ORIGINAL ARTICLES

Plantar Pressure During Gait in Pregnant Women

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Background: During pregnancy, physical and hormonal modifications occur. Morphologic alterations of the feet are found. These observations can induce alterations in plantar pressure. This study sought to investigate plantar pressures during gait in the last 4 months of pregnancy and in the postpartum period. A comparison with nulliparous women was conducted to investigate plantar pressure modifications during pregnancy.

Methods: Fifty-eight women in the last 4 months of pregnancy, nine postpartum women, and 23 healthy nonpregnant women (control group) performed gait trials on an electronic walkway at preferred speeds. The results for the three groups were compared using analysis of variance.

Results: During pregnancy, peak pressure and contact area decreased for the forefoot and rearfoot. These parameters increased significantly for the midfoot. The gait strategy seemed to be lateralization of gait with an increased contact area of the lateral midfoot and both reduced pressure and a later peak time on the medial forefoot. In the postpartum group, footprint parameters were modified compared with the pregnant group, indicating a trend toward partial return to control values, although differences persisted between the postpartum and control groups.

Conclusions: Pregnant women had altered plantar pressures during gait. These findings could define a specific pattern of gait footprints in late pregnancy because plantar pressures had characteristics that could maintain a stable and safe gait. (J Am Podiatr Med Assoc 106(6): 000-000, 2016)

During pregnancy, several modifications occur: ligament laxity increases[1] and skeletal alignment changes.[2-4] Furthermore, many women experience an increase in the size of their feet, forcing them to wear larger shoes. Pregnant women's foot morphology and, therefore, footprints are likely to change.[5-8]

Alvarez et al[5] analyzed morphologic alterations of the feet between the 13th and the 35th weeks of pregnancy. They showed no modifications of foot length and width; however, the average volume of the foot increased by 8.5% and then decreased after delivery. These changes can be attributed to fluid retention in the tissues, increased tissue, or a modification in ligament laxity. This study did not clearly identify the factors responsible for the increased foot volume. In 2013, Segal et al[6] pointed out a decrease in medial arch height and greater flexibility of the feet in 60 pregnant women. Therefore, mean $\pm$ SD foot length increased by 1.4 $\pm$ 0.3 mm during the first trimester of pregnancy. Medial arch drop was correlated with excess foot pronation ($r = 0.8$). This pronation, leading to flatfoot, was also observed by Block et al[7] and Nyska et al.[8] Hypotheses to explain these observations could be increased ligament laxity of the first metatarsophalangeal, subtalar, and midtarsal joints and decreased stiffness of the tibialis posterior muscle, causing a decrease in the talar head size by 1 to 2 cm.[7,8]

These observations can induce alterations in plantar pressure. For several authors,[6,8,9] footprint modifications may contribute to the increased risk of musculoskeletal disorders in women.

According to Birtane and Tuna,[10] in their study of obese people, it seems that plantar pressures are dependent on mass. During pregnancy, women gain

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approximately 10 kg.[11,12] So, pregnancy seems to be a time when plantar pressure can change. Nevertheless, we must keep in mind that mass gain in pregnant women differs, in place and time, from that in an obese population.

According to the literature, pregnant women when walking show increased rearfoot pressure and decreased forefoot pressure, with more loading on the metatarsal heads than on the toes.[13] The midfoot appears larger, with more support on the medial side of the hallux causing greater peak pressure and foot pronation; therefore, the contact surface of the foot increases by 8% in pregnancy.[8,14,15] On the other hand, peak pressure increases on the lateral side of the foot, suggesting lateralization of gait.[8] Pregnant women also walk with a wider base of support, and, consequently, center of pressure displaces in a different pattern.[16] These changes were in relation to foot adaptations to distribute the uniformly increasing load without increasing the overall plantar pressure.[8,15] Contact time on the ground increased significantly throughout pregnancy, confirming that pregnant women walk slower.[14,17]

According to Titianova et al[18] and Mitternacht et al,[19] footprints are directly or indirectly dependent on mass: heavier individuals have a longer peak time, a larger midfoot contact area, and increased peak pressure under the heel. Footprint parameters are connected with the spatiotemporal parameters of gait. For this reason, the study of plantar pressures and especially peak pressures can contribute to the clinical evaluation[18] of foot pain during pregnancy.

The purpose of this study was to investigate plantar pressures during gait in the last 4 months of pregnancy and in the postpartum period. A comparison with nulliparous women was conducted to investigate plantar pressure modifications during pregnancy.

Methods

Participants

The characteristics of the study samples are presented in Table 1. Fifty-eight pregnant women aged 25 to 41 years with no history of foot, ankle, or knee musculoskeletal pain; no pelvic girdle pain; no neuromuscular trauma or disease; and no cardiovascular problems participated in this study. Women with twin pregnancies and pregnancies with complications were excluded. The pregnant group (PG) was divided into four subgroups: 1) month 6 (amenorrhea gestational weeks 25–28), 2) month 7 (amenorrhea gestational weeks 29–32), 3) month 8 (amenorrhea gestational weeks 33–36), and 4) month 9 (amenorrhea gestational weeks 37–41). Of the pregnant women, 59% worked, 28% were inactive, and 13% were students. Concerning parity, 71% of women had no children, 27% had one child and 2% had two or more children.

The postpartum group (PPG) comprised nine women (16–32 weeks after delivery) (Table 1). The pregnant and postpartum participants were recruited via direct contact during prenatal and postnatal gymnastic classes.

Twenty-three healthy nulligravidae women aged 21 to 38 years agreed to take part in the study as a control group (CG) (Table 1). All of the participants gave written informed consent before participation in the study as approved by the local ethics committee. Participants were recruited between January 1, 2009, and December 31, 2011.

Table 1. Characteristics of the Pregnant, Postpartum, and Control Groups

Group	No. of Women	Age (Years)	Height (cm)	Mass (kg)	BMI		Mass Gain (kg)
					Before Pregnacy	During Test	
Pregnant							
Month 6	8	26 ± 1	168 ± 6	72 ± 9	23 ± 3	25 ± 3	8 ± 4
Month 7	17	28 ± 5	165 ± 6	70 ± 9	22 ± 3	26 ± 3	11 ± 3
Month 8	23	30 ± 6	165 ± 6	73 ± 10	23 ± 6	28 ± 6	10 ± 4
Month 9	10	29 ± 3	168 ± 7	73 ± 8	19 ± 7	26 ± 3	12 ± 4
Global	58	29 ± 5	166 ± 6	72 ± 9	22 ± 5	27 ± 5	10 ± 4
Postpartum	9	31 ± 6	167 ± 6	74 ± 19	NA	26 ± 6	NA
Control	23	27 ± 5	168 ± 6	63 ± 10	NA	22 ± 3	NA

Note: Data are given as mean ± SD.

Abbreviations: BMI, body mass index (calculated as the weight in kilograms divided by the square of the height in meters); NA, not applicable.

Materials

Footprint parameters during gait were measured using the GAITRite electronic walkway (GAITRite Gold; CIR Systems, Franklin, New Jersey), measuring 6.1 m long and 61 cm wide. Embedded pressure sensors form a horizontal grid. Data were sampled at a frequency of 100 Hz. The walkway is connected to a personal computer by a serial interface cable. The characteristics of the plantar pressure were treated by the software associated with the system (GAITRiteGOLD, version 3.9).

The GAITRite algorithm defined the footprint by a quadrilateral of a footprint, which is geometrically represented by 12 trapezoids: six medial and six lateral (Fig. 1A). To simplify the results, the 12 trapezoids were assembled two by two to obtain six zones corresponding to the following areas: medial and lateral rearfoot, medial and lateral midfoot, and medial and lateral forefoot (Fig. 1B). The software provides a visual representation of the pressure distribution with a seven-level chromatic pressure scale. The system normalizes the pressure value and expresses it as a percentage of the maximum pressure.[20]

Methods

Before performing the motor task, anthropometric data (age, shoe size, body mass, and height) were recorded for each participant. The length of the lower limbs (from the anterosuperior iliac spine to the medial malleolus) was determined with a tape measure in dorsal decubitus. Each participant was invited to walk barefoot on the GAITRite walkway. The motor task consisted of three gait trials at their preferred speed. A rest period was allowed between trials. To counter the methodological bias of acceleration and deceleration in gait, the participants started walking 2 m ahead of the walkway and finished the trial 2 m after the end of the walkway.

Data Processing

Four dependent variables[20] were analyzed for the six zones. P*t is the sectional integrated pressure over time expressed as a percentage of the overall integrated pressure over time. Peak time is the first time point at which one or more sensors in a zone were at the maximum switching level. Area represents the sum of the active sensor areas in a zone. Peak pressure is the maximum sectional switching level expressed as a percentage of the overall maximum switching level.

Statistical Analysis

All of the statistical procedures were conducted using Statistica 5.0 software for Windows (StatSoft Inc, Tulsa, Oklahoma). To investigate normal distribution of data, we used the Kolmogorov-Smirnov test. All of the scores were found to be

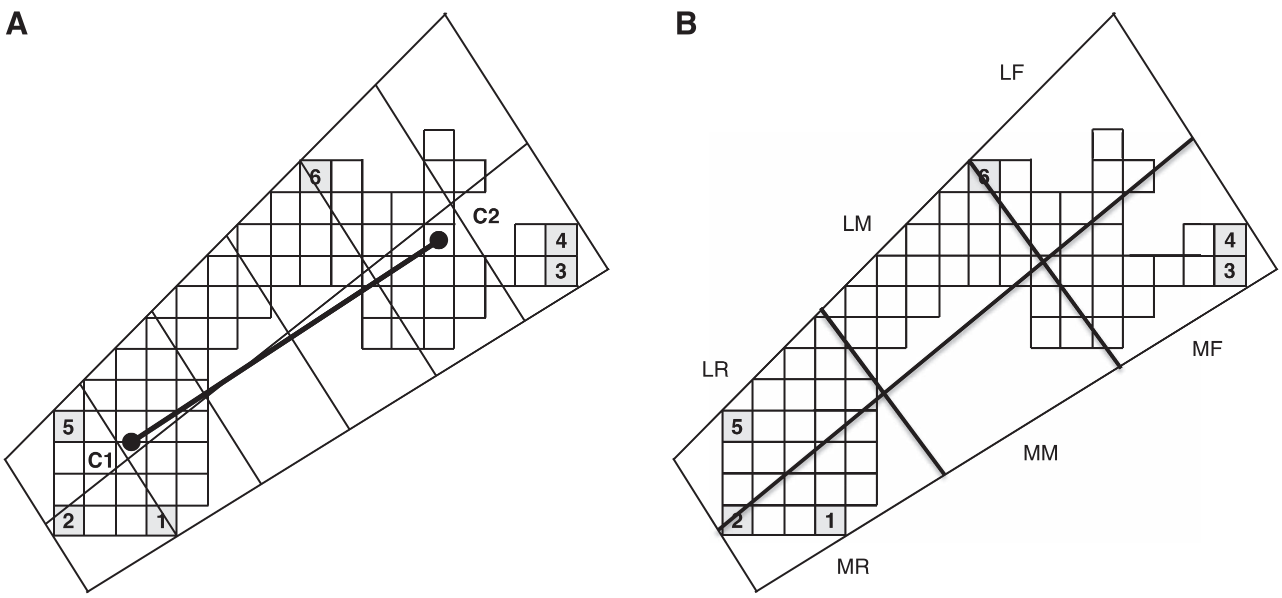

Figure 1. Footprint subdivisions. A, The 12 trapezoids.[20] B, The reduction to six trapezoids. LF, lateral forefoot; LM, lateral midfoot; LR, lateral rearfoot; MF medial forefoot; MM, medial midfoot; MR, medial rearfoot.

normally distributed. A Student t test for paired samples was not significantly different between sides; data from the left and right feet were, thus, averaged.

A first analysis of variance (ANOVA) for repeated measures was performed for comparison of all of the variables between the different groups (between-groups factor) and zones (within-group factor). A second ANOVA was performed for comparison of all of the variables between the different months of pregnancy (between-groups factor) and zones (within-group factor). When a significant effect was found, the least significant difference post hoc test was applied. The statistical level of significance was set at $P < .05$.

Results

For all four parameters (peak time, P*t, peak pressure, and area), ANOVA showed significant differences among the six zones ($P < .001$).

Peak Time

Figure 2A shows peak time for all of the groups. No significant differences were observed among the different months of pregnancy. Nevertheless, a significant difference ($P < .001$) was noted among the three groups (PG, PPG, and CG); between PG and CG, the differences were significant for all of the areas.

The PG had a later mean ± SD peak time than CG (0.10 ± 0.03 sec; $P < .001$). This value represents an increase of time by 27% for the rearfoot, 43% for the medial midfoot, 77% for the lateral midfoot, and 16% for the forefoot.

Between PG and PPG, a mean ± SD decrease of 0.05 ± 0.02 sec over the entire foot was measured ($P = .001$). It was the same between PPG and CG, with a mean ± SD reduction of 0.06 ± 0.02 sec ($P \leq .001$). Note that all of the groups presented the largest differences in the midfoot, especially on the lateral side.

P*t

Figure 2B shows the P*t results. No significant difference was observed between the months of pregnancy or between groups. Concerning laterality (P zones $< .001$), larger pressure was applied to the medial rearfoot (+4%). The lateral midfoot (+11%) and lateral forefoot (+4%) side received higher pressure than the medial side.

Peak Pressure

No significant differences were noted among the months of pregnancy, but a difference ($P = .013$) was found among the three groups. Figure 2C shows the distribution of the peak pressure. Compared with CG, PG displayed decreased peak pressure for the medial rearfoot and forefoot by 1% ($P < .001$), accompanied by an increase of midfoot pressure by 2% on the lateral side and by 1% on the medial side ($P < .001$). Between PG and PPG, PPG peak pressure increased on the medial forefoot (+1%) and decreased on the lateral midfoot (–1%).

Area

No significant change was observed during pregnancy. However, a significant difference ($P = .017$) was found among the three groups. During pregnancy, PG had reduced contact surfaces compared with CG for the rearfoot and forefoot (–10% for the medial rearfoot and –8% and –13% for the medial and lateral forefoot, respectively) ($P < .001$). In contrast, an increase of 41% was recorded for the lateral midfoot ($P < .001$) (Fig. 2D). The contact area of the lateral midfoot was reduced by 18% in PPG compared with PG.

Discussion

In this study, we investigated plantar pressures during gait in the last 4 months of gestation. In addition, via a control group, the effect of pregnancy was assessed.

Plantar Pressures in the Last 4 Months of Pregnancy

Within the limitations of the study, the present results suggest that plantar pressures were not altered in the last 4 months of pregnancy. The differences in plantar pressures shown between pregnant women and controls suggest that the adaptations might have taken place before the last 4 months of pregnancy and remained stable until delivery.

Effect of Pregnancy

We observed in previous studies that pregnant women showed decreased gait velocity and increased stance phase.[17] Peak time could confirm these results: In each area it increased significantly by a mean ± SD of 0.10 ± 0.03 sec, in particular for

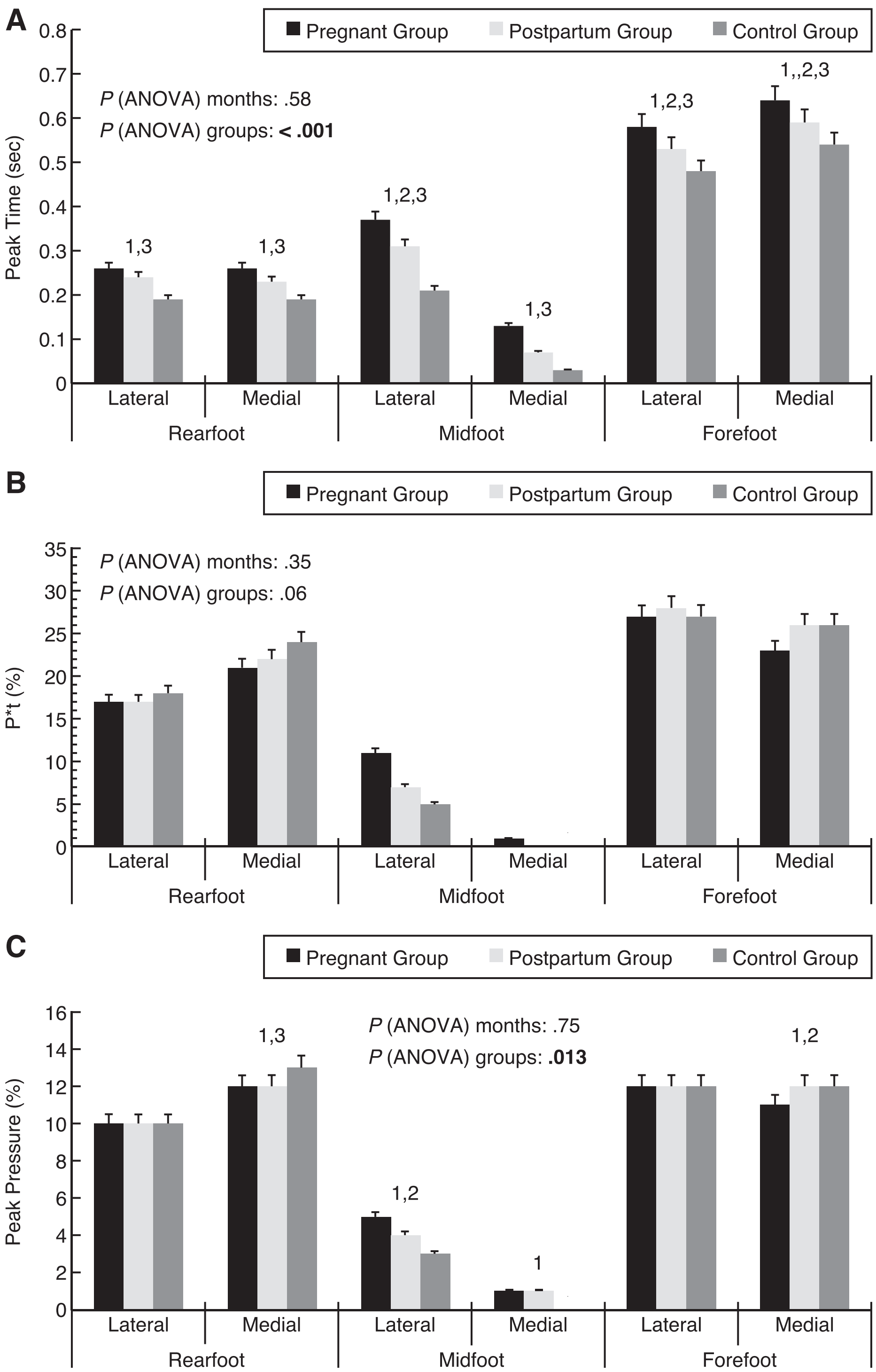

Figure 2. Mean ± SD values of the four footprint variables in the pregnant, postpartum, and control groups for the six zones. A, Peak time. B, P*t. C, Peak pressure. D, Area. $^{1}P < .001$ pregnant vs control. $^{2}P < .001$ pregnant vs postpartum. $^{3}P < .001$ control vs postpartum.

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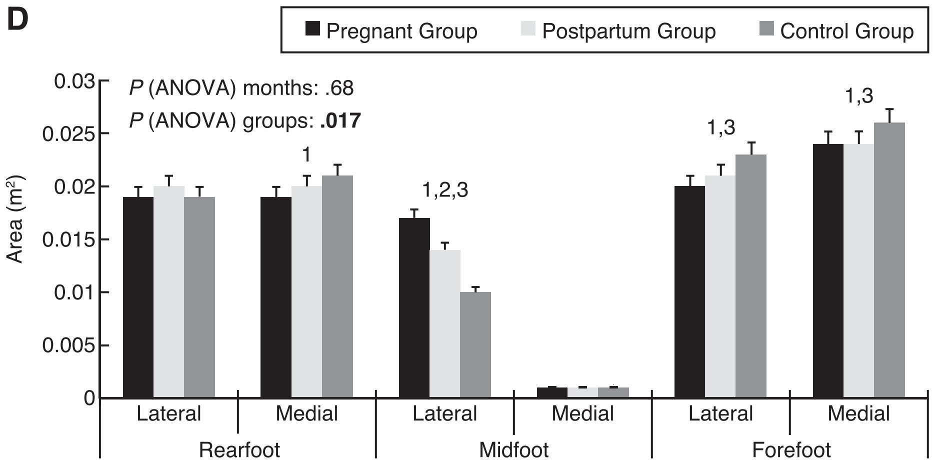

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the midfoot, which recorded an increase in peak time of 77% laterally and 43% medially. These findings are consistent with lower gait velocity[17] and longer step times.[10,12,19] Goldberg et al[14] reported an increase in contact time, indicating a slow gait, and observed a link between gestation and contact time ($r = 0.39$; $P = .0007$). The present study showed that peak time increases in pregnant women were especially large in the midfoot areas, which may be related to gait stabilization strategies developed during pregnancy.

Concerning peak pressure, two peaks were observed corresponding to heel strike (first peak) and propulsion (second peak). Pregnant women had decreased peak pressure and contact area at the forefoot and rearfoot, resulting in an increase of these two parameters at the midfoot. Nevertheless, the results of previous studies were disparate. In agreement with the present work, Gaymer et al[15] observed increased plantar pressure at the midfoot but not at the heel or forefoot. In contrast, Goldberg et al[14] measured a general increase in ground contact forces during pregnancy: Pregnant women displayed amplified pressures on the rearfoot but decreased pressures on the forefoot.

The increased contact area of the midfoot is probably linked to the body mass gain in pregnant women. Titianova et al in 2004[18] showed a link between these two variables ($0.35 < r < 0.41$; $P < .001$). With the increase in mass, they observed a larger midfoot contact area, and the forefoot and rearfoot contact areas were reduced. Nyska et al[8] highlighted an increase of 8% of the total plantar area in pregnant women. The present study confirmed these values, with an increase of 10%.

Another hypothesis advanced to explain the changes in footprints during pregnancy was the modification of the structure of the foot. Several authors[5,8,19] observed that an increase in the volume of feet could promote distribution of support across all areas of feet. On the other hand, foot pronation observed during pregnancy could alter the footprint. This pronation, leading to flatfoot, increases the support surface, particularly in the medial midfoot. The increase in peak pressure at the midfoot can be a consequence of flatfoot in pregnant women.

Conversely, the decrease in plantar pressure at the forefoot can be explained by the stance strategy of pregnant women as explained by Nyska et al.[8] A preferential support on the metatarsal heads and not on the toes used during pregnancy may induce shortening of the posteroanterior displacement of the center of pressure. This strategy would improve the stability of the pregnant woman in the sagittal plane despite the increase in abdominal mass.

These considerations lead us to consider that pregnant women more evenly use the different areas of the feet while promoting lateralization of support when they walk. This lateralization was accentuated on the forefoot and midfoot: peak pressure decreased on the medial forefoot and increased on the lateral midfoot. On the other hand, the contact area increased significantly on the lateral midfoot (+41%). Nyska et al[8] highlighted this lateralization during gait in pregnant women. These observations can be linked to the trend toward hypermobile flatfoot, especially at the first ray, which is observed in pregnant women. Pregnant women tend to exert more pressure on the second metatarsal, thus promoting lateral support. They also walk with a wider base of support,[16] which may explain some of the present results.

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These results confirm the relationship between footprint, body morphology, and the temporal and spatial gait parameters highlighted by Titianova et al.[18] One of the possible explanations for gait modifications in pregnant women may be found in mass gain, as similar gait characteristics were reported in overweight people: a slow gait[17,21] marked by an increase in step width (1–2 cm),[22] with lateral support[8,23] on the feet. Pregnant women seemed, thus, to enhance body weight transfer from one side to the other when they were walking.

The gait footprint patterns observed in the last 4 months of pregnancy show particular characteristics of plantar pressure distribution that might aim at maintaining normal gait, with optimal stability.[22]

Postpartum Women

In pregnant women compared with women in the postpartum period, peak pressure was increased on the medial forefoot and decreased on the lateral midfoot. On the other hand, contact area decreased on the lateral midfoot.

Average postpartum values for these variables were closer to those observed in healthy controls, suggesting a tendency to return to control values. However, several differences persisted between women in PPG and CG. For example, contact area remained reduced at the forefoot and larger at the midfoot in PPG.

Concerning the limitations of this study, the methods of selection of women may have influenced the results: Women were recruited during prenatal and postnatal gymnastic classes. It can be claimed that participation in such classes improves body perception and muscle strength. Furthermore, for organizational reasons, a longitudinal study could not be achieved. It would have reduced the risk of differences between groups other than those related to pregnancy progression. Finally, the small number of individuals in some groups could be a limitation of the study. For these reasons, further studies are required to confirm the results of the present study.

Conclusions

In pregnant women, a change in plantar pressures during gait was found compared with healthy controls. Decreases in peak pressure, contact area, and peak time were observed for the forefoot and rearfoot. In contrast, an increase in these parameters was demonstrated for the midfoot. The gait strategy adopted by pregnant women seemed to be lateralization of gait with an increased contact area of the lateral midfoot and both a reduced pressure and later peak time on the medial forefoot. These findings could define a specific pattern of gait footprints in late pregnancy because plantar pressures had characteristics that could maintain a stable and safe gait.

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Conflict of Interest: None reported.

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