

Changes of kinematic gait parameters due to pregnancy

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When a woman becomes pregnant her body undergoes tremendous changes hormonally and anatomically. Our survey revealed very little literature on biomechanics of gait in gravidas and lack of consensus among scientists in pregnancy-related mechanisms of body adaptation. That is why the authors felt encouraged to determine the effect of pregnancy on the biomechanical pattern of walking. To investigate alterations in natural locomotion, we used a 3D motion-analysis system Vicon. The inclusion criteria aimed at selecting only healthy subjects ($n = 13$). Each woman participated in 3 sessions: before pregnancy, during the last trimester of gestation and, finally, half year after delivery. For the purpose of this study, selected kinematic parameters for pregnant and non-pregnant conditions were compared. Gravid women performed lower velocity of their gait and lower frequency of steps. The length of their step decreased in comparison to pre pregnancy state. The results did not reveal any changes in the range of motion of the ankle, knee and hip in different physiological conditions. However, we observed increased base of support and double support phase in gravidas comparing to non pregnant states (by about 10%). This finding indicates that there is a tendency to maximize safety in gait during pregnancy.

Key words: base of support (BOS), locomotion, pregnancy, range of motion (ROM), safety, Vicon

1. Introduction

Biomechanical investigations of human locomotion showed that control of the movements during walking is based on choosing one of the two dominant strategies: energy or safety. The first strategy may be reflected in the movements of long-distance walker. On the other hand, safety becomes a priority during walking for people with injuries and trauma within the musculoskeletal system. Of course, there are also possible situations where it is difficult to indicate the cause of the manner of walking chosen by a human. Then, usually the two criteria are complementary, and the observer can only indicate a dominant strategy.

Pregnancy, as a natural and physiological process, produces in a woman a series of changes involving the motor system. Weight gain, especially changes within its distribution requires functional adaptation of the musculoskeletal system [1]. These changes make both

the posture and gait pattern of pregnant women different from non pregnant subjects.

Analysis of the literature showed many detailed reports on the posture of gravid women (e.g., [2]–[6]), but the number of studies on gait of such women is relatively small. In addition, available materials, based on a small sample of the subjects are still far from final decisions of such a quantitative assessment of their movement. Consequently, research is fragmentary and describes only a mechanic state. It rarely combines the results of different studies in order to create the overall concepts to explain the gait phenomenon of expectant mothers in a broader aspect.

It is well known that during pregnancy hormonal changes occur in women, and the level of certain hormones influences the structure of the movements [7]. According to most researchers, increased level of relaxin affects the greater range of motion of the pelvic girdle and the peripheral joints [8]–[10]. At the same time, the lack of agreement about the time of

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Received: December 23rd, 2011

Accepted for publication: August 4th, 2012

persistence of the higher level of relaxin in women after delivery makes it unclear when the movement returns to the functional pre pregnancy state [11], [12].

POLDEN and MANTLE [13] estimate the length of time needed to complete restoration of joint flexibility, even for half a year. Drawing inference about the mechanisms occurring in pregnant women is difficult; scientists are careful in this respect and recognize large inter-individual differences in adaptation to pregnancy, so that every woman solves this problem on her own. Additional problems result from the low back pain that is common in gravid women. It may be either a consequence of the increased lumbar lordosis [3], or associated with the displacement of the center of mass [14], or finally, musculoskeletal disorders in pregnant women [15]. Probably due to the accumulation of all these problems, TSAN-HSUN et al. [10] stated that gait analysis of pregnant women is possible but very complicated.

The main purpose of the study was to measure the selected gait parameters in one group of women in three different states: before pregnancy, during pregnancy and after delivery and evaluate the differences in their way of locomotion. Besides, the authors were going to determine the effect of gestation on the biomechanical pattern of walking, and to find out whether a 6-month time period after delivery is sufficient to reach pre pregnancy gait pattern.

2. Materials and methods

The study of women's locomotion at a natural speed was carried out in the Biomechanics Department, University School of Physical Education in Kraków.

During measurements we used a three-dimensional motion-analysis system, Vicon 250 (Oxford Metrics Limited, Oxford, England). The recruitment of subjects started at the beginning of 2009 and finished 2.5 years later. The inclusion criteria aimed at selecting only healthy women, planning a child in a near future. Such an approach was possible due to the cooperation of the research team with a gynecologist. There were excluded from the group those subjects who suffered from previous orthopaedic or neurological injuries. Finally, 13 women met our requirements. The average age in the group, at the time when the study started was 29.15 ± 3.5 years. The body height of females did not change during the whole experiment (166.4 ± 7 cm). Other anthropometric data, relevant to the work, are given in table 1.

Each woman participated in 3 sessions:
 – first, before pregnancy (**pre** pregnancy state);
 – second, during the last trimester of pregnancy (33 – average week of gestation) (**in** pregnancy state);
 – third, half year after delivery (**post** pregnancy state).

Consequently, when describing the results we made a division into 3 groups: pre, in, post.

Table 1. Average values of selected morphological parameters in women: Inter-Asis – distance between Anterior Superior Iliac Spines; PRE, IN, POST – state of women in terms of pregnancy

State	Body mass ^{a, b, c} [kg]	Inter-Asis ^{a, b} [cm]
PRE	54.73	23.21
IN	68.25	25.76
POST	60.36	24.15

a – statistically significant difference between PRE and IN group ($p \leq 0.05$),

b – statistically significant difference between IN and POST group ($p \leq 0.05$),

c – statistically significant difference between PRE and POST group ($p \leq 0.05$).

The body mass of women changed during the experiment and was the highest during pregnancy (IN). This value was about 14 kg higher than prior to pregnancy (PRE) and 8 kg higher than after delivery (POST). The statistical analysis revealed that all these differences were statistically significant. Considering Inter-Asis distance its value observed in pregnancy was 1.5–2 cm larger than in PRE and POST states, and this difference was significant.

To register locomotion we used five video cameras emitting infrared light, reflected by the markers placed on the subject's skin. Reflective markers were placed over the standard anatomical landmarks according to the Golem model, which required 39 markers (placed as follows: 4 on the head, 4 on the trunk, 3 on the pelvis and 7 on each of the upper and lower limbs). After the calibration of the measuring system, the women were asked to walk barefoot at a self-selected speed across the room on the floor covered with a special non-slip and antistatic surface. In all patients we registered 15 gait cycles for each leg (30 steps). The parameters analyzed were averaged over all trials of all walking subjects. Overall, the woman during one session covered a distance of about 50 meters with short intervals (about 1 minute) between each section of the way. After gait registration, the measurement of approx-

appropriate anthropometric parameters was carried out that enabled the mathematical processing of data. The methodology was the same as in earlier works of the authors [16], [17].

From among a number of variables obtained in the study, for the purposes of this paper we presented only selected gait characteristics for women in different physiological states. From the group of time and distance gait variables we chose velocity (v) and gait frequency (f), the length of steps (l) and time of a single (SS) and double support (DS). In addition, we analyzed ranges of motion in the sagittal plane in the major joints of the lower limbs: ankle, knee and hip, and calculated the width of the base of support (BOS) in double support phase of gait. The last of these variables is the mean shortest distance joining lines which contain projections of the ANK (markers placed respectively on the left and right lateral malleolus) and parallel to the direction of movement (figure 1).

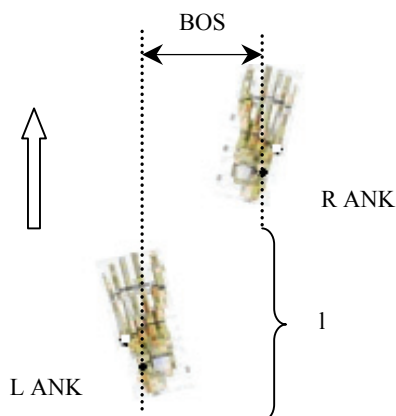


Fig. 1. Schematic diagram explaining the method of linear variables measurement (LANK, RANK – lateral malleolus of left and right limb, respectively, bold arrow – direction of subject’s movement)

Statistical Analysis

The statistical package used to analyze data was Statistics 8.0. To investigate normal distribution of the results in the groups we used the Shapiro–Wilk test. All the scores were found to be normally distributed. Descriptive statistics of kinematic variables characterizing the subjects in each state are presented in tables 2–4. An analysis of variance (ANOVA) was performed for comparison of all variables between the three periods evaluated. When interaction was found, the Tukey *post hoc* test was applied. A statistical level of significance was set at 0.05.

3. Results

In table 2, the ranges of motion in the sagittal plane of the major lower limb joints in women are presented. The characteristics indicate that the time of pregnancy does not affect this aspect of gait; mean ranges of motion of the ankle, knee and hip joint have not changed. The mobility of these joints in this plane of motion during gait at a natural speed in each state was approximately 30°, 60° and 50°, respectively. This observation is supported by the results of statistical analysis. ANOVA shows that the ranges of motion of the main joints of the lower limbs during gait in women before, during and after pregnancy are not significantly different.

Table 3 shows the statistical characteristics of the basic parameters of gait: velocity (v) and frequency (f). As one can see, the velocity in each state of the study exceeds 1.4 m/s, which is more than 5 km/h. At the same time, the value of v in pregnant females (IN)

Table 2. Descriptive characteristics of range of motion [deg] in the sagittal plane in the major joints of the lower limbs during gait at natural speed

	Ankle			Knee			Hip		
	PRE	IN	POST	PRE	IN	POST	PRE	IN	POST
$\bar{x} \pm SD$	30 ± 3.8	30 ± 5.2	30 ± 4.9	63 ± 3.8	63 ± 3.3	61 ± 2.4	51 ± 4.2	49 ± 3.9	50 ± 3.3
min	26	21	23	57	58	57	44	43	47
max	37	37	38	67	70	64	56	55	56

Table 3. Characteristics of velocity (v) and frequency of steps (f) during gait of women

	v [m/s] ^{a, b}			f [steps/min] ^b		
	PRE	IN	POST	PRE	IN	POST
$\bar{x} \pm SD$	1.53 ± 0.28	1.41 ± 0.21	1.52 ± 0.24	122 ± 11	119 ± 8	124 ± 8
min	1.2	1.08	1.09	113	106	112
max	1.96	1.72	1.74	139	130	135

(a, b – see table 1)

was lower than in the same group before and after pregnancy, and this difference was about 8%. In both PRE and POST states this difference was statistically significant. Besides, gravid women are moving at a lower frequency of steps than before pregnancy and after delivery.

In absolute terms, these differences range from 3 to 5 steps/min, but only those referring to IN and POST states are significant. Analysis of these data also revealed that the speed and frequency of walking (v and f) return to prepregnancy state in half a year after childbirth.

An additional (complementary) illustration of the above observations of the basic gait parameters approaching each other in PRE and POST group, is given in figure 2. It presents the average length of steps (l) during gait in each state under study. As one can see, the values of pre and post pregnancy differed by only 1 cm, but at the same time were about 3–4 cm higher than recorded in expectant mothers. However, ANOVA analysis confirmed that only in PRE and IN states the values differed significantly.

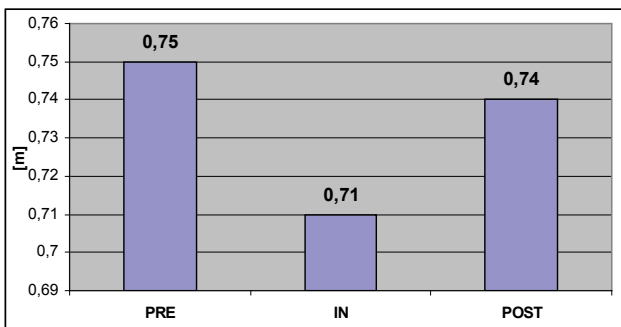


Fig. 2. The average length of the steps noted in women in three gait sessions

The duration of double support during free gait of gravid women increased by approximately 0.02 s (10%) (figure 3). Therefore, the relative contribution of this phase in one cycle of gait was also the largest and amounted to 35%, whereas in PRE and POST groups to 31–33%. Consequently, despite the lack of differentiation between duration of a single support phase in gait of women before and in gestation, the relative contribution of this phase was the lowest (65%). The above tendency of changes in relation to Single Support and Double Support time during gait in each physiological state was not confirmed by statistical analysis.

The width of the area of support presented in table 4 reflects the alterations in the way of walking in women. The average value of this variable (over 18 cm) was highest in pregnant individuals and exceeded by 1.5–2.0 cm (8 to 13%) the value recorded in their locomotion

prior to and after pregnancy. The analysis of variance revealed that these differences were statistically significant. Table 4 also indicates the tendency to equate the width of BOS between pre pregnancy state and the state 6 months after giving birth to a child.

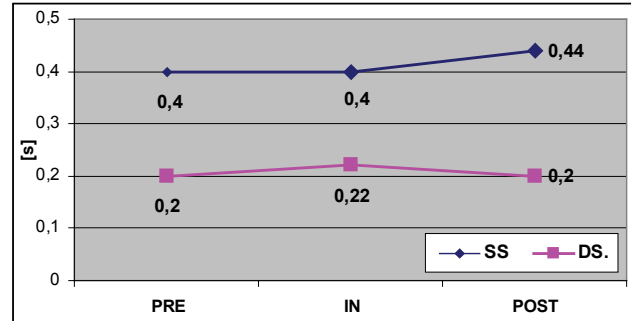


Fig. 3. Single support time (SS) and double support time (DS) noted in women during three gait sessions

Table 4. The width of the base of support (BOS) during double support phase in women's gait

	BOS [mm] ^{a, b}		
	PRE	IN	POST
$\bar{x} \pm SD$	160 ± 28	181 ± 29	167 ± 25
min	104	113	116
max	214	258	232

(a, b – see table 1)

4. Discussion

Even a cursory observation of gait of pregnant women clearly shows the distinctness of this type of locomotion in relation to non pregnant subjects. There is no doubt that this is a consequence of the developing and growing fetus, and changes in body mass and its proportion in mother's body [18], [19]. Applying proper methods of measurement we can assess those differences in terms of quality and quantity. Interestingly, analysis of the literature on gait kinematics of pregnant women provides quite unexpected conclusions, often contradictory, e.g., [4], [5]. It is possible that this is a consequence of the imposition (a kind of superposition) of two kinds of phenomena: first, the individual gait pattern of mothers [18], [20], second, individualized fetal growth, and especially its orientation in the womb before delivery. Only considering these factors provides a basis for justifying and explaining the differences in locomotion not only of gravid and non-gravid women, but also among women in various stages of gestation.

Additionally, if we realize different gait strategies (mentioned in the introduction), the explanation of movement in pregnant women and changes in their way of walking in a different physiological state becomes more troublesome. The problem could become even more complex if it turns out that the strategy of expectant mother varies with the duration of pregnancy. It should be noted that there are some indications of this thesis: BUTTER et al. [21] highlight greater stability of kinematic and kinetic measures of gait during pregnancy than in the control group. At the same time, JANG et al. [22] demonstrate a significant enlarging of the area of support during pregnant gait, and the results of DONELAN et al. [23] leave no doubt – the cost of locomotion increases with the width of the steps (base of support). All this may be the evidence of adaptive changes in movement control in pregnant women during walking, and these changes may be varied between individuals, either individually focused on minimizing the energy cost of locomotion, or to maximize safety during locomotion. However, it is possible that the second type of strategy may be dominant in the population of gravidas.

Our study suggests that different physiological state (pregnancy) does not affect the range of motion of major joints of the lower limbs in the sagittal plane. The values noted for ankle, knee and hip joints were similar. Such an observation seems to be a bit surprising in view of already mentioned reports of a higher concentration of relaxin in the blood of pregnant women [7].

It is well known that the secrecy of this hormone affects an increase of the range of motion of the pelvis and peripheral joint in pregnant women [10], and such an increased level of relaxin may stay even half year after delivery. Those hormonal changes may be the main cause of increased lumbar lordosis and increased anterior pelvic tilt [3] as well as other postural alterations. Thus, despite the existence of potential variation in flexion/extension range of motion in women's joints in different physiological conditions, such differentiation does not occur. Our findings in this respect are confirmed in the work of FOTI et al. [18] and CARPES et al. [12]. Most likely, this type of physical activity, which is free gait, does not require from pregnant women exploitation of the full motor potential. However, for the accuracy of the description, it should be noted that the first of the last research teams mentioned, observed diversity in the behavior of lower limb joints, but not for sagittal plane.

The results of our studies show that natural walking of expectant mothers is characterized by a slower

velocity and lower frequency and length of steps, compared with pre pregnancy state. These observations have been made previously by several investigators [19], [20], [24]. Equally obvious is the impossibility of comparing the absolute values of each variable listed by various authors. The main reason for these difficulties is different speed of walking performed by women. As everyone knows, gait speed affects the values of other kinematic parameters, including length and frequency of steps [25]. From a mechanical point of view, as described above, the external illustration of expecting mother movement resulting in increased safety of bipedal locomotion is similar to the gait of older people [26].

This study has also brought some unexpected observations of walking women in different physiological states. It turned out that during locomotion at a natural speed, regardless of the status, the ranges of motion of the lower limb joints are similar, and significant differences are noted in the length and frequency of steps. Perhaps this phenomenon is supported by the diversity of pelvic girdle work during gait in pregnancy, as well as before and after gestation. This difference is probably due to the changes of mass distribution within the body, as mentioned above, which limits movements of the pelvis around the longitudinal axis of the body (in the transverse plane).

The measure of the mechanical equilibrium of the human body is the size of base of support, and the results obtained show that its width during gait in pregnant women is about 10% higher. The investigations of others [16], [27]–[29] revealed similar results. It is evident that BOS depends on the size of the body and walking technique. Due to the fact that both factors are individually determined, comparison of absolute values of such parameters from various works is a purely mathematical task. In a mechanical sense, however, Bird et al. [29] recognized this effect of BOS increase as the need to increase the so-called “locomotion stability”. As it seems, in this case, the goal is to guarantee the safety of mother and child. The probability of displacement of the vertical projection of center of gravity beyond the base of support is minimized in two ways: by increasing the width of the BOS and the relative reduction of the lateral oscillations of the center of gravity. The above thesis seems to be possible in view of the study of JANG et al. [22], however their project was carried out in statics using stationary force platform. The mechanisms mentioned enable a safer transfer of weight from limb to limb during walking. Striving to maximize safety in gait of gravid women is supplemented by lengthening the double support phase of gait, as

quoted frequently in [12], [18]. These researchers emphasize that it is a manifestation of minimizing the negative effects of imbalances.

After delivery, within the musculoskeletal system of women, it seems to be a natural tendency to reach the values of kinematic gait parameters recorded before pregnancy. Scientists argue about the length of this period: from 3 months [11], [19] to 6 months [13]. It was not the purpose of our research to resolve this dilemma, nonetheless we noticed that half year post partum almost all kinematic gait variables returned to the pre pregnancy level.

Practical aspect of the results obtained lies in the fact of using biomechanical methods to assess the rate of succession of these changes after childbirth, or dynamics of the return of prepregnancy gait pattern within musculoskeletal system. Another possible application in the future may be evaluation of the effect of, e.g., non-pharmacological treatments (physical activity) on the returning process of locomotion pattern in women after delivery.

5. Conclusions

Analysis of the results obtained during the registration of gait at a self selected speed performed by women before, during and after pregnancy allowed us to make some specific proposals:

1. Different physiological state (pregnancy) does not affect the ranges of motion of the main lower limb joints in the sagittal plane.

2. Natural locomotion of pregnant women is characterized by slower speed and lower frequency and length of steps, as compared to the pre-pregnancy and post partum state.

3. In free gait of expectant mother, the duration of double support phase and the width of the base of support increase, which may seem to contribute to increase the safety of movement.

4. Within the musculoskeletal system is a natural tendency to return to pre pregnancy values of kinematic gait parameters, and biomechanical measurements can assess the rate of succession of the changes.

Acknowledgements

We wish to thank all the women participating in our study for their patience and invaluable cooperation during the whole experiment.

The project was supported by the grant for young researchers from the Polish Ministry of Science and Higher Education (grant no. 17/MN/KA/2011).

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