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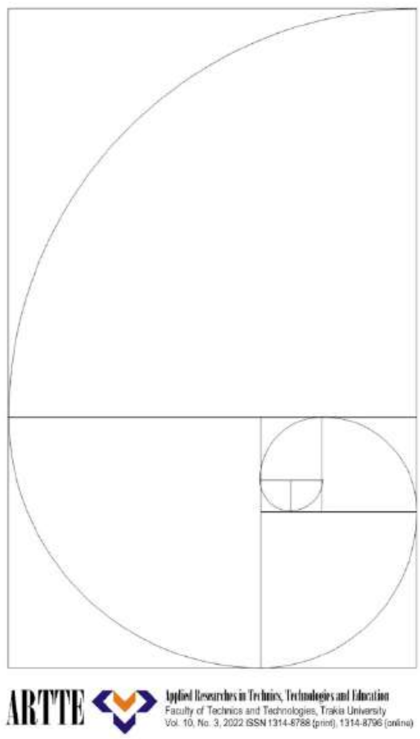

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Author Guidelines

Editors

General Topics

Indexing

Issues

ARTTE Vol 13

**ARTTE Vol 13 No 2**

ARTTE Vol 13 No 1

ARTTE Vol 12

ARTTE Vol 11

ARTTE Vol 10

ARTTE Vol 9

# ARTTE Vol 13 No 2

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**Articles**

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# ANTHROPOMETRIC CHANGES IN THE FOOT OF A PREGNANT WOMAN

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***Abstract:*** *The aim of this study is to investigate the anthropometric and biomechanical changes in women's feet during pregnancy and the postpartum period, as well as to assess their impact on the design of the internal shoe form. The research included serial anthropometric measurements of the foot during the first, second, and third trimesters of pregnancy and six weeks after childbirth, evaluating the length, width, circumferences of the forefoot and midfoot, and the height of the longitudinal arch. Tensometric platforms and gait dynamics analysis were used to examine walking biomechanics and load distribution, allowing the identification of both morphological and functional changes in the foot.*
*The results showed that pregnancy is accompanied by a decrease in the height of the longitudinal arch, an increase in foot length and width, larger circumferences of the forefoot and midfoot, as well as periodic swelling of the lower leg, especially in the third trimester. Biomechanical analysis revealed an increase in mean and peak plantar pressure, an expansion of the contact area, and a shift of the maximum pressure zones toward the forefoot. After childbirth, most parameters return to their baseline values; however, some women retain residual changes in foot shape and size.*
*The scientific novelty of this work lies in the comprehensive approach to assessing the impact of morphological and biomechanical changes in the foot during pregnancy and the early postpartum period on the internal shoe form.*
***Keywords:*** *pregnancy, anthropometric foot changes, gait biomechanics, tensometry, adaptive footwear, deformation prevention.*

## 1. INTRODUCTION

In recent years, footwear design has undergone a marked shift from prioritizing aesthetic criteria toward emphasizing comfort, functionality, and ergonomics, ensuring a harmonious interaction between the foot and the shoe (Wesley V. et al., British Journal of Podiatry, 2007; Buades J.M. et al., 2013) [1–2]. The study of foot anatomy and biomechanics serves as the foundation for developing anatomically justified footwear that supports the natural biomechanics of gait.

A review of current literature indicates that pregnancy is accompanied by significant morphological and biomechanical changes in the foot, affecting comfort, balance, and shoe construction. Research by Chertenko L., Kuzina N. and Kernesh V. [3–5] revealed that increases in body weight, foot length and width, a decrease in arch height, and a shift in the center of gravity require the adaptation of the last, insole, and upper materials. Shubenok O.S., Omelchenko N.M. and Konoval V.P. [6] emphasize the importance of orthopedic components—such as insoles and arch supports (medial shanks)—in reducing the load on the musculoskeletal system during pregnancy. Findings from studies by Segal, Rodríguez, Zangão, Bertuit, Nyska, Johnson, Branco and Cheng [7–14] demonstrate that pregnancy leads to a reduction in the longitudinal arch height, an increase in foot length, and alterations in plantar pressure distribution and gait kinematics. Hormonal influences, particularly the action

of relaxin, decrease ligament stiffness, promote tissue softening, and increase joint mobility, resulting in edema, expansion of the support base, and changes in gait pattern.
Failure to account for these transformations during the design process results in footwear that does not correspond to the anatomical and biomechanical needs of pregnant women, potentially causing fatigue, pain, and foot deformities. Therefore, contemporary research focuses on implementing tensometric and 3D scanning technologies, as well as on the use of adaptive constructions and smart materials that respond dynamically to volume and load variations. Thus, a systemic analysis of morphological and biomechanical foot transformations during pregnancy provides the scientific basis for designing adaptive, preventive, and ergonomic footwear capable of ensuring stability, comfort, and overall musculoskeletal health throughout this critical period.
**Object of the study:** a 35-year-old pregnant woman; pre-pregnancy body mass – 60 kg; height – 170 cm. The observation period extended from the early stages of pregnancy (8 weeks) to the late stages (38–40 weeks), as well as during the postpartum period (up to 6 weeks after delivery).

## 2. RESEARCH METHODS

### 2.1. Anthropometric studies

Key measurements were carried out to characterize the dimensions and volume of the foot, including ball girth, instep girth (midfoot circumference), and oblique foot girth. Measurements were taken using a measuring tape on the non–weight-bearing foot (in a sitting position) for both the right and left foot. These measurements were performed at different stages of pregnancy: at the beginning of the first trimester (~8 weeks), at the end of the first and beginning of the second trimester (~14–15 weeks), in mid-pregnancy (~25–30 weeks), in the third trimester (28–38 weeks at various intervals), and postpartum (2, 4, and 6 weeks after delivery). Additionally, foot length (in cm) and longitudinal arch height (measured as the vertical distance from the navicular bone to the floor using a ruler) were recorded. These parameters were qualitatively assessed over time, reflecting changes in shoe size and foot profile.
In parallel, the woman's body mass and pelvic circumference were recorded. Body weight was measured using electronic medical scales with an accuracy of ±0.1 kg under standard conditions — in the first half of the day, wearing minimal clothing, and after physiological procedures. Pelvic circumference was measured with a tape measure in the horizontal plane, passing through the most prominent points of the buttocks, while standing upright with the body weight evenly distributed on both legs.
To assess leg edema, the circumference of the lower leg (left and right) was measured at different levels above the ankle: at 10 cm, 15 cm, 20 cm, 25 cm, 30 cm, 35 cm, and 40 cm from the floor. These measurements were taken during selected periods — in mid-pregnancy (~20 weeks), in the third trimester (30–38 weeks), and after delivery — to monitor fluid accumulation (edema) in the lower limbs. All measurements were performed using a flexible measuring tape in a standing position, with the leg muscles relaxed, in the first half of the day, before visible signs of swelling occurred. To ensure accuracy, each measurement was repeated three times, and the mean value was calculated for further analysis.

### 2.2. Study of foot load distribution

Plantar pressure measurement provides clinicians and footwear designers with valuable insights into foot structure and function, overall gait biomechanics, and serves as an effective tool for evaluating patients with foot pathologies or localized discomfort (Rosenbaum D.,

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Becker H.P. Plantar pressure distribution measurement: Technical background and clinical application. Foot and Ankle Surgery, 3(1), 1997, pp. 1–14) [15].

A biomechanical analysis of the foot was performed using an electronic FootScan platform [16] (a flat-plate tensometric pressure sensor) during walking. The parameters recorded included mean plantar pressure for each foot and peak plantar force exerted during the stance phase of gait. The study was conducted twice: at the end of the second and beginning of the third trimester (28–29 weeks of pregnancy, body mass ~81 kg) and near term (35–36 weeks, body mass ~85 kg). The subject walked along the sensor walkway at a comfortable, self-selected pace. The system registered the average plantar pressure per step, the contact area of the foot with the support surface, and the peak (maximum) push-off force. All pressure values were normalized to body mass (divided by weight in kilograms) to allow comparison between different stages of pregnancy. The pressure distribution pattern across the plantar surface was also analyzed, identifying which regions — heel or forefoot — exhibited higher load concentrations. The collected data were statistically processed and compared between the two measurement sessions. All results were presented in tabular and graphical form for further analysis (Fig. 1).

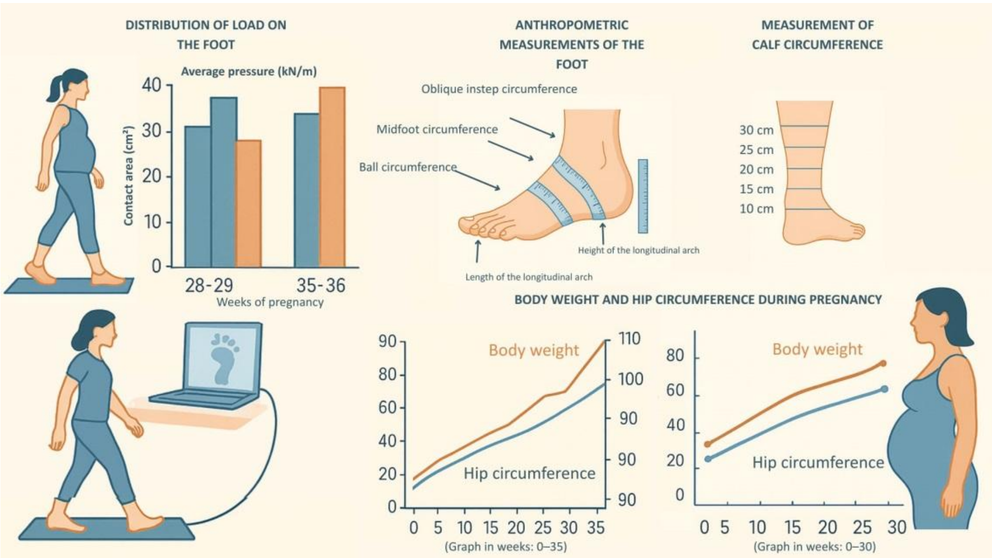


Figure 1. Dynamics of anthropometric measurements of the foot and lower leg during pregnancy

## 3. RESULTS AND DISCUSSION

### 3.1. Dynamics of body mass and pelvic circumference

Throughout pregnancy, the woman's body weight increased from 60 kg (first trimester) to a maximum of 86 kg at 36 weeks, followed by a slight decrease before delivery (to approximately 84 kg at 39–40 weeks). The pelvic circumference increased correspondingly — from about 95 cm at the beginning of pregnancy to approximately 113 cm by week 40. In the postpartum period (six weeks after delivery), the body mass decreased to 75 kg, while the pelvic circumference reduced to around 106 cm, which still exceeded the pre-pregnancy measurement. The increase in pelvic girth reflects anatomical adaptations, such as pelvic bone widening and soft tissue expansion of the thighs, necessary for childbirth. These morphological changes influence gait biomechanics: the center of body mass shifts, resulting in a more unsteady or waddling gait. The characteristic external pelvic rotation observed in late

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pregnancy contributes to an altered foot placement and enhanced stability, yet it may also cause a sense of stiffness in the hip joints and affect the distribution of body weight between the feet (Fig. 2).

### 3.2. Changes in foot dimensions during pregnancy

Table 1 summarizes the main foot measurements (right and left) at selected stages: at the beginning of pregnancy, in the third trimester (30 and 38 weeks), and in the postpartum period. The data include the ball girth (forefoot circumference), instep girth (midfoot circumference), and oblique foot girth.

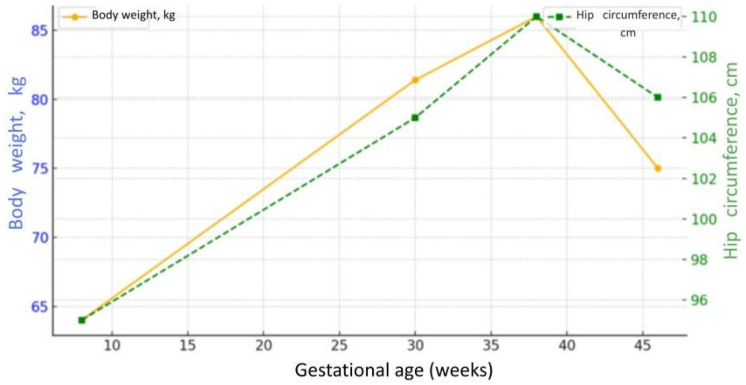


Figure 2. Graph of changes in body weight and pelvic circumference during pregnancy and after childbirth

Table 1. Changes in anthropometric parameters of the foot during pregnancy (right/left foot)

| Term (weeks) | 8 (I trimester) | 30 (III trimester) | 38 (III trimester) | 46 (6 weeks postpartum) |
|---|---|---|---|---|
| Weight, kg | 64* | 81,4 | 86 | 75 |
| Pelvic circumference, cm | 95 | 105 | 110** | 106 |
| Forefoot circumference (right), cm | 24,3 | 24,5 | 24,5 | 24,5 |
| Forefoot circumference (left), cm | 24,4 | 24,5 | 25,0 | 24,5 |
| Midfoot circumference (right),cm | 24,5 | 25,4 | 25,5 | 25,0 |
| Midfoot circumference (left), cm | 24,5 | 25,5 | 25,0 | 25,0 |
| Oblique foot circumference (right), cm | 32,8 | 33,6 | 34,5 | 33,0 |
| Oblique foot circumference (left), cm | 32,7 | 33,6 | 35,0 | 33,0 |

*Notes: 64 kg – body mass at approximately 8 weeks (ranging from 60–64 kg during weeks 1–8). At 38 weeks, body mass was 86 kg; a pelvic circumference of 110 cm is shown for week 38 (the maximum value of 113 cm was recorded at week 40).*

From Table 1, it can be observed that during the first trimester, the foot dimensions remained nearly unchanged compared to the baseline: the ball girth (forefoot circumference) measured approximately 24.3–24.5 cm, the midfoot girth about 24.5 cm, and the oblique girth around 32.7–32.8 cm. By the end of the second and the beginning of the third trimester (around 28–30 weeks), the first noticeable changes were recorded — the foot volume increased slightly. Specifically, at 30 weeks, the midfoot girth increased to ~25.4–25.5 cm (about +0.9 cm from baseline), while the oblique girth reached ~33.6 cm (+0.8 cm). The ball girth remained almost

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unchanged (~24.5 cm). This indicates that the initial foot volume increase occurred primarily in the instep region, likely due to mild arch lowering and fluid retention.
In the third trimester (around 38 weeks), the increase became more pronounced, particularly in the forefoot region: the ball girth rose to ~25.0 cm (left foot), approximately +0.5–0.7 cm above the initial measurement. The midfoot girth reached ~25.5 cm on the right foot (+1.0 cm) and ~25.0 cm on the left (+0.5 cm). The oblique girth showed the greatest increase — up to ~34.5–35.0 cm, or +1.7–2.3 cm compared to early pregnancy. Thus, by the end of pregnancy, the foot became visibly fuller in the forefoot and midfoot regions, indicating an overall increase in foot volume. Visually, the foot appeared flatter, with a lowered longitudinal arch. Although foot length in this particular case changed only slightly (by a few millimeters, remaining within the same shoe size), many studies report a permanent increase in foot length by 2–10 mm after pregnancy, attributed to arch flattening (Fig. 3).

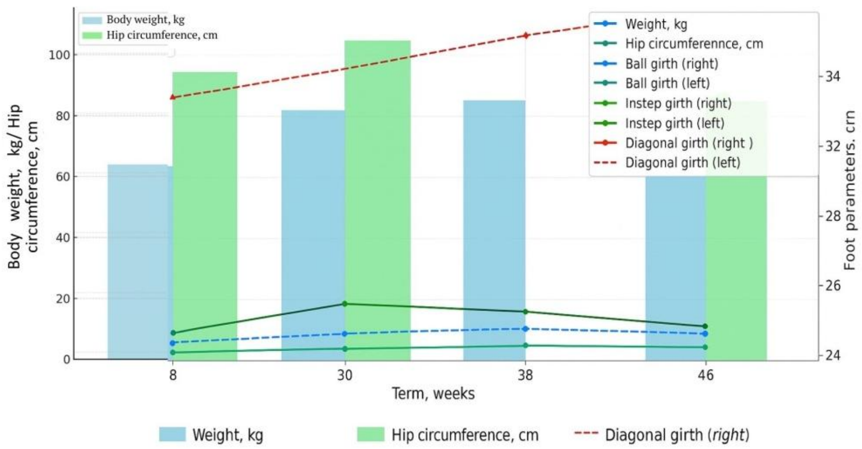


Figure 3. Changes in anthropometric parameters of the foot during pregnancy

### 3.3. Postpartum changes (6 weeks after delivery)

Measurements taken six weeks postpartum showed a tendency toward the restoration of foot dimensions to their baseline values. The ball girth and midfoot girth decreased to approximately 24.5–25.0 cm, while the oblique girth returned to around 33 cm, only slightly exceeding the initial measurements. This indicates that part of the foot enlargement was caused by reversible factors such as edema and temporary ligament laxity. However, complete recovery of foot shape does not occur in all cases. Data suggest that a reduction in arch height and increased ligamentous flexibility may lead to a permanent increase in foot length and width in a significant proportion of women after their first pregnancy. In the present observation, the near-complete recovery of foot dimensions was likely due to individual anatomical characteristics and a relatively mild degree of flatfoot development.

### 3.4. Foot loading and gait alterations

During walking, distinct changes in load distribution across the plantar surface and in balance between the right and left foot were observed. The results of tensometric (plantar pressure) analysis are presented for two stages — 28–29 weeks and 35–36 weeks of pregnancy (Table 2; Fig. 4).

Table 2. Parameters of plantar pressure during walking in the third trimester of pregnancy

| Indicator (units) | 28–29 weeks (weight 81 kg) | 35–36 weeks (weight 85 kg) |
|---|---|---|
| Average pressure on the right foot, kPa | 295,0 | 298,5 |
| Average pressure on the left foot, kPa | 250,0 | 253,0 |
| Contact area of the right foot, cm² | 143,5 | 147,0 |
| Contact area of the left foot, cm² | 135,0 | 138,3 |
| Maximum load (right), N | 818,5 | 858,6 |
| Maximum load (left), N | 845,8 | 884,5 |
| Normalized pressure on the right foot, kPa/kg | 3,64 | 3,51 |
| Normalized pressure on the left foot, kPa/kg | 3,09 | 2,97 |
| Difference in normalized pressure right–left, kPa/kg | 0,554 | 0,540 |

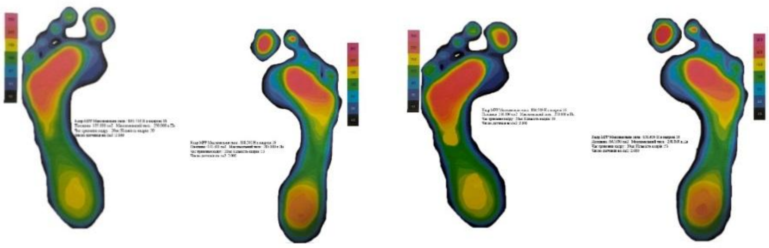

Figure 4. Study of pregnant women's feet using computer-based tensometry in the second and third trimesters

As shown in Figure 5, the average plantar pressure exerted on the support surface (averaged over the stance phase) increased proportionally to body mass — from approximately 250/295 kPa (left/right foot) at 28–29 weeks to 253/299 kPa at 35–36 weeks. The contact area of the foot increased slightly (by about 2–3 cm² for each foot), which corresponds to an increase in foot size and possibly a flatter arch configuration, as a larger portion of the plantar surface came into contact with the ground. The maximum ground reaction force (peak load during push-off) also rose in line with body weight, from approximately 818 N to 858 N for the right foot and from 846 N to 884 N for the left foot.

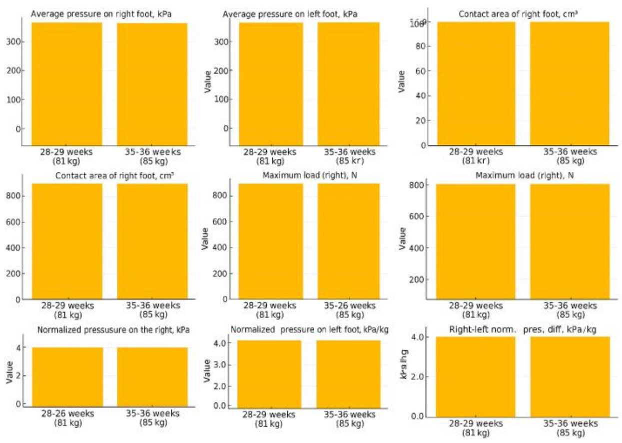


Figure 5. Dynamics of average plantar pressure, foot contact area, and maximum ground reaction force during the gestational period

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In the late stages of pregnancy, the load on the feet increases significantly, which may cause discomfort and pain in the feet and joints. The distribution of body weight between the right and left foot becomes more balanced, indicating an adaptive adjustment of gait aimed at maintaining stability. The forefoot bears the primary load due to the forward shift of the center of gravity and increased joint flexibility. During the third trimester, the foot becomes flatter, and the load is distributed over a wider area, which helps reduce pressure on the medial arch and provides greater stability during stance.

### 3.5. Edema and calf circumference

Measurements of calf circumference throughout pregnancy revealed the development of peripheral edema, particularly pronounced in the third trimester. The increase in circumference was caused by fluid retention in the tissues and was most noticeable in the upper calf region, and to a lesser extent around the ankle and mid-calf. After childbirth, these changes gradually resolved within 1–1.5 months. For the footwear industry, these findings highlight the need to consider the increase in lower-leg volume during the design of boots and high-top shoes — in particular, by incorporating wider shafts or adjustable fastenings to ensure comfort for women in late pregnancy (see Fig. 6).

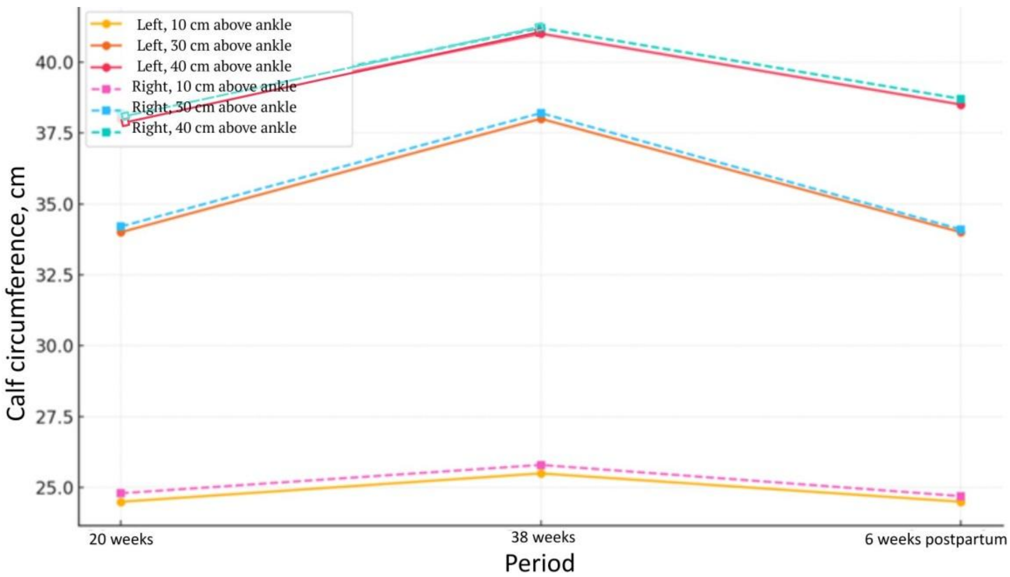


Figure 6. Dynamics of changes in calf circumference at different stages during pregnancy and after childbirth

## 4. CONCLUSIONS

The study confirmed that pregnancy is accompanied by significant morphological and biomechanical changes in the feet and lower limbs, which directly affect comfort, stability, and gait. An increase in body weight and pelvic circumference leads to a shift in the center of gravity, altering the nature of foot loading and activating the body’s adaptive mechanisms. An increase in the circumferences of the forefoot and midfoot, a reduction in the longitudinal arch height, and partial development of flatfoot, which may persist postpartum, were observed. Biomechanical analysis revealed higher average and peak plantar pressures, an expanded contact area of the sole, and a more balanced load distribution between the legs. In the third trimester, edema and an increase in calf circumference were recorded, emphasizing the importance of considering changes in foot and leg volume during footwear design. The obtained results highlight the need for individualized and adaptive footwear constructions that ensure optimal load distribution, arch support, and comfort. The increase in body mass and shift of the center of gravity intensify foot loading, which is compensated by gait adjustments and an increase in the support area.

All these findings define the key requirements for footwear designed for pregnant women: an increased internal volume, the possibility of adjusting the upper construction, lightweight and convenient fastening, arch support provided by an anatomical insole, and stability and cushioning of the sole achieved through a balanced shape and carefully selected materials. The use of lightweight, resilient, and non-slip sole materials enhances walking stability and comfort both during pregnancy and in the postpartum period.

A comprehensive consideration of anthropometric and functional changes forms the foundation for the development of safe, ergonomic, and adaptive footwear that meets the physiological needs of women during this special period.

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