. This finding is consistent with the notion that absolute BMI may be too crude a measure to capture pregnancy-specific biomechanical loading. Previous studies have emphasized that excessive weight gain and obesity may aggravate musculoskeletal complaints and alter posture during pregnancy.[4,10,29] However, when BMI values are relatively similar across groups, as in the present study, BMI may not be sufficiently sensitive to explain differences in balance or arch behavior. This interpretation also aligns with Ersal *et al.*,[30] who reported that pregnancy-related weight gain alone may not be enough to produce major changes in balance performance. In other words, how mass is redistributed during pregnancy, rather than BMI per se, may be more important for postural control.

Parity deserves more nuanced interpretation. In the unadjusted group comparison, parity differed significantly only between the first and second trimesters. In the regression analysis, parity remained a significant predictor of navicular drop, although the direction of the association was modest and inverse after adjustment for gestational age. This adjusted result should be interpreted cautiously. Prior pregnancy exposure may leave residual musculoskeletal adaptations, including persistent changes in lower-extremity loading and foot structure, as suggested by earlier work showing that pregnancy-related musculoskeletal changes and foot pronation may persist postpartum.[10,31] However, the negative coefficient in the present model indicates that the relationship between parity and navicular drop is not purely linear once current gestational age is accounted for. This may reflect sample-specific distribution, adaptive mechanisms in multiparous women, or the fact that cumulative reproductive history

and current pregnancy progression influence foot posture through partly different pathways. Accordingly, parity appears relevant, but its biological meaning requires confirmation in larger longitudinal cohorts.

One of the clearest findings of the present study was the significant increase in navicular drop in the third trimester. This indicates a greater lowering of the medial longitudinal arch in late pregnancy and is consistent with previous reports describing progressive foot pronation and decreased arch height during gestation.[2,7,10,32] Several mechanisms likely contribute to this pattern. First, pregnancy-related hormonal changes, especially increased ligamentous laxity associated with relaxin and other endocrine factors, may reduce passive support around the foot and ankle complex.[1,33] Second, the combined rise in body mass and the anterior displacement of the center of mass elevate plantar loading, particularly in the later weeks of pregnancy.[10,34] Third, prolonged exposure to these mechanical demands may progressively stress the medial arch, resulting in greater navicular displacement by the third trimester.[35,36]

Gestational age was the strongest predictor of navicular drop, indicating that the duration of pregnancy-related loading and adaptation may be more important than static anthropometric variables. This is clinically meaningful because it suggests that foot posture changes are not simply a byproduct of body size, but may represent a time-dependent response to pregnancy progression. This also fits with recent work emphasizing the importance of pregnancy stage when interpreting postural control and movement adaptations.[16,17,37] From a biomechanical perspective, the medial longitudinal arch may behave as a cumulative stress-sensitive structure throughout pregnancy, with the third trimester representing the point at which compensatory capacity becomes less effective and structural lowering becomes more evident.[1]

Lordosis angles were comparable in the first and second trimesters, but increased significantly in the third trimester. This finding is consistent with the well-established view that pregnancy, particularly late pregnancy, is associated with an anterior shift in the body's center of mass and compensatory changes in lumbopelvic alignment.[1,9] As the uterus enlarges and abdominal volume increases, women may adopt a more extended lumbar posture to maintain upright stance and preserve sagittal balance. This adaptation may help maintain visual orientation and whole-body stability, but it may also increase lumbar loading and contribute to discomfort or reduced functional efficiency.[14,18]

Notably, however, lumbar lordosis did not remain in the final regression model predicting navicular drop. This suggests that although lordosis and navicular drop both worsen in late pregnancy, they may represent parallel responses to the same underlying biomechanical challenge rather than a direct cause-and-effect relationship. Put differently, gestational progression may simultaneously influence spinal alignment and foot posture, but the unique contribution of lordosis to arch lowering may be limited once gestational age is considered. This distinction is important because it prevents overinterpretation of lordosis as the primary driver of foot changes. Instead, both variables may reflect broader pregnancy-related changes in center-of-mass regulation and musculoskeletal loading.[1,2,38]

Functional balance, measured with the BBS, was significantly lower in the third trimester than in the first trimester. This finding supports earlier work showing that postural control becomes more challenging as pregnancy advances, particularly during tasks that require controlled whole-body motion, weight transfer, and changes in the base of support.[6,39,40] The BBS captures precisely these kinds of functional demands. Although originally developed for older adults, it includes everyday balance tasks such as standing up, reaching, turning, and maintaining stability during transitions. These activities are highly relevant to pregnant women because they involve coordinated control of the trunk, pelvis, and lower limbs under changing mechanical constraints. The decline in BBS performance in late pregnancy likely reflects the combined effect of increased body mass, anterior displacement of the center of mass, increased trunk stiffness, and reduced efficiency of rapid postural adjustments. In addition, lumbopelvic discomfort, increased joint laxity, and altered proprioceptive input may further compromise performance in tasks requiring rapid reweighting or directional change. Although the BBS is not pregnancy-specific, our results suggest that it may still capture meaningful functional balance limitations in this population. This interpretation is compatible with previous studies showing that performance-based functional tests, including sit-to-stand and timed mobility tasks, are feasible and informative during pregnancy.[41-43]

Perhaps the most interesting finding of the study is the absence of significant trimester-related differences in YBT performance. At first glance, this may appear inconsistent with the observed deterioration in foot posture, lumbar lordosis, and BBS performance. However, several explanations may account for this pattern. First, the YBT may assess a different dimension of balance than the BBS. Whereas the BBS reflects functional balance during whole-body transitional tasks, the YBT primarily measures reach performance during controlled single-leg stance in three standardized directions. Success on the

YBT depends not only on balance but also on lower-limb flexibility, neuromuscular coordination, task familiarity, and deliberate pacing. Therefore, pregnant women may have preserved YBT reach distances across trimesters by adopting more cautious, slower, and highly controlled movement strategies. This interpretation is supported by recent findings from Dumke *et al.,*[37] who reported that pregnant women performed dynamic mobility tasks more slowly than nonpregnant controls as gestation advanced, while maintaining relatively similar movement quality. Such behavior suggests compensation rather than frank loss of dynamic control. Second, the lack of difference may reflect adaptive motor strategies developed during pregnancy. Pregnant women often increase movement caution, reduce speed, widen their base of support during daily activities, and rely more heavily on visual and anticipatory control to preserve stability.[6,39,40] These compensations may be particularly effective in a structured clinical test such as the YBT, where the participant is allowed to prepare, focus attention, and perform repeated trials under supervision. In other words, the YBT may permit successful compensation in healthy pregnant women, even when underlying biomechanics have changed substantially. Third, the methodological characteristics of the YBT may reduce its sensitivity to trimester-related differences in this specific population. In the present study, reach distances were normalized to lower-limb length, which is methodologically appropriate but also minimizes anthropometric variability.[44,45] Moreover, the participants were healthy and relatively homogeneous in terms of age and BMI, which may have further reduced between-group variance. A cross-sectional design may also obscure subtle within-person deterioration that would be more easily captured in a longitudinal follow-up. Thus, absence of statistical significance should not necessarily be interpreted as absence of adaptation. Fourth, the literature genuinely lacks studies examining the use of the YBT during pregnancy. The YBT is widely used and well established in sports medicine and general adult populations, but pregnancy-specific validation studies are lacking, and pregnancy is often treated as an exclusion criterion in YBT-related research.[46] The relatively low reach values observed across all groups may not indicate that the test is inappropriate, but rather that normative values developed for nonpregnant or athletic populations may not be transferable to pregnant women. Recent pregnancy balance research has focused more on gait, static posturography, and timed functional mobility than on directional reach tests like the YBT.[16,17,37] Therefore, the present finding may reflect both physiological compensation and the limited pregnancy-specific sensitivity of the YBT. This actually strengthens the novelty of the current study, because it suggests that dynamic reach performance and functional balance should not be assumed to change in parallel during pregnancy.

The regression model adds an important explanatory layer to the descriptive findings. The model was statistically significant and explained a large proportion of the variance in navicular drop, which supports the clinical relevance of the selected predictors. The fact that gestational age remained the strongest predictor is consistent with the broader interpretation that pregnancy progression itself is the dominant driver of foot-posture change. As gestation advances, repeated exposure to altered loading, hormonal influences, and center-of-mass displacement likely accumulates, making arch lowering more pronounced.[1,14,47] The finding that BMI did not remain in the final model is also informative. It suggests that general body size, at least as captured by BMI, contributes less to navicular drop than pregnancy-specific biomechanical progression.[18] Likewise, lumbar lordosis did not independently predict navicular drop once gestational age and parity were considered. This may be because lordosis is a visible compensatory manifestation of pregnancy-related sagittal adaptation, but not a direct determinant of medial arch collapse.[1,14] In other words, lordosis may co-occur with navicular drop without independently explaining it. The parity result requires the most cautious interpretation. Because parity remained significant but with a modest inverse coefficient, it would be inappropriate to conclude simply that higher parity protects against arch lowering. A more conservative interpretation is that reproductive history influences current foot posture in a complex manner, potentially through residual postpartum adaptations, altered connective-tissue behavior, behavioral experience from prior pregnancies, or sample-specific characteristics. This is also an area where the literature remains limited. Earlier work has suggested that some pregnancy-related musculoskeletal changes may persist after delivery,[10,31] but whether these long-term adaptations amplify or moderate foot-posture changes in subsequent pregnancies is still unclear. Future longitudinal studies should examine parity more carefully, ideally separating primiparous and multiparous women and tracking foot structure from early pregnancy into the postpartum period.

This study has several limitations. First, the cross-sectional design prevents the ability to track individual changes throughout pregnancy or establish causal relationships. Because participants were recruited by convenience sampling in a cross-sectional design, selection bias may be present; we therefore caution that between-group differences could reflect sample characteristics as well as gestational effects, and we recommend longitudinal

cohort studies to confirm within-person changes across pregnancy. Second, only healthy pregnant women were included; therefore, the findings may not apply to women with pain, obesity, high-risk pregnancies, or other comorbidities. Third, the YBT has not been specifically validated for pregnancy, and pregnancy-specific normative data are lacking, which complicates interpretation of the dynamic balance findings. Finally, potentially relevant variables such as physical activity levels, dietary patterns, pregnancy-related pain, ligament laxity, lower-extremity strength, and fall history were not incorporated into the analysis.

5. Conclusion

In conclusion, the present findings indicate that late pregnancy is associated with increased navicular drop, increased lumbar lordosis, and reduced functional balance, whereas YBT performance may remain relatively stable across trimesters, possibly because healthy pregnant women adopt effective compensatory movement strategies. Gestational age was the strongest predictor of navicular drop, underscoring the cumulative biomechanical effect of pregnancy progression, while parity also contributed to the model in a more complex manner. Overall, these results suggest that pregnancy-related change is more evident in foot posture and functional balance than in normalized directional reach performance, and that clinical assessment in pregnancy should therefore include task-specific, functionally meaningful measures rather than relying on a single balance test.

The findings have several practical implications. First, routine assessment of foot posture and functional balance may be particularly important in the third trimester, when navicular drop, lumbar lordosis, and BBS changes become more pronounced. Second, because gestational age was the strongest predictor of navicular drop, clinicians should not wait for symptoms to emerge before monitoring foot mechanics in late pregnancy. Third, the discrepancy between BBS and YBT findings suggests that functional balance tasks may be more clinically informative than isolated reach tests when screening pregnant women for balance-related difficulty. Fourth, women with greater gestational progression and distinct parity histories may benefit from targeted education regarding footwear, arch support, balance training, lumbopelvic stabilization, and fall prevention strategies. These interventions may be especially relevant during the final trimester, when mechanical demands are greatest. Finally, while this cross-sectional study provides important insights into trimester-specific differences, future research should utilize prospective, longitudinal designs to monitor the same cohort from the first through the third trimester to more effectively capture individual-level musculoskeletal adaptations across the full course of gestation. Furthermore, extending this research to include higher-risk populations, such as overweight or obese pregnant women with concomitant diseases, could benefit from the inclusion of specific biochemical markers to detect early coagulation disorders.

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Conflict of interest

The authors declare they have no competing interests.

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Ethics approval and consent to participate

The study protocol received approval from the Scientific Research Ethics Committee of Near East University (Approval No. YDU/2020/85-1191; November 26, 2020). All participants provided written informed consent before enrollment. The research was conducted in accordance with the ethical principles set forth in the World Medical Association Declaration of Helsinki.

Consent for publication

Written informed consent was obtained for publication of the figures and from each of the subjects to participate in the study.

Availability of data

The findings of this study are supported by data that can be obtained from the corresponding author following a reasonable request.

Further disclosure

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