INTRODUCTION

The human walking involves the sequential contacts of foot on the ground, with recurrent periods of double stance, which maintains the constant forward movement (Inman, Ralston and Todd 1998). Gait events include the stance phase comprising the period between foot strike, corresponding to 0% of the gait cycle, and toe-off, corresponding to 62% of the cycle, and the swing phase, i.e., the period between toe-off at 62% of the cycle and the second ipsilateral foot strike at 100%, with a period of double stance in the transition from stance to swing phase (Sutherland, Kaufman and Moitoza, 1998).

Pregnancy, a natural and physiological process in women, causes musculoskeletal, postural and hormonal alterations that are responsible for changes in the body mechanics of pregnant women (Alvarez et al., 1988; Bird, Menz and Hyde, 1999; Foti, Davids and Bagley, 2000). The functional adaptation due the progressive weight gain increases the joints and muscles overload during static and dynamics postures, and are associated to a considerable increase of abdominal volume, breast volume, and hormonal modifications (Conti, Calderon and Rudge, 2003). Postural stability decreases during pregnancy and remains diminished until 6 to 8 weeks post-partum (Butler et al., 2006). Also, there is pain in the pelvis and low back with prevalence of 50% among pregnant (Fast et al., 1987; Berg et al., 1988), persistent or arising after partum (Mens et al., 1996).

The functional changes in the low back region could be related to the fetus weight increasing the lordosis and leading to pelvis anteversion (Carvalho and Caromano, 2001). It lead the pregnant to increase spine flexion, head position forwards and hyperextend the knees, increasing the support base and transferring the weight to calcaneus’s region (Winter,
Pregnant's gait

Even so this effects could be minimized by a regular physical activity during pregnancy (Garshasbi and Zadeh, 2005), the pregnant women is described was presenting a walking pattern classified as "waddling gait" (Foti, Davids and Bagley, 2000). The changed pattern compared to normal gait elicit increased base of support, larger foot progression angle, increased pelvic movements, and increased rotation of the pelvis. Even well described, this data are frequently found as inconsistent (Alvarez, 1998; Foti, Davids and Bagley, 2000), and "waddling gait" is not completely accepted to describe the pattern of walking in pregnant women (Wu et al., 2004). More complete understanding of the effects of pregnancy on gait requires statistical and dynamic analyses of walking at different periods, in order to determine the alterations that occur during these periods and the return to previous patterns of locomotion (Jensen, Doucet and Treitz, 1996).

Here we analyzed the kinematic aspects of gait in pregnant women during the gestational-puerperal and post-partum period, including temporal and spatial aspects of gait and hip and knee flexion/extension angles in attempt to describe the changes during pregnancy and the return to normal gait post partum.

METHODS

Subjects and experimental procedure

This study was approved by the local ethic committee. Seven women ranging in age from 23 to 35 years participated in the study after sign an informed term confirming the agreement with the methods. The 3-D gait kinematics measurements were taken during three trials with two complete unshod gait cycles at a self-selected velocity. 3-D angular data were acquired by a video analysis system (Peak Motus, Peak Performance Technologies Inc., Englewood, CO) with two high-speed synchronized cameras operating at a sampling rate of 60 Hz. The Peak Motus system has an angular displacement reliability of 0.99 and measurement error of 0.5% (Scholz and Millford, 1993).

The defined laboratory (global) orthogonal coordinate system (frame) followed the right-hand rule with the positive x-direction oriented in the direction of forward progression, the positive y-direction oriented to the left and the positive z-direction oriented vertically upwards (Gruen, 1997). The cameras were placed perpendicularly in relation to each other and positioned approximately four meters from the center of the movement. The Direct Linear Transformation method (Abdel-Aziz and Karara, 1971) was employed to obtain 3-D coordinates from 2-D data from two synchronized cameras. The raw 3-D coordinates were smoothed using a quintic spline function with a smoothing factor of 0.003 (Xu, Chow and Wang, 2006). The markers path data were filtered using a fourth-order low-pass Butterworth digital filter with a cutoff frequency of 5 Hz (Winter, 1990). Reflexives markers were positioned over the specific anatomical landmarks of ASIS (anterior-superior iliac spine), greater trochanter, lateral femoral epicondilus, calcaneous, lateral tibia epicondilus, II metatarsal, V metatarsal from both right and left lower limbs.

The kinematics assessment was carried out for three periods: the first evaluation period (P1) during the second trimester between 22 and 28 weeks of gestation, the second evaluation period (P2) during the third trimester between 34 and 40 weeks, and the last evaluation period (P3) during the postpartum period by the end of the fourth month. The periods of evaluation were established considering the secretion of relaxin.

Variables

Total cycle time or stride time was measured as the period between the initial contact of the heel of one foot and the next contact of the heel of the same foot. This variable is obtained based on the time difference between two successive strikes of the same heel. Double-support time was measured as the period during both feet were in contact with the floor during one walking cycle, corresponding to the period between the initial contact of the heel of one foot and the toe off of the contralateral foot. Single-support time or swing phase of the contralateral limb was determined as the period of time when only one foot was in contact with the floor. The stance phase was measured as the period of time when the foot was in contact with the floor. Cycle length or stride length was measured as the distance between two consecutive heel strikes by the same foot in the direction of displacement, while the step length was the distance between two consecutive heel strikes. Temporal and spatial variables were calculated as absolute and relative or normalized by height values. Temporal parameters were normalized according to total cycle time, while spatial variables were normalized according to body height. Four walking cycles were analyzed for each individual at each collection time. For statistical purposes, all repetitions of temporal and spatial variables performed during each cycle were included in the sample. All variables were evaluated bilaterally.

Statistical analysis

Data normality was confirmed applying Shapiro-Wilk’s test. Student t-test was applied to each variable obtained for the different evaluation periods in order to determine whether differences between the right and left side occur. With no difference found between right and left sides, the subsequent statistical procedures were applied considering data from right side. An analysis of variance (ANOVA) for repeated measures was performed for comparison of all
variables between the three evaluation periods. When interaction was found, the Tukey HSD post-hoc test was applied. A statistical level of significance was set at 0.05.

RESULTS

Anthropometric variables

Figure 1 shows the mean body mass of the subjects at P1, P2 and P3.

![Figure 1 - Mean body mass of the seven pregnant women during the different collection periods.](image)

Temporal and spatial variables

Table 1 summarizes the normalized values obtained for the temporal and spatial gait variables at the different evaluation periods. A similar behavior for temporal variables was observed for the three periods.

Table 1 - Temporal and spatial variables obtained during the first (P1), second (P2) and third (P3) period

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean (S.D.)</th>
<th>N</th>
<th>Mean (S.D.)</th>
<th>N</th>
<th>Mean (S.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double support</td>
<td>112</td>
<td>14.22 (9.52)</td>
<td>112</td>
<td>15.03 (9.68)</td>
<td>98</td>
<td>15.00 (9.67)</td>
</tr>
<tr>
<td>Single support</td>
<td>112</td>
<td>35.76 (1.88)</td>
<td>112</td>
<td>35.00 (2.26)</td>
<td>97</td>
<td>34.89 (2.00)</td>
</tr>
<tr>
<td>Stance phase</td>
<td>112</td>
<td>64.33 (1.95)</td>
<td>112</td>
<td>65.06 (2.08)</td>
<td>97</td>
<td>65.21 (1.87)</td>
</tr>
<tr>
<td>Stride length</td>
<td>112</td>
<td>70.19 (5.91)</td>
<td>112</td>
<td>67.56 (5.25)</td>
<td>97</td>
<td>68.73 (5.58)</td>
</tr>
<tr>
<td>Step length</td>
<td>140</td>
<td>35.19 (3.20)</td>
<td>140</td>
<td>33.83 (2.99)</td>
<td>127</td>
<td>34.50 (3.02)</td>
</tr>
</tbody>
</table>

Different letters indicate statistical significant difference (p < 0.05)

Angular variables

Table 2 shows the mean hip flexion/extension angle at the different percentages of the gait cycle during the three evaluation periods. At 0%, mean hip flexion was lower during P1 than P2, which in turn was lower than during P3, indicating a progressive increase in mean hip flexion over the three periods. The same behavior was observed at 10, 20, 30, 40, 50, 90 and 100% of the gait cycle, with hip flexion being greater during P3. At 60%, mean hip flexion was greater during P2 compared to the other periods, while at 70 and 80% of the gait cycle flexion was greater during the first period.

Figure 2 shows the curves of the hip flexion/extension angles obtained for the three periods. Hip flexion/extension of the individuals analyzed was within the time limits reported in the literature (Sutherland, Kaufman and Moitoza, 1998). No significant differences in hip flexion/extension were observed between the three periods.

Greater mean knee flexion/extension angle was obtained for the second period compared to P1 and P3 at all percentages of the gait cycle (Table 3). Statistical analysis revealed significant differences in knee flexion/extension at 40 and 50% of the gait cycle. At 40%, a difference was observed between P1 and P2, and between P2 and P3. At 50% of the gait cycle, a difference was only found between P2 and P3, while no differences were observed for the other percentages of the gait cycle. The mean knee flexion/extension curves obtained for the different periods are shown in Figure 3. Knee flexion/extension angle of the sample analyzed agreed with the time limits reported in the literature (Sutherland, Kaufman and Moitoza, 1998).
Table 2 - Mean flexion/extension angle (in degrees) of the hip obtained during the first (P1), second (P2) and third (P3) period according to percentage of gait cycle

<table>
<thead>
<tr>
<th>% of gait cycle</th>
<th>P1 Mean</th>
<th>P1 S.D.</th>
<th>P2 Mean</th>
<th>P2 S.D.</th>
<th>P3 Mean</th>
<th>P3 S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>9.10</td>
<td>6.68</td>
<td>9.50</td>
<td>9.03</td>
<td>10.34</td>
<td>7.32</td>
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<tr>
<td>10</td>
<td>4.52</td>
<td>7.63</td>
<td>5.15</td>
<td>9.25</td>
<td>5.05</td>
<td>8.51</td>
</tr>
<tr>
<td>20</td>
<td>-0.96</td>
<td>7.35</td>
<td>-0.25</td>
<td>8.72</td>
<td>0.09</td>
<td>8.07</td>
</tr>
<tr>
<td>30</td>
<td>-3.17</td>
<td>6.80</td>
<td>-2.77</td>
<td>8.87</td>
<td>-2.47</td>
<td>7.48</td>
</tr>
<tr>
<td>40</td>
<td>-5.68</td>
<td>6.64</td>
<td>-5.48</td>
<td>8.87</td>
<td>-4.90</td>
<td>6.58</td>
</tr>
<tr>
<td>60</td>
<td>-10.21</td>
<td>5.70</td>
<td>-9.55</td>
<td>8.29</td>
<td>-10.82</td>
<td>6.04</td>
</tr>
<tr>
<td>70</td>
<td>1.57</td>
<td>5.68</td>
<td>1.41</td>
<td>9.14</td>
<td>0.12</td>
<td>7.37</td>
</tr>
<tr>
<td>80</td>
<td>12.19</td>
<td>5.15</td>
<td>11.38</td>
<td>9.22</td>
<td>11.86</td>
<td>7.56</td>
</tr>
<tr>
<td>90</td>
<td>12.57</td>
<td>5.78</td>
<td>12.92</td>
<td>9.14</td>
<td>13.79</td>
<td>7.29</td>
</tr>
<tr>
<td>100</td>
<td>9.51</td>
<td>6.81</td>
<td>10.07</td>
<td>9.72</td>
<td>11.09</td>
<td>8.23</td>
</tr>
</tbody>
</table>

Underlined values indicate the highest mean obtained at the respective percentage.

\( N = 56 \) for P1 and P2; \( N = 48 \) for P3.

Figure 2 - Mean hip angle obtained for the three periods as a function of percentage of gait cycle.
Table 3 - Mean flexion/extension angle (in degrees) of the knee obtained during the first (P1), second (P2) and third (P3) period according to percentage of gait cycle

<table>
<thead>
<tr>
<th>% of gait cycle</th>
<th>P1 Mean</th>
<th>P1 S.D.</th>
<th>P2 Mean</th>
<th>P2 S.D.</th>
<th>P3 Mean</th>
<th>P3 S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.01</td>
<td>4.68</td>
<td>4.99</td>
<td>3.02</td>
<td>4.39</td>
<td>4.65</td>
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<tr>
<td>10</td>
<td>12.07</td>
<td>5.10</td>
<td>13.19</td>
<td>4.16</td>
<td>12.78</td>
<td>5.70</td>
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<tr>
<td>20</td>
<td>12.36</td>
<td>5.44</td>
<td>14.36</td>
<td>4.71</td>
<td>13.00</td>
<td>5.67</td>
</tr>
<tr>
<td>30</td>
<td>10.40</td>
<td>5.70</td>
<td>12.73</td>
<td>5.49</td>
<td>10.46</td>
<td>5.96</td>
</tr>
<tr>
<td>40</td>
<td>10.03</td>
<td>5.54</td>
<td>12.70</td>
<td>5.92</td>
<td>10.03</td>
<td>5.85</td>
</tr>
<tr>
<td>50</td>
<td>14.23</td>
<td>4.44</td>
<td>16.42</td>
<td>5.03</td>
<td>13.98</td>
<td>5.56</td>
</tr>
<tr>
<td>60</td>
<td>32.59</td>
<td>5.03</td>
<td>33.41</td>
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<td>6.88</td>
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<tr>
<td>70</td>
<td>58.75</td>
<td>4.41</td>
<td>58.37</td>
<td>5.96</td>
<td>56.80</td>
<td>7.52</td>
</tr>
<tr>
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<td>53.50</td>
<td>4.96</td>
<td>54.40</td>
<td>5.72</td>
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<td>20.54</td>
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<td>4.43</td>
<td>5.42</td>
<td>5.28</td>
<td>3.38</td>
<td>4.20</td>
<td>5.06</td>
</tr>
</tbody>
</table>

Underlined values indicate the highest mean obtained at the respective percentage.

N = 56 for P1 and P2; N = 48 for P3.

DISCUSSION

The purpose of this study was to evaluate the time-course of gait kinematics during the pregnancy period. The main find was the increase in joint mobility during pregnancy and the effects of relaxin on the pregnant woman’s body might persisting for a longer period than those reported in the literature. The spatial-temporal gait characteristics at the third period suggest the persistence of pregnancy adaptations in walking even at four months post partum, whereas angular gait kinematics at third evaluation period were similar to normal pattern expected.

The longest mean double-support time was observed for the second evaluation period, with the difference being more significant between P1 and P2 than between P1 and P3. Such behavior suggests a greater search for body balance during the gestational period between the first and second collection in view of the higher body weight and in view of the fact that the growing uterus is displaced in the direction of its inclination and the center of gravity is displaced upwards and forwards (Foti, Davids and Bagley,
In order to minimize the effects of body imbalance, the pregnant women maintain both feet on the floor for a longer period of time, thus increasing the double-support time. This is a characteristic well described for elderly people gait, which walks slower and with higher time on support phase (Riley, Croce and Kerrigan, 2001). In pregnancy, it is probably related to improve of dynamics body stability. Only a small difference in mean stance phase was observed between P2 and P3 (65.06% and 65.21%), suggesting a similar gait pattern and persistence of walking changes by four months post partum. Higher mean values of the two parameters cited were observed for the second and third period compared to the first one, indicating a greater search for body balance. Again, the differences were significant between P1 and P2 and between P1 and P3.

Mean single-support time, which corresponds to the swing phase of the contralateral limb, was longer during the first period compared to the other periods. This finding agrees with the results obtained for double-support time and stance phase, suggesting that the body's requirements for adaptation and balance are smaller during the first than during the second period. As a result, the double-support time and stance phase were shorter during the first collection while the single-support time was longer. Again, significant differences were observed between P1 and P2 and between P1 and P3.

Comparing gait in pregnant women at the end of pregnancy (35 and 40 weeks) and one year post partum, significant differences were found in variables such as single and double support time between the two periods, with the values being suggestive of a return to normal gait patterns (Foti, Davids and Bagley, 2000). The authors describe these changes as dependent on body mass and width increased leading to an increased demand for hip abductor and extensor muscles, as well as planter flexor muscles during walking. Our results indicate that a period of more than four months is necessary to identify significant differences. The anatomical effects of relaxin can be present up to 12 weeks post partum (Artal, Wiswell and Drinkwater, 1993). The present results suggest that the effects of relaxin on the pregnant woman's body might persist for a longer period of time than that reported in the literature. Complete post partum regression of joint flexibility to the pre-pregnancy state might require a period of six months (Polden and Mantle, 1993).

Mean spatial variables – stride length and step length – were highest during the first evaluation period and lowest during the second evaluation period, with this difference being statistically significant. This finding agrees with literature data showing that the gait of pregnant women consists of shorter and more oscillating steps as pregnancy progresses. The values observed for the third period were lower than those obtained for the first period, indicating that these variables have not yet returned to pre-pregnancy patterns. Significant difference in step length was not observed when analyzing pregnant women at the end of pregnancy and again one year post partum (Foti, Davids and Bagley, 2000).

With respect to the angular variables, hip and knee flexion/extension occurred within the time limits reported in the literature, suggesting that pregnancy does not influence these parameters. Statistical analysis did not reveal significant differences in hip flexion/extension between the three periods, in contrast to a study where significant variations in both hip flexion and extension were found between the periods analyzed (Foti, Davids and Bagley, 2000). Regarding knee flexion/extension, the present study showed significant differences at 40 and 50% of the cycle, while no variations in this variable were observed by the same authors (Foti, Davids and Bagley, 2000).

Little increments in kinetic and kinematics measures done at the final phase of hip extension and knee flexion were found in pregnant compared to non-pregnant women (Butler et al., 2006). These changes were associated with an increased knee extensor moment and increased maximal ankle dorsiflexion in the final of the gait cycle for a group of final pregnancy. There were also increased hip extension, adduction and internal rotation in the start of the pregnancy period, which were related to decreased postural stability with more remarkable changes observed at six months of pregnancy, and continuing in the period of post-partum (Butler et al., 2006).

It is important to mention that, although significant differences in knee flexion/extension were only observed at 40% and 50% of the gait cycle, mean knee angles were greater during the second evaluation period at all percentages analyzed. This finding agrees with literature reports showing an increase in joint mobility during pregnancy (Birch et al., 2003). The lack of pre-gestational evaluation, which would represent the normal gait pattern of the sample, limits the discussion and conclusion of the study, even so the same group was compared in a considerable period post partum.

**CONCLUSION**

The data obtained for spatial-temporal gait characteristics at the third period, four months post partum, suggest the persistence of pregnancy-required adaptations in walking even at four months post partum, whereas angular gait kinematics at third evaluation period were similar to normal pattern expected. These results can be used as parameter for physical activity prescription in the post partum.
REFERENCES


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