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Three-dimensional kinematic adaptations of gait throughout pregnancy and post-partum

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Purpose: The kinematic analysis of gait during pregnancy provides more information about the anatomical changes and contributes to exercise and rehabilitation prescription. The purposes were to describe and quantify the spatial, temporal and kinematic parameters in the joints of the lower limb during gait at the end of the first, second and third trimesters of pregnancy and in the postpartum period. *Methods*: A three-dimensional analysis was performed in eleven pregnant women. Repeated measures ANOVA was performed for comparisons between periods. *Results*: The longitudinal effect of pregnancy was not observed in spatial and temporal parameters. In joint kinematics the effect of pregnancy was observed in all joints for the three planes of motion. The hip joint and pelvis are the structures with more changes, and the results point to an increase in the anterior tilt of the pelvis as the pregnancy progresses, as well as a decrease of the amplitudes of the hip joint. The results suggested that pregnant women need to maintain the stability of the body, and become more efficient in locomotion. *Conclusions*: In general, the results retrieve the values from the beginning of pregnancy, indicating that the body was self-organized in order to overcome the morphological and physiological changes which women suffer during pregnancy, indicating that they have the ability to adapt depending on the demands, and after the effect of pregnancy is over, they return to values similar to those found in early pregnancy.

Key words: *pregnancy, biomechanics, joint kinematics, temporal and spatial parameters, gait*

1. Introduction

Pregnant women undergo various changes during pregnancy, including hormonal and morphological changes [1]. Although, these changes may lead to many complaints, discomfort and pain in lower limbs, it is unclear whether the biological, hormonal and morphological changes lead to the modification of gait pattern. Few studies describe the temporal, spatial and kinematic motion on the lower limb of the pregnant women, particularly in a longitudinal perspective.

Foti et al. [7] analyzed a set of gait three-dimensional (3D) kinematic parameters in 15 women, from the 3rd trimester of pregnancy until one year postpartum. The overall results showed changes in the gait pattern of those women compared with a non-pregnant group. In the pregnant group gait pattern the amplitude of hip extension is decreased while the anterior pelvic tilt, hip flexion and hip adduction are increased. Regarding temporal parameters significant increases were found in double support time and significant decreases in single support time. In spatial parameters they found a significant increase for pelvic width and ankle separation. Lymbery and Gilleard [12] investigated the temporospatial and ground reaction force (GRF) variables in the stance phase of walking in 13 women at 38 weeks' gestation and 8 weeks after birth. They concluded that in

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late pregnancy, there was a wider step width, and mediolateral GRF increasing in a medial direction. They suggested that women may adapt their gait to maximize stability in the stance phase of walking and to control mediolateral motion. Huang et al. [10] compared the natural pattern of walking, tested once, in 10 pregnant women, divided into three groups (12, 13–28 and 29–40 weeks of gestation) with of control group of 10 nulliparous. They reported significant differences between the pregnant and non-pregnant women, especially in knee abduction angle, knee and hip internal rotation angles. Also, with the gestational age progress, the pregnant women showed increase in hip extension moment and knee adduction moment, and decrease in knee extension moment, and ankle plantar flexion moment. According to these authors, the hip is the main work-loading area, associated with an overstretch of the hip extensors, which are highly related with sacroiliac pain, caused by an easy fatigue of these muscles.

Few studies analyzed gait kinematic changes throughout pregnancy, in each trimester of gestation, or associated the kinematic and kinetic variables for each phase of the gait cycle. In a previous study Branco et al. [4] found that the gait pattern of pregnant women showed changes between second and third trimesters in such a way that the stride and right and left step lengths decreased, while double limb support time increased. Joint kinematics showed a significant decrease of right-hip extension and adduction during stance phase between trimesters. Also, an increase in left knee flexion and a decrease in right-ankle plantarflexion were found between trimesters.

No studies were found performing a longitudinal analysis encompassing the three trimesters of pregnancy and the postpartum period, so that the changes arising from pregnancy are not fully quantified. This leads us to wonder whether there are changes in kinematic parameters during pregnancy, and if so, are women able to recover values close to those found in early pregnancy?

The main objective of this study was to analyze the kinematic changes of gait as the pregnancy progresses. Having confirmed these changes, the second objective was to ascertain whether women can recover to the initial kinematic patterns in the postpartum period. The hypothesis tested is that the gait of pregnant women has changes in the kinematic parameters throughout their pregnancy, and women in postpartum period recover these parameters to values similar to those of early pregnancy. To achieve the main objective, it is necessary to describe the kinematic variables in the joints of the lower limb during gait at the end of the first, second and third trimesters of pregnancy and in the postpartum period.

2. Materials and methods

Subjects

Eleven pregnant women (age: 33.20 ± 1.62 years; range: 32 to 37 years) with no trauma or disease history of foot, ankle, knee, musculoskeletal, and neuromuscular, participated in this study. The characteristics of the participants are described in Table 1.

Table 1. Characteristics of the sample data for weight, body mass index (BMI) and gestational weeks, in each collection phase

	1st trimester		2nd trimester		3rd trimester		Postpartum	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Weight (kg)	61.1	6.6	66.6	8.5	71.0	8.0	62.4	7.4
BMI ($kg \cdot m^2$)	22.7	2.7	24.7	3.6	26.4	3.4	23.2	3.3
Gestational week	14.2	2.4	27.3	1.0	36.3	0.9	20.6	5.2

Pregnant participants were recruited via direct contact and flyers placed in gym and health centers and have volunteered to participate in the study. None of the participants had contraindications to physical exercise. The study was approved by the ethical committee of the Faculty of Human Kinetics, University of Lisbon (FMH-UL) and all subjects gave written informed consent prior to the participation in the study.

Data collection and processing

Data were collected at the Laboratory of Biomechanics and Functional Morphology (FMH-UL) during the later stages of each trimester of pregnancy and once between the 4th and the 6th month after delivery.

In each data collection session anthropometric and biomechanical data were recorded. The weight and height were measured according to the International Society for the Advancement of Kinanthropometry (ISAK) standardized measurement protocol [15] by ISAK certified anthropometrists. These anthropometric data were used to calculate the mass of body segments and inertia moments.

The biomechanical data were recorded while the subject walked barefoot a distance of 10 m, between two points, in a straight line in both directions at a natural and comfortable speed, during 3 min. Participants were allowed to get familiar with the laboratory system and no fatigue occurrence was reported. The last four gait cycles performed by each participant were considered for the analysis.

Markers setup were in agreement with the suggestion of Cappozzo et al. [5], for lower limb segments, and CODA (Charnwood Dynamics, Ltd., Leicestershire, United Kingdom) protocols for model of the pelvis segment (Fig. 1). Pelvis model allows the estimation of the right and left hip joint center using the regression equation proposed by Bell et al. [2], [3]. Planar motion of the hip, knee and ankle joint was calculated with Visual 3D (V3D) software (C-Motion Inc., Germantown, USA) through the application of Cardan-Euler method.

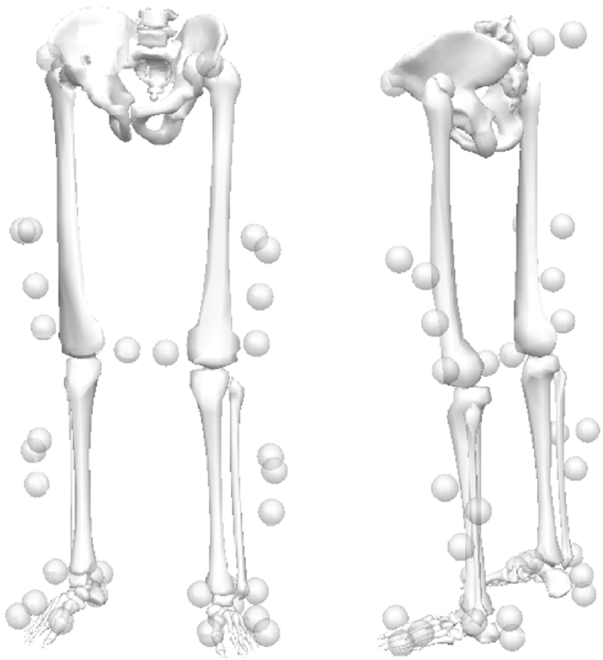

Fig. 1. Reconstructed biomechanical model in Visual 3D. Model anterior and lateral view with marker setup used in motion capture

Kinematic and kinetic data were collected by means of twelve infrared high-speed cameras (Oqus-300, Qualisys, Sweden; FR: 200 Hz), two Kistler force platforms (Kistler AG, Winterthur, Switzerland) and one AMTI platform (Advanced Mechanical Technology, Inc., Watertown), at a rate of 1000 Hz. The capture hardware was connected to Qualisys USB Analog Acquisition interface in order to synchronize kinetic and kinematic data with software Qualisys Track Manager (QTM; Qualisys AB, Gothenburg, Sweden). Both data sequences were recorded in the same file. The system was calibrated by wand type, with an exact wand length of 751.4 mm moved randomly across the recorded field, before the data collection of each participant. Calibration was accepted if the standard deviation of the wand length measures was below 0.5 mm. The cameras were positioned statically to minimize light reflection artifacts and to allow recording of at least two consecutive walking cycles, defined as the time between two consecutive initial ground contacts of the heel strike for each side.

A three-dimensional analysis was performed including both sides of the body. The trajectory of the reflective markers was smoothed using a Butterworth low-pass filter with a 10 Hz cut-off. Collected data were interpolated using a Cubic Spline Interpolation as suggested by Robertson et al. [14], for a maximum of 10 frames gap, and filtered with a Butterworth digital low-pass filter, at 10 Hz cutoff frequency for kinematic and kinetic data, as suggested by Robertson and Dowling [13]. All data were normalized in time.

Considering the four phases in analysis, kinematic pattern curves were estimated relative to the walking stride cycle. The gait cycles were selected based on both feet GRF data and the heel markers pattern recognition followed by correction if needed. The data curves and the peak angle values were estimated, for left and right sides, with V3D. Lower-extremity joint angles and spatial and temporal parameters during the walking gait cycle were calculated with the use of V3D.

In each trimester of pregnancy and in the postpartum period, a set of kinematic variables were considered, the analyzed peaks being described in our previous study [4].

Statistical analysis

All statistical procedures were conducted using IBM SPSS Statistics 22 software for Windows. The Shapiro–Wilk normality tests were conducted and not assumed for all cases. The Mauchly's test of sphericity was performed before Repeated Measures (RM) ANOVA analysis and sphericity was not assumed in all tests. For post-hoc tests, the Bonferroni test was used based on Student's *t* statistic, adjusting the observed significance level because multiple comparisons were made. When the data set did not commit the assumptions for the RM analysis, the Friedman test was performed, and for pairwise analysis the Wilcoxon test was performed. In this case, Bonferroni confidence interval adjustment was applied to allow an adjustment to the confidence intervals and significance values for multiple comparisons.

3. Results

Spatial and temporal parameters

The longitudinal effect of pregnancy was not observed in any spatial or temporal parameter (Table 2), regarding the results of the statistical tests.

Table 2. Spatial and temporal parameters of gait during pregnancy and in postpartum period

Parameter		First trimester (M ± SD)	Second trimester (M ± SD)	Third trimester (M ± SD)	Postpartum (M ± SD)
Speed (m/s)		1.215 ± 0.182	1.222 ± 0.164	1.154 ± 0.165	1.267 ± 0.226
Stride length (m)		1.277 ± 0.131	1.282 ± 0.113	1.246 ± 0.107	1.301 ± 0.147
Stride width (m)		0.089 ± 0.024	0.096 ± 0.028	0.103 ± 0.029	0.095 ± 0.026
Cycle time (s)		1.058 ± 0.069	1.056 ± 0.065	1.089 ± 0.076	1.039 ± 0.081
Double limb support time (s)		0.201 ± 0.038	0.205 ± 0.033	0.220 ± 0.035	0.198 ± 0.045
Step length (m)	Right	0.638 ± 0.067	0.642 ± 0.059	0.626 ± 0.053	0.653 ± 0.077
	Left	0.639 ± 0.064	0.640 ± 0.056	0.620 ± 0.056	0.649 ± 0.071
Step time (s)	Right	0.531 ± 0.036	0.525 ± 0.031	0.542 ± 0.041	0.515 ± 0.040
	Left	0.527 ± 0.035	0.535 ± 0.036	0.544 ± 0.036	0.524 ± 0.044
Stance time (s)	Right	0.628 ± 0.053	0.636 ± 0.050	0.656 ± 0.053	0.620 ± 0.067
	Left	0.631 ± 0.052	0.622 ± 0.048	0.652 ± 0.055	0.616 ± 0.060
Swing time (s)	Right	0.429 ± 0.022	0.425 ± 0.021	0.434 ± 0.028	0.419 ± 0.021
	Left	0.428 ± 0.019	0.430 ± 0.023	0.436 ± 0.023	0.424 ± 0.021

M = Mean and SD = Standard Deviation.

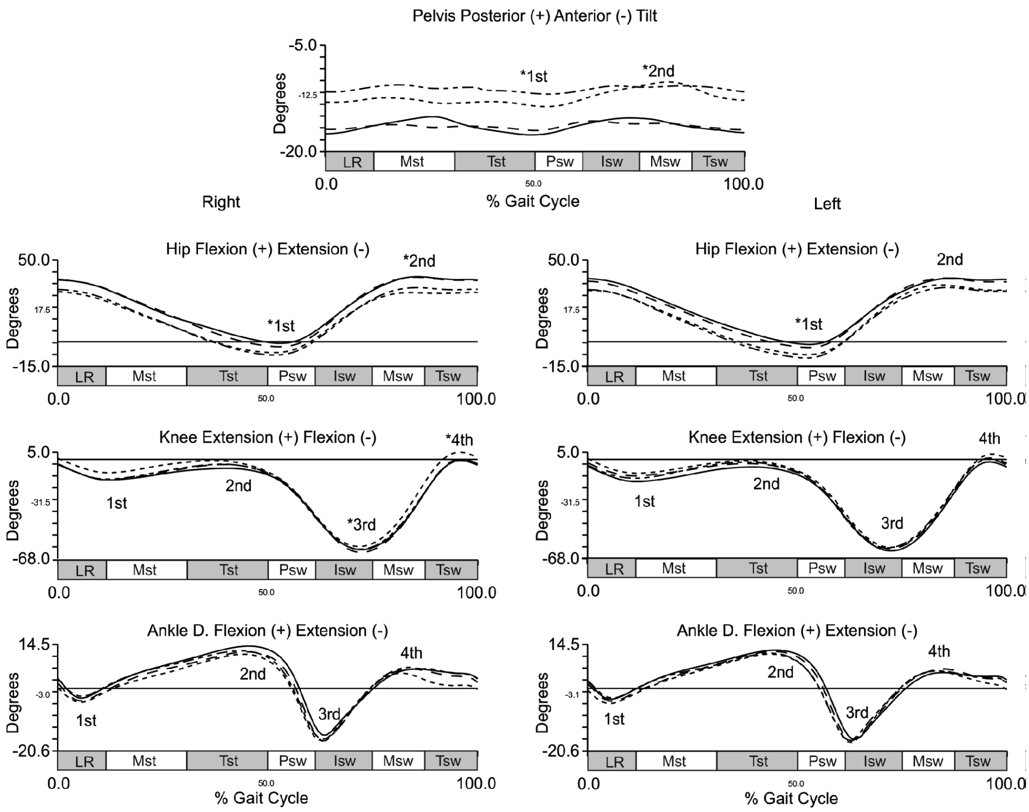

Fig. 2. Mean joint angles of the pelvis, hip, knee, and ankle, for right and left lower limbs, in sagittal plane. The curve peaks are indicated by numbers: 1st, 2nd, 3rd and 4th, and (*) points the significant differences

After the pairwise comparison among the different collection phases, the spatial and temporal parameters did not show any statistical differences, indicating no changes in the course of pregnancy, and also from the different stages of pregnancy to postpartum period.

Joint kinematics

Sagittal plane

A longitudinal effect of pregnancy was observed in joint kinematics, in the sagittal plane, namely for the angular data of all lower limb joints (Fig. 2).

Differences between pairs of collections and their levels of significance for post-hoc comparisons are presented in Table 3. A significant effect of pregnancy was observed in all joints of the lower limb with the exception of the hip joint.

Between the first and second trimesters the right limb showed a significant increase in maximum knee flexion (third peak) with an average difference of 3.1 deg and a significant decrease in maximum knee extension (fourth peak), with a difference of 4.2 deg. The hip joint shows a significant decrease of hip extension in the first peak from the second trimester and from the third trimester to postpartum period of 5.6 deg and 7.3 deg, respectively. The second peak of the right hip joint has a significant increase of hip flexion from first to second and to third trimesters, and also from second and third trimesters to postpartum period, with values of flexion which are increased above five degrees at the end of pregnancy. In the segment of the pelvis, significant changes were verified between the first trimester, and the second and third trimesters, with an increase of 2.97 deg, 3.68 deg, 4.6 deg and 5.31 deg, respectively for first peak, and above 5 deg for second peak. Between the second and the third trimesters with postpartum period a significant decrease was seen in pelvic tilt of 4.6 deg and 5.31 deg, respectively, for the first peak.

Frontal plane

In the frontal plane, it was found that pregnancy influences the angular values of the joints of the lower limbs (Fig. 3).

Table 3. Angular differences between two of each collection moment pairs and their level of significance of post-hoc tests for sagittal plane of motion

			2nd trim – 1st trim		3rd trim – 1st trim		Postpartum – 1st trim		3rd trim – 2nd trim		Postpartum – 2nd trim		Postpartum – 3rd trim	
Joint	Side	Peak	dif.	*p*-value	dif.	*p*-value	dif.	*p*-value	dif.	*p*-value	dif.	*p*-value	dif.	*p*-value
Ankle	Right	1st	–0.06	1.000	0.69	1.000	1.27	1.000	0.75	1.000	1.33	1.000	0.59	1.000
		2nd	0.18	1.000	1.85	1.000	0.82	1.000	1.67	1.000	0.64	1.000	–1.03	1.000
		3rd	0.22	1.000	1.76	1.000	0.74	1.000	1.54	0.673	0.52	1.000	–1.02	1.000
		4th	1.29	0.110	1.17	0.110	1.82	0.041	–0.13	0.859	0.53	1.000	0.66	0.594
	Left	1st	0.71	1.000	0.85	1.000	0.88	1.000	0.15	1.000	0.17	1.000	0.03	1.000
		2nd	0.55	1.000	1.01	0.577	–0.08	1.000	0.46	1.000	–0.63	1.000	–1.09	1.000
		3rd	1.00	1.000	1.05	1.000	–0.82	1.000	0.05	1.000	–1.82	0.554	–1.87	1.000
		4th	0.50	1.000	–0.37	1.000	–0.61	1.000	–0.87	1.000	–1.11	0.679	–0.24	1.000
Knee	Right	1st	–2.38	0.091	–3.36	0.131	–2.97	0.091	–0.98	0.722	–0.59	0.594	0.39	0.374
		2nd	–3.18	0.334	–5.23	0.294	–1.13	1.000	–2.06	1.000	2.05	1.000	4.10	0.366
		3rd	**–3.10**	**0.004**	–0.10	0.050	–1.17	0.286	3.00	0.534	1.93	0.075	–1.07	0.155
		4th	**–4.18**	**0.029**	–4.88	0.127	–3.56	0.433	–0.70	1.000	0.62	1.000	1.32	1.000
	Left	1st	–2.91	1.000	–4.92	0.526	–1.91	1.000	–2.00	1.000	1.01	1.000	3.01	1.000
		2nd	–2.50	0.155	–4.65	0.033	0.45	0.929	–2.15	0.374	2.94	0.041	5.10	0.021
		3rd	0.16	1.000	–1.68	0.813	0.61	1.000	–1.84	1.000	0.45	1.000	2.29	0.461
		4th	–2.94	1.000	–4.63	0.519	–1.44	1.000	–1.69	1.000	1.50	1.000	3.19	1.000
Hip	Right	**1st**	3.74	0.088	5.46	0.176	–1.88	0.807	1.72	1.000	**–5.61**	**0.033**	**–7.33**	**0.025**
		2nd	**6.24**	**0.003**	**7.12**	**0.002**	0.95	1.000	0.88	1.000	**–5.29**	**0.039**	**–6.17**	**0.027**
	Left	**1st**	**4.71**	**0.004**	**6.19**	**0.005**	–1.92	1.000	1.49	1.000	–6.63	0.051	**–8.12**	**0.003**
		2nd	3.48	0.041	4.61	0.021	–1.56	0.657	1.14	0.286	–5.04	0.016	–6.17	0.026
Pelvis		**1st**	**–2.97**	**0.013**	**–3.68**	**0.013**	1.63	0.248	–0.71	0.594	**4.60**	**0.010**	**5.31**	**0.004**
		2nd	**–5.88**	**0.033**	**–5.11**	**0.050**	–0.98	1.000	0.77	1.000	4.90	0.098	4.14	0.308

Difference units between trimesters are in degrees. Bold values represent statistical differences.

The differences of the pairs of collection moments and respective levels of significance of post-hoc tests are presented in Table 4. Most of the variables did not show any changes during pregnancy and postpartum, with the exception of the second and third peaks of the ankle, the first peak of the hip, and the second peak of the pelvis.

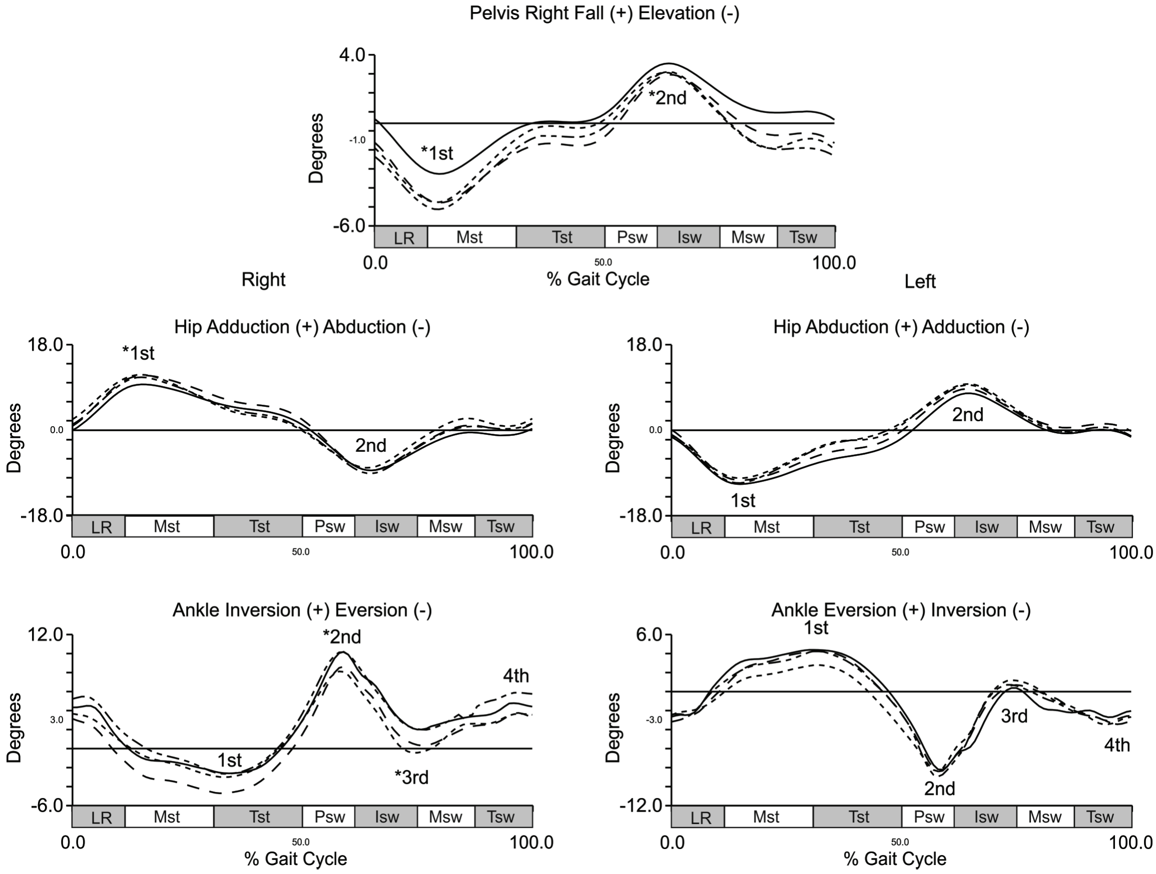

Fig. 3. Mean joint angles of the pelvis, hip, knee, and ankle, for right and left lower limbs, in frontal plane. The curve peaks are indicated by numbers: 1st, 2nd, 3rd and 4th, and (*) points the significant differences

Table 4. Angular differences between pairs of collection moments and their level of significance of post-hoc tests for frontal plane of motion

			2nd trim – 1st trim		3rd trim – 1st trim		Postpartum – 1st trim		3rd trim – 2nd trim		Postpartum – 2nd trim		Postpartum – 3rd trim	
Joint	Side	Peak	dif.	sig.	dif.	sig.	dif.	sig.	dif.	sig.	dif.	sig.	dif.	sig.
Ankle	Right	1st	–2.34	0.131	–0.13	0.859	–0.53	0.657	2.20	0.131	1.81	0.026	–0.40	0.722
		2nd	1.10	0.328	**3.19**	**0.021**	**2.45**	**0.021**	2.09	0.286	1.35	0.328	–0.74	0.722
		3rd	1.11	1.000	**2.96**	**0.043**	1.29	0.844	1.85	1.000	0.18	1.000	–1.67	0.714
		4th	–0.72	1.000	1.03	1.000	1.18	1.000	1.75	0.636	1.90	0.208	0.15	1.000
	Left	1st	–0.83	1.000	–1.38	0.167	–1.58	0.935	–0.55	1.000	–0.75	1.000	–0.19	1.000
		2nd	0.00	0.594	–0.13	0.790	0.83	0.790	–0.14	0.790	0.83	0.477	0.96	0.424
		3rd	0.65	0.424	1.06	0.213	0.09	0.929	0.41	0.859	–0.56	0.534	–0.97	0.286
		4th	–0.52	0.722	–0.72	0.374	–0.18	0.859	–0.20	0.534	0.33	0.859	0.54	0.859
Hip	Right	**1st**	0.38	0.859	**–2.06**	**0.013**	–0.12	0.722	–2.44	0.026	–0.50	0.657	1.93	0.110
		2nd	0.21	1.000	0.12	1.000	–1.33	1.000	–0.09	1.000	–1.54	0.107	–1.45	0.692
	Left	1st	–0.37	1.000	0.77	1.000	0.74	1.000	1.15	1.000	1.12	1.000	–0.03	1.000
		2nd	0.49	0.859	1.43	0.213	–0.49	0.534	0.94	0.374	–0.98	0.374	–1.92	0.182
Pelvis		1st	–0.32	0.594	1.70	0.033	–0.56	0.248	2.02	0.041	–0.24	0.594	–2.26	0.021
		2nd	**–0.61**	**0.033**	**0.22**	**0.050**	0.08	1.000	0.83	1.000	0.69	0.098	–0.14	0.308

Difference units between trimesters are in degrees. Bold values represent statistical differences.

Changes between the first and third trimesters of pregnancy in the second and third peak of the ankle are subtle but significant, with an increase of 3 deg in ankle inversion for late pregnancy, and 2.45 deg between the first trimester and postpartum period. The hip joint shows a slight decrease of 2 deg in hip adduction between first and third trimesters, and the segments of the pelvis are even more subtle, verifying a slight decrease of 0.61 deg of elevation on the right side between the first and second trimesters, and a slight increase of 0.22 deg between the first and third trimesters.

Transverse plane

The statistical analysis of angular data, in the transverse plane, show that these are influenced by the stage of pregnancy in which the women are (Fig. 4).

The differences between pairs of collection moments and respective level of significance from post-hoc comparisons are presented in Table 5. In general, the angular movement of the joints of the lower limbs remains similar throughout pregnancy and in the post-partum period, with the exception of the hip joint.

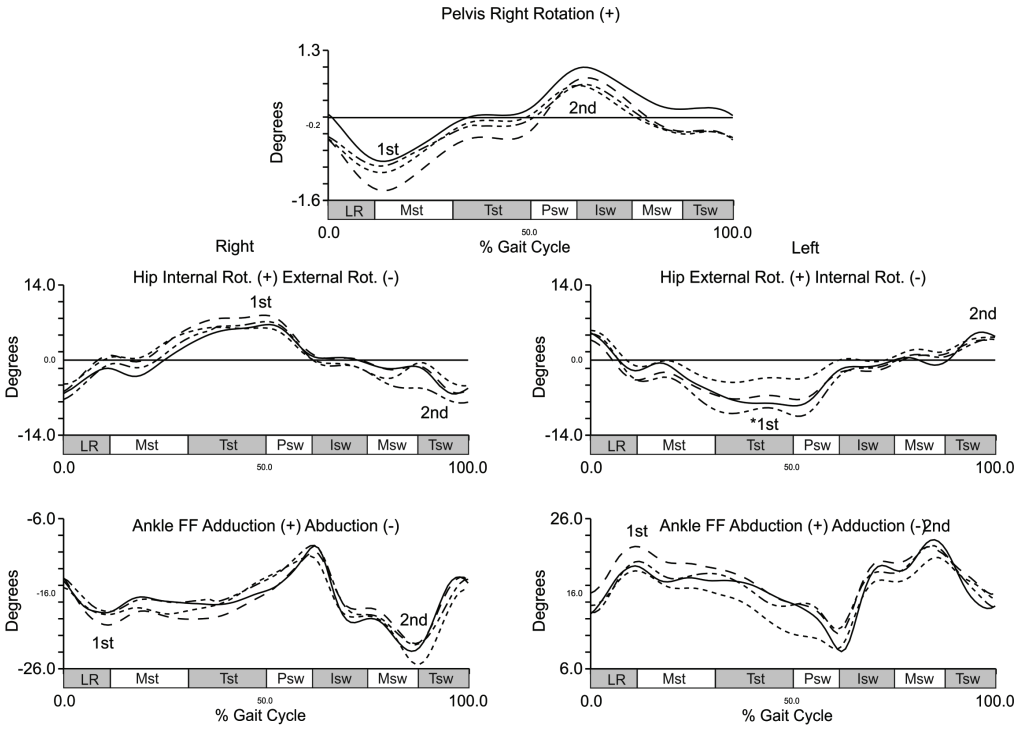

Fig. 4. Mean joint angles of the pelvis, hip, knee, and ankle, for right and left lower limbs, in transverse plane. The curve peaks are indicated by numbers: 1st, 2nd, 3rd and 4th, and (*) points the significant differences

Table 5. Angular differences between pairs of collection moments and their level of significance of post-hoc tests for transversal plane of motion

			2nd trim – 1st trim		3rd trim – 1st trim		Postpartum – 1st trim		3rd trim – 2nd trim		Postpartum – 2nd trim		Postpartum – 3rd trim	
Joint	Side	Peak	dif.	sig.	dif.	sig.	dif.	sig.	dif.	sig.	dif.	sig.	dif.	sig.
Ankle	Right	1st	–3.06	1.000	–0.93	1.000	–0.44	1.000	2.14	1.000	2.62	1.000	0.49	1.000
		2nd	0.50	1.000	–0.43	1.000	1.66	1.000	–0.94	1.000	1.16	1.000	2.10	0.560
	Left	1st	–3.66	1.000	–0.98	1.000	–4.02	0.790	2.68	1.000	–0.36	1.000	–3.04	0.708
		2nd	–1.22	1.000	–0.64	1.000	–1.02	1.000	0.58	1.000	0.20	1.000	–0.37	1.000
Hip	Right	1st	4.48	0.560	1.89	1.000	1.55	1.000	–2.59	0.640	–2.93	1.000	–0.34	1.000
		2nd	2.54	1.000	0.84	1.000	–0.48	1.000	–1.70	1.000	–3.02	0.556	–1.33	1.000
	Left	**1st**	**2.37**	**0.003**	**3.30**	**0.006**	5.31	0.182	0.93	0.213	**2.93**	**0.004**	**2.01**	**0.003**
		2nd	1.63	1.000	1.07	1.000	1.72	1.000	–0.55	1.000	0.09	1.000	0.65	1.000
Pelvis		1st	–0.43	0.225	0.23	0.912	0.06	1.000	0.66	0.115	0.49	0.201	–0.17	1.000
		2nd	–0.02	1.000	0.26	1.000	–0.03	1.000	0.28	1.000	–0.01	1.000	–0.29	1.000

Difference units between trimesters are in degrees. Bold values represent statistical differences.

The first peak of the hip joint in the transverse plane has a slight but significant increase in internal rotation of the thigh from the first to the second and third trimesters. However, from the second and third trimesters to postpartum, there continues to be a significant increase, both increases are between two and three degrees of internal rotation of the hip.

4. Discussion

The main goal of this longitudinal study was to describe the changes of the gait biomechanical parameters throughout pregnancy and in postpartum period. The 3D analysis of kinematic parameters as well as of spatial and temporal parameters was performed. The hypothesis that these parameters are influenced by the course of pregnancy is rejected for the spatial and temporal variables during walking, and accepted for the kinematic variables in the three planes of motion. In our previous study [4] and in Foti et al. [7], higher values were found in the stride width and in the double support time for the third trimester, when compared to the values found in the postpartum or in control group, respectively, and are largely influenced by the stage of pregnancy. However, even without significant changes in this study, the stride width was 1.4 cm larger in the third trimester than in early pregnancy, and decreases in postpartum, and the double support time also features the inverted U-shaped, with an increase of 0.17 seconds between the first and the third trimesters and a decrease from the third trimester to postpartum of 0.20 seconds, which seems to point to the same behavior as in the literature. A possible explanation for discrepancies in the results between our study and literature may be due to sample size.

The kinematic parameters in the three planes of motion are influenced by the progression of pregnancy, checking for deviations in several angular data of the lower limb joints. In the sagittal plane, the knee, hip, and the segment of the pelvis present the major changes during pregnancy. There are few studies in the literature referred to knee changes during pregnancy and postpartum. Our results are in line with Carpes et al. [6], who found a significant increase in knee flexion in the terminal stance phase, and with our previous study [4]. We also found a decrease in knee extension during the end of swing phase, which may be the result of the lower participation of the knee extensors. This may be associated with back pain, specifically with sacroiliac pain, referred by pregnant women [10].

The hip joint has been referenced in the literature as the joint where major changes occur in late pregnancy. In our study, an increase of flexion of the hip during stance phase was found which is supported by previous studies [4], [7], [9], leaving effectively no peak of the hip extension during pre-swing phase.

The published results about the pelvis are consistent across the studies, showing an increased anterior tilt of five degrees throughout the gait cycle [7], [9]. In this study, in addition to assessing the significant increase in this anterior tilt, we discriminate that this increase occurs between the first and second trimesters and remains similar between the second and third trimesters, as previously observed [4]. This pelvis position seems to agree with the morphological changes already undertaken by pregnant women at the end of the second trimester, where there is an increase in abdominal volume and weight of the fetus that affects about 40% of its final weight [16], combined with a lower capacity for force production by rectus abdominis. However, Foti et al. [7] state that the function of the anterior pelvic tilt, combined with an increase of lumbar lordosis is to keep the body in an upright position. After delivery, between the fourth and sixth months, there is a significant reduction in the pelvic anterior tilt angle similar to those found in the first trimester which seems to be an indicator of the recovery of the pelvis position in postpartum, also observed in the literature between pregnancy and the postpartum [4], [7], [9]. Regarding the sagittal plane, the results confirmed that the angular data show deviations associated with pregnancy and are recovered in the postpartum period.

In the frontal plane, there are influences of the stage of pregnancy on the angular data, revealing significant changes in the ankle, hip and pelvis segment. Few studies have examined the frontal plane changes. Gilleard [8] found a reduction in the amplitude of the unilateral elevation of the pelvis. In this study, during the mid-stance, there was an increase of the magnitude of the fall of the pelvis from the third trimester to the postpartum period. During the toe-off, the pelvis shows a slight decrease in elevation between the first and second trimesters, and an increased elevation of the pelvis between the first and the third trimesters. Both results suggest that, in late pregnancy, the dynamic of the two angular peaks of the pelvis is related to the attempt to control the angular momentum of the trunk caused by an increase of its moment of inertia [8]. In the hip joint, this study showed a decrease in the hip adduction during the mid-stance phase, between the first and the third trimesters. In a previous study [4], we found similar results between the second and third trimesters and between pregnant and non-pregnant women. However, Foti et al. [7] point to a contradictory result, showing an increase in hip adduction between participants at the end of pregnancy and one year after delivery. The ankle joint showed no changes in the frontal plane in the literature [4]. In this study, however, there are significant changes in the pre-swing phase, with an increase of ankle inversion from the first to the third trimester and to the postpartum period, showing that this parameter does not recover and remains at least up to six months after delivery. The ankle inversion between the first and third trimesters keeps significantly increased until the mid-swing phase, showing that both stance as the swing phases of the pregnant woman are with an increased inversion of the foot during pregnancy. Since the changes only occur between the first and the third trimester, and remain in the postpartum, justifies the fact that it has not been found in previous studies, which only studied women since the end of the second trimester. In the frontal plane, the hypothesis that the data show angular deviations associated with pregnancy, is accepted for the above variables. However, the hypothesis that these variables retake the values of early pregnancy is not accepted only for the inversion of the ankle, which keeps increased up to the postpartum period.

The kinematic parameters in transverse plane remain largely unchanged during pregnancy and postpartum, however, there is an increase in the hip internal rotation from the first to the second and to the third trimester. In the postpartum period there is a continuous increase in internal rotation during the terminal stance phase. According to Los Amigos Research Education Institute Inc., Service [11], the internal rotation of the hip during the single support, is associated with an internal rotation contracture, femoral anteversion or an intention to increase knee stability, leading to a toe-in position, hindering the forward advancement and may increase pressure on the lateral side of the knee joint. Regarding transverse plane, the hypothesis that the data show angular deviations associated with pregnancy, is rejected for most variables except for internal rotation of the hip. This variable, however, does not return the values of early pregnancy, rejecting that hypothesis, by remaining increased until the last moment of collection.

5. Conclusions

This study followed a descriptive longitudinal type design, in which pregnant women were assessed in the first, second and third trimesters of pregnancy and also in postpartum period. The gait analysis showed that pregnancy is a factor which influences the kinematic variables of the lower limb joints. The pelvis and hip joint are the segments that experience greater changes throughout pregnancy. Changes in the sagittal plane indicate that there is greater care in the anterior progression of the body. However, the temporal and spatial data reveal no significant changes over the gait cycle. In the remaining planes of motion, there is less amplitude of motor actions, which seems to indicate greater constraints on movement. In general, the results retrieve the values from the beginning of pregnancy, indicating that the body was self-organized in order to overcome the morphological and physiological changes which women suffer during pregnancy and that has the ability to adapt depending on the demands. Other questions are raised by these results, in particular if these kinematic changes bring an overload to the musculoskeletal system of the pregnant woman and its association with lumbopelvic pain.

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