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ORIGINAL RESEARCH

A Cross-Sectional Study of the Effect of Pregnancy on the Foot Arch Index of Women

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Abstract

Background: Pregnancy induces some changes in the musculoskeletal system. Few studies have investigated these changes, especially their effects on foot structures.

Objective: To examine the effect of pregnancy on women's foot arch index and determine the relationship between the foot arch index (FAI), Body Mass Index, and the gestational age of pregnant women.

Methods: A cross-sectional examination of a sample of 118 pregnant, 101 nulliparous, and 101 non-pregnant women (who had been previously pregnant) was conducted. Footprints were obtained using the Ink and Plain Paper method, and foot arch indices were obtained from their footprints.

Results: The study revealed a statistically significant difference ($p < 0.001$) in FAI between pregnant and non-pregnant women, with pregnant women exhibiting a higher average FAI. A positive linear correlation ($r = 0.354$, $p < 0.001$) was observed between BMI and FAI in pregnant women, indicating that higher BMI was associated with an increased FAI. Also, a statistically significant relationship between gestational age and FAI was observed among pregnant women ($r = 0.231$, $p = 0.012$). Altered FAI resulting from pregnancy persisted post-pregnancy. Age and weight were predictors of flat feet during pregnancy, whereas gestational age was not associated with the odds of flat feet.

Conclusion: Pregnancy induces significant changes in the foot arch. These changes persist beyond the pregnancy period. It is essential to monitor and address foot arch alterations during and after pregnancy, thus emphasising the need for appropriate interventions to mitigate potential discomfort and functional limitations in pregnant women and beyond.

Keywords: Biomechanics, Flat Foot, Foot Arch Index, Foot Health, Pregnancy.

Introduction

The foot arch is an important factor in maintaining proper foot biomechanics and gait, and alterations in the foot arch can lead to various foot and lower limb conditions. [1] The foot arch is also an essential structure of the foot, providing support and shock absorption during walking and running. The arches of the foot, especially the medial longitudinal arch, add to the weight-bearing capacity and resiliency of the foot. [2] It is composed of the bones, muscles, and ligaments of the foot, and its shape can vary with factors such as age, weight, and physical activity.

The Foot Arch Index (FAI) is an important parameter used to determine whether an individual has a flat foot. It is a measure of the height and width of the arch, and it is used to assess the foot structure and function. The FAI is a commonly used parameter for determining the presence of flatfoot or high arches in individuals. It is defined as the ratio of the midfoot length to the length of the foot and is often used as an indicator of foot structure and function. [3]

Pregnancy is a physiological state that can significantly affect the foot arch due to changes in hormonal and biomechanical factors. The increase in the hormone relaxin during pregnancy can cause the ligaments and joints of the foot to become laxer, leading to a decrease in the arch height and an increase in the foot width. As pregnancy progresses, the position of the centre of gravity shifts, and body mass increases, leading to greater load transferred to the weight-bearing joints. The resultant effects of these changes increase around the distal weight-bearing segments of the body, especially the foot, cause muscle imbalances, and distort the integrity of the weight-bearing structures and their related soft tissues. [4] During pregnancy, weight gain, hormonal changes, and alterations in body posture can affect the structure and function of the foot, leading to changes in the foot arch. These changes can affect the foot arch and lead to various foot and lower-limb conditions, such as plantar fasciitis, flat feet, and heel pain. [5]
Understanding the changes that occur in the foot arch during pregnancy is important for developing appropriate interventions to prevent and manage foot and lower limb conditions in pregnant women. Previous studies have shown that the foot arch index can be influenced by factors such as age, sex, body mass index, and physical activity level. [6]
Also, several studies have investigated changes in foot arch height and foot characteristics during pregnancy. A previous study comparing foot characteristics between pregnant and non-pregnant women found that pregnant women had significantly higher FAI than non-pregnant women. [5] Another study also reported that foot arch height decreased substantially during pregnancy. [1]
Studies in different locations have reported changes in the foot arches, indicating an increased likelihood of the occurrence of pes planus in the pregnant population. [7 - 9] Other studies have also shown significant increases in foot width, length, and volume with a concomitant decrease in arch height during pregnancy. [8]
Despite some insights into the relationship between pregnancy and foot health from previous studies, there remains an obvious need to further investigate this research area, especially in the Nigerian population, where indigenous research literature on the topic is limited. Therefore, this study is designed to address this knowledge gap. Understanding the foot arch indices in pregnant and non-pregnant women would provide valuable information for healthcare professionals (including Orthopedists and Orthotists), and footwear designers to develop appropriate interventions and footwear to prevent and manage foot and lower limb conditions in pregnant women. Additionally, this study will provide valuable information for pregnant women to be aware of the changes that

occur in their feet during pregnancy, help identify potential risk factors, and provide interventions to improve their foot health and overall well-being. This study aimed to investigate the effect of pregnancy on the FAI of women and to determine the relationships among the FAI, Body Mass Index, and gestational age of pregnant women.

Methods

Design

Comparative, cross-sectional study.

Definition and description of terminologies

The foot arch is the curved structure along the sole, formed by the arrangement of bones, tendons, and ligaments. It acts as a spring-like mechanism, supporting body weight, absorbing shock during movement, and enabling flexibility for activities like walking and running. The foot arch may be normal, flat, or high.

Normal Arch (Neutral Arch): This is an arch that is moderately raised, providing a good balance of flexibility and support. The footprint shows a clear curve along the inside of the foot, with the heel and ball of the foot connected by a moderate-width band. The biomechanics typically indicates a neutral gait (normal pronation).

Flat Arch (Low Arch / Pes Planus): This is the arch that is very low or nonexistent, causing the entire sole to touch the ground. From the footprint, nearly the whole foot is visible with minimal or no curve on the inside. Biomechanics often lead to overpronation (foot rolls in excessively).

High Arch (Pes Cavus): This is an arch that is very high and rigid, resulting in less of the foot contacting the ground. The footprint shows a very narrow band connecting the heel and forefoot; sometimes only the heel and ball are visible. Biomechanics often lead to underpronation (supination), in which the foot does not roll in enough.

Ethics

The study was granted ethical approval by the School of Health Technology, Federal University of Technology, Owerri, Imo State. Informed consent was obtained from all subjects before they participated in the study.

Sample size determination

The sample size was justified by estimating proportions with 95% confidence and a 5% margin of error. Using the standard formula for estimating proportions: $n = \frac{Z^2 \cdot p(1-p)}{e^2}$

Where: z = 1.96 for 95% confidence, p = 0.5 (maximum variability, for conservative estimate), and e = 0.05 (margin of error). The minimum sample size was calculated at 384, but a total of 320 participants was deemed sufficient for subgroup analysis.

Study population

The subjects were aged 18 to 40 years in Owerri, Imo state, Nigeria. They comprised 118 currently pregnant women and 202 non-pregnant women. Within the non-pregnant group, 101 participants have never been pregnant (nulliparous), while 101 had previously experienced pregnancy but were not pregnant at the time of data collection (primiparous and multiparous).

The inclusion criteria for pregnant women required a gestational age of at least 14 weeks (from the second trimester), a singleton pregnancy, and no history of foot or ankle injuries, foot swellings/inflammations, ulcers, or other foot conditions.

Sampling

The participants were selected by random sampling between April 2023 and August 2023. Pregnant women were recruited from antenatal clinics and maternity hospitals within Owerri. In contrast, non-pregnant women were selected from various locations, including schools, malls, markets, and other settings within the same time

frame. A convenience sampling technique was employed to recruit participants, and efforts were made to ensure a wide range of participants were included. Purposive sampling was utilised to select healthcare facilities that cared for a diverse population of pregnant women in Owerri.

Data Collection

Data collection utilised a purpose-designed structured questionnaire, which obtained participant's demographics, including age, weight (kg), height (cm), BMI (kg/m^2), and occupation, number of previous pregnancies, gestational age, and foot variables such as the foot arch index (FAI), foot pain, arch type (normal, flat, high), foot alignment (pronation, supination), toe structure (bunions, hammertoes), and lifestyle/activity level parameters like; (daily walking, standing time), and type of physical activity.

To measure the foot arch index (FAI), footprints of the participants were manually obtained using the ink-and-plain-paper method. This involved placing the subjects' feet on a glass tile impregnated with stamp ink and spreading it evenly with a roller brush to create an impression on plain white A4-size paper. The process utilised endorsing ink, white paper (A4), plain tile, roller brush, bowl, water, liquid soap, cotton wool, and acetone. After obtaining the footprints, the feet were washed with soap and water and cleaned with acetone. The footprint was clearly visible in the heel, midfoot, and forefoot. A bounding box around the footprint was created by drawing a rectangle that tightly fitted the entire footprint from the heel to the tip of the longest toe. The footprint was divided into three equal parts along its length: A (rear foot): Posterior third (heel region); B (midfoot): Middle third (arch region); and C (forefoot): Anterior third (ball of the foot/toe region). The area (m^2) of each of the three regions of the footprint was calculated using the formula: Area = length × Width. It should be noted that only the part of the foot that touched the ground was included, not the full bounding box.

Foot Arch Indices (FAI) were measured from footprints using the method proposed by Cavanagh and Rogers [10], which is the ratio of the mid-foot area to the total area excluding the toes; a higher ratio indicates a flatter foot. The FAI has since been found to be highly reliable. [11, 12]

The truncated foot length (without the toes) of the footprint area was divided equally into three sections, including the rear foot area (A), midfoot area (B), and forefoot area (C). On obtaining the areas of the three sections, the Foot Arch Index (FAI) was calculated by dividing the mid-foot area (B) by the total foot area (without the toes) using the formula:

$$FAI = \frac{B}{A+B+C}$$

Where:

After obtaining the index values for right and left feet of both genders, the foot types were classified into: high arched foot or pes cavus (arch index $\leq$0.21, normal foot (0.22 ≤ arch index < 0.26) and flat foot (arch index ≥ 0.26). [11, 13]

Figure 1 shows a sample of the right and left footprints, respectively, of one of the participants, indicating how the footprints of the participants were obtained and analysed in the study.

Statistical analysis

Data analysis for this study employed the Statistical Package for the Social Sciences (SPSS) version 24 as the primary tool. Sociodemographic characteristics and FAI values were summarised using descriptive statistics. At the same time, inferential statistical analyses, including t-tests and Levene's Test for Equality of Variances, were conducted to assess potential differences in FAI values between pregnant and non-pregnant women. Pearson correlation tests and multiple regression analysis were also deployed as necessary.

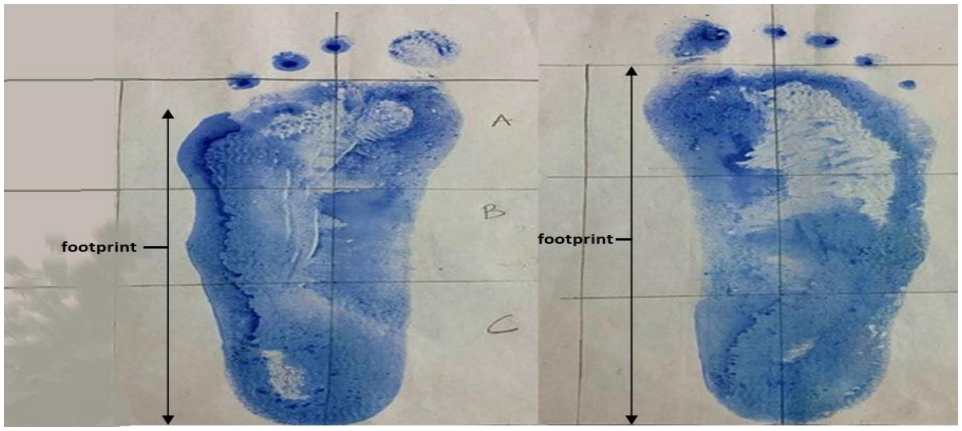

Figure 1: A sample of left and right footprints obtained using the Ink and Paper method

Results

Sociodemographic characteristics

The highest proportion of pregnant women fell within the 24-29 years age group, while the comparative groups were mostly aged 18-23 years and 30-34 years, respectively. A majority of non-pregnant women were categorised as "healthy" BMI (18.5 – 24.99 kg/m²) (65.3%), as shown in Table I. In contrast, among pregnant women, the majority were classified as "overweight" BMI (55.9%). Women who had been pregnant in the past but were currently non-pregnant also showed concentration in the "overweight" group (74.3%). Table I shows the demographic characteristics (age, BMI, and gestational age) of participants.

Correlation Between BMI and FAI of pregnant women

A statistically significant positive linear association was observed between the BMI of pregnant women and their FAI ($r = 0.354$, $p < 0.001$) (Table IV).

Correlation Between Gestational Age and FAI of Pregnant Women

Prevalence of different arch types among the three groups of women (Table II)

Pregnant women had the highest proportion of "Low Arch" on both the right (68.6%) and left (71.2%) feet. Non-pregnant women showed a distribution of 50.5% "Low Arch" on the right foot and 45.5% on the left foot. Similarly, women who had been pregnant before recorded 60.4% as "Low Arch" on the right foot and 62.4% on the left foot.

Table III shows a statistically significant difference in FAI between non-pregnant women (0.2507 ± 0.03248) and pregnant women (0.2714 ± 0.2961) at a p-value <0.001.

As shown in Table V, a statistically significant relationship ($r = 0.231$, $p = 0.012$) between gestational age and Foot Arch Index was observed among pregnant women.

Post-Pregnancy Foot Arch Changes

The findings in Table VI shows a statistically significant difference in the Foot Arch Index (FAI) between pregnant women and non-pregnant women ($t = 2.349$, $df = 216$, $p = 0.020$).

Table I: Sociodemographic characteristics

Variables	*Pregnant N (%)*	*Non-pregnant N (%)*	*Non-pregnant but have been pregnant before N (%)*
Age group (Years)			
18-23	11 (9.3)	35 (34.7)	7 (6.9)
24-29	45 (38.1)	35 (34.7)	21 (20.8)
30-34	42 (35.6)	22 (21.8)	46 (45.5)
35-40	20 (16.9)	9 (8.9)	27 (26.7)
BMI Classification			
Healthy (18.5 – 24.99 kg/m²)	11 (9.3)	66 (65.3)	16 (15.84)
Overweight (25 – 29.99 kg/m²)	66 (55.9)	24 (23.8)	75 (74.3)
Obese (≥30 kg/m²)	41 (34.7)	6 (5.9)	10 (9.9)
Underweight (<18.5 kg/m²)	0 (0.0)	5 (5.0)	0 (0.0)
Gestational age (in Months).			
4	19 (16.1)		
5	18 (15.25)		
6	22 (18.64)		
7	18 (15.25)		
8	19 (16.1)		
9	22 (18.64)		

Table II: Prevalence of different arch types among the three groups of women

Groups of Women	*Right Arch*						*Left Arch*					
	High Arch		*Normal Arch*		*Low Arch*		*High Arch*		*Normal Arch*		*Low Arch*	
	n	%	n	%	n	%	n	%	n	%	n	%
Pregnant women	3	2.5	34	28.8	81	68.6	3	2.5	31	26.3	84	71.2
Non-Pregnant women	11	10.9	39	38.6	51	50.5	15	14.9	40	39.6	46	45.5
Been Pregnant Before	9	8.9	30	29.7	61	60.4	8	7.9	29	28.7	63	62.4

Predictors of flat feet in pregnancy

The logistic regression analysis shows that age, weight, and gestational age of pregnant women can predict the occurrence of flat feet in pregnant women. Table VII reveals that weight (B = 0.076, p = 0.011) and age (B = 1.029, p = 0.032) were statistically significant predictors of the odds of having flat feet during pregnancy. In contrast, the role of gestational age (B = 0.181, p = 0.162) was not statistically significant in predicting the odds of flat feet during pregnancy.

Table III: Differences between FAI in pregnant and non-pregnant women

		Levene's Test for Equality of Variances		*t-test for Equality of Means*						
		F	*Sig.*	*t*	*df*	*Sig. (2-tailed)*	*Mean Difference*	*Std. Error Difference*	*95% Confidence Interval of the Difference*	
									Lower	*Upper*
Mean FAI	Equal variances assumed	0.226	0.635	-4.931	217	0.000	-0.02070	0.00420	-0.02897	-0.01242
	Equal variances not assumed.			-4.896	204.472	0.000	-0.02070	0.00423	-0.02903	-0.01236

Table IV: Correlation analysis between BMI and FAI among pregnant women

	Pearson correlation	*BMI (kg/m²)*	*Mean FAI*
Body Mass Index (kg/m²)	r		0.354
	p		<0.001
Mean FAI	r	0.354	
	p	<0.001	

Table V: Correlation analysis between gestational age and FAI among pregnant women

	Pearson correlation	*BMI (kg/m²)*	*Mean FAI*
Gestational age (weeks)	r		0.231
	p		0.012
Mean FAI	r	0.231	
	p	0.012	

Table VI: Differences between FAI in pregnant and post-pregnant states

		Levene's Test for Equality of Variances		*t-test for Equality of Means*						
		F	*Sig.*	*t*	*Df*	*Sig. (2-tailed)*	*Mean Difference*	*Std. Error Difference*	*95% Confidence Interval of the Difference*	
									Lower	*Upper*
Mean FAI	Equal variances assumed	4.497	0.035	2.349	216	0.020	0.00888	0.00378	0.00143	0.01633
	Equal variances not assumed.			2.308	189.375	0.022	0.00888	0.00385	0.00129	0.01647

Table VII: Logistic regression analysis of predictors of flat feet during pregnancy

		B	*S.E.*	*Wald*	*df*	*p-value*
Step 1	Weight	.076	.030	6.393	1	.011
	Gestational Age	.181	.129	1.951	1	.162
	Age	1.029	.479	4.611	1	.032
	Constant	-6.667	2.385	7.814	1	.005

B – Coefficient of Regression; SE – Standard Error of the Mean

Discussion

There is a high prevalence of low-arch feet among pregnant women, both on the right and left feet. This prevalence accentuates the impact of physiological changes and biomechanical adjustments that accompany pregnancy. The higher prevalence of low arch indexes among pregnant women is consistent with the existing literature [4, 7, 8, 16], which has documented the association between pregnancy and alterations in arch configuration. This phenomenon can be attributed to both physiological and hormonal changes during pregnancy, which can potentially compromise the integrity of the supportive soft tissues in the foot. These physical changes, often associated with increased body weight [14], are the primary factors influencing arch dynamics.

The study describes the relationship between pregnancy and post-pregnancy changes in foot structure and the foot arch index. There is a notable prevalence of low arch foot (pes planus) among pregnant women, which was comparable to the pattern recorded among non-pregnant women. Post-childbirth, the prevalence of low arch foot was 60.4% on the right and 62.4% on the left. This implies that the prevalence of pes planus among pregnant women may be influenced by physiological changes during pregnancy, and that induced pes planus may persist in some women after childbirth. The physiological changes that occur during pregnancy also contribute to the increased body weight among expectant mothers. As the foetus develops, the uterine muscles stretch and expand, which inherently adds to the overall weight of the pregnant woman. Additionally, the mammary glands prepare for lactation, leading to breast enlargement and increased weight. These changes are essential for the successful progression of pregnancy and the well-being of the growing fetus. [14]

However, the findings of the study suggest that these induced changes persist in some women, even after the loading/weight gain linked to the induced structural changes is removed post-birth. Another potential factor in the flattening of the foot arch is the effect of pregnancy hormones, particularly relaxin, which can increase joint laxity. [17- 21] This hormone can modify joint mechanics by stimulating the production of enzymes like collagenase, matrix metalloproteinases, and plasminogen activator. [22] As a result, the supporting ligaments may become insufficient, leading to joint laxity. Given that the primary support for the medial longitudinal arch comes from the ligaments on the plantar surface of the foot, it is plausible that the influence of pregnancy hormones on these ligaments could contribute to instability in the structure of the foot arch, ultimately leading to its collapse. However, it is beyond the scope of this study to correlate changes in hormone concentrations, like relaxin, with alterations in the structure of the medial longitudinal arch

throughout and after pregnancy. Further studies will be needed in this regard.

Socioeconomic factors and access to healthy food options can influence dietary choices and potentially lead to excessive weight gain among pregnant women. In Nigeria, the use of foot insoles to maintain foot arches and the practice of clinical interventions to prevent and manage foot deformities are not widely practised. This aspect could potentially add to the heightened prevalence of pes planus during pregnancy in this region. Understanding the persistence of pregnancy-induced changes in the foot arch is important not only for appreciating the long-term effects on foot structure but also for its significant implications for clinical interventions, preventive measures, and future research endeavours. Healthcare professionals and practitioners should be aware that the foot arch may continue to exhibit altered characteristics in post-pregnancy stages. This awareness can guide the development of tailored interventions, such as orthotics or specific exercises, to address these changes and alleviate potential discomfort or pain.

Upon conducting a detailed examination of the individual predictors, this study has unveiled crucial insights into the factors influencing the occurrence of flat feet during pregnancy. These findings described the intricate interplay of age, weight, and their potential impacts on the likelihood of developing flat feet during this crucial period. It is noteworthy that weight and age emerged as significant predictors, underlining the importance of considering these variables when assessing the risk of flat feet during pregnancy. Older pregnant women may be more susceptible to age-related structural changes in their feet, which could increase their risk of flat feet.

Conversely, the analysis did not find a significant relationship between gestational age and the odds of developing flat feet during pregnancy. This result suggests that the duration of pregnancy, in and of itself, may not be a direct predictor of flat feet. Other factors, such as weight and age, have a greater influence on the development of this condition.

These findings provide valuable insights into the risk factors associated with flat feet during pregnancy. Recognising the significance of weight and age as predictors enables healthcare professionals to assess better and counsel pregnant women about potential risks and preventive measures. For instance, healthcare providers may recommend weight management strategies and arch-supportive footwear for pregnant women, particularly those who are older or have a higher body mass index (BMI).

Conclusion

This study highlights the role of the Foot Arch Index (FAI) as a useful measure for quantifying foot arch characteristics. Pregnant women exhibit an increase in FAI compared to non-pregnant women. There is also a positive correlation between BMI and FAI among pregnant women, indicating a meaningful association between increased BMI and elevated FAI during pregnancy. Pregnancy may have a lasting impact on foot arches, leading to persistent alterations even after pregnancy. This research emphasises the importance of FAI in understanding foot arch dynamics, especially during pregnancy. Ongoing attention to foot arch health in pregnant and postpartum women is essential to improving women's quality of life of women.

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