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BIOMECHANICAL ASPECTS OF POSTURAL CONTROL OF THE HUMAN BODY

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The uterus is a muscle-elastic-collagen system of levers involved in stabilizing a woman's posture during pregnancy; being in an unusual state due to changes in the connective tissue elements of both the uterus and extrauterine structures. With the increase of the uterus during pregnancy, the recovery of the typical posture changes due to changes in its muscular and elastic apparatus and in elastic-collagen connections with the bones of the pelvis. It is important that the dense area of the ligaments is a collagen structure and is the least elastic component of this chain. The uterus is attached to the pelvis from the inside. In contrast, the areas of the external spiroid dynamic muscle chains are attached from the outside, thus entwining the body both homolaterally and heterolaterally. Based on the above, we hypothesize that these are synergistic and mutually competing biomechanical structures. Disturbance in the balance of these structures can lead to a suboptimal condition of the pregnant woman's body in statics and dynamics.
Key words: postural control, diaphragm, uterus, center of gravity, muscle spirals, biomechanics.

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БІОМЕХАНІЧНІ АСПЕКТИ ПОСТУРАЛЬНОГО КОНТРОЛЮ ТІЛА ЛЮДИНИ

Матка являє собою м'язово-еластично-колагенову систему важелів, що беруть участь у стабілізації пози жінки під час вагітності, перебуваючи в нехарактерному стані внаслідок змін сполучнотканинних елементів як матки, так позаматкових структур. При збільшенні матки під час вагітності змінюється відновлення типової постави за рахунок змін в її м'язово-еластичному апараті, а також в еластично-коллагенових зв'язках з кістками таза. Важливо, що щільна ділянка зв'язок є колагеновою структурою і є найменш еластичним компонентом цього ланцюга. Матка прикріплюється до малого тазу зсередини, а ділянки зовнішніх спіроїдних динамічних м'язових ланцюгів прикріплюються ззовні, обплітаючи тіло як гомолатерально, так і гетеролатерально. Виходячи з вищесказаного, ми припускаємо, що це синергетичні та взаємоконкуруючі біомеханічні структури. Порушення балансу цих структур може призвести до неоптимального стану організму вагітної в статиці та динаміці.
Ключові слова: постуральний контроль, діафрагма, матка, центр ваги, м'язові спіралі, біомеханіка.

The study is a fragment of the research project "Pathogenetic role of endothelial dysfunction and genetic features in pathology during pregnancy and gynecological diseases", state registration No. 0121U005253.

Postural control is the most important component of the static and dynamic balance of the human body [13]. The biomechanical explanation of the center of gravity is applied in the field of physical rehabilitation for the construction of dynamic models; in the choice of the optimum protocol of physical therapy; in determining the stability and angular acceleration of equipment used by people in various postural manifestations; in designing the aircraft seats; in the study of muscle biomechanics, etc [2, 11, 15].

From the point of view of biomechanics, postural control is the ability of an individual to regulate the spatial position of the human body, the ability to maintain and control the overall center of gravity of the body to prevent falls or loss of balance in static and dynamic positions [4].

The lack of a generally accepted definition of "postural control" in clinical practice and biomechanics does not deny the statement that maintaining the spatial body balance requires coordination of signals of the vestibular, somatosensory, and visual systems, i.e., the triad of postural control. Signal coordination from these systems plays the leading role in postural control, as information on the orientation of the spatial body from different senses is not always available (closed eyes, uneven supporting surface, etc.). [5]. Assessment of postural control of pregnant women is important for a timely preventive effect on the detection of changes in the structure of the bone-ligamentous-muscular apparatus, which leads to the occurrence of pain syndrome.

Although the problems of biomechanics in the human body's postural control have been extensively highlighted in the scientific literature, the issues of the diaphragm contribution to the postural balance of the human body and the changes in the postural balance of pregnant women have not been sufficiently studied yet.

The purpose of the study was to establish the parameters and factors that determine the spatial position of the human body and the maintenance of the equilibrium state.

Materials and methods. The study was performed based on the Municipal Enterprise "City Clinical Maternity Hospital of the Poltava City Council".

The study relied on the survey of 50 pregnant women (25-33 aged old) with a physiological course of pregnancy who were undergoing inpatient treatment at the Municipal Enterprise "City Clinical Maternity Hospital of the Poltava City Council".

The average pregnancy period was 37 weeks of gestation. Multigravidas made up 54 % of the subjects. At this pregnancy stage, the fetus's maximum increase and displacement of the center of gravity of these patients are determined. For the inclusion of pregnant women in the study, neurological history and visual acuity were not considered. This category of patients was taken for further research.

In the course of the study, the Rules of Humane Treatment of Patients were observed following the requirements of the Tokyo Declaration of the World Medical Assembly, the requirements of the International Recommendations of the Helsinki Declaration of Human Rights, the "Council of Europe Convention on Human Rights and Biomedicine", the Law of Ukraine "Basics of Ukrainian Legislation on Health Care" with amendments, the Orders of the Ministry of Health of Ukraine, the Code of Ethics of a doctor of Ukraine and the Code of Ethics of a scientist of Ukraine, current legislation. Voluntary informed consent to participate in the study was obtained from all patients before the start of the study.

The Spielberger-Khanin test was used to detect personal and reactive anxiety, and the FAM questionnaire (Feeling. Activity. Mood: the differential self-assessment test of the functional state) was applied to study the human condition. The main criteria of women's psychological and emotional state in our study were as follows: the level of reactive (situational) anxiety, well-being, activity, and mood.

Determining the center of gravity of a person provides information about the biomechanical characteristics of body segments and measurement of the center of gravity for individuals in specific postural settings, using the average data of specific experiments.

Fig. 1A shows a schematic representation of the migration of the projection for the center of gravity of a person with an increasing inclination angle from 0º to $\alpha°$ – an angle at which maintaining the vertical position of the body becomes impossible and a person falls forward.

Fig. 1B demonstrates that the force of gravity (P) acting on the human body is balanced by the support reaction force (R), with an angle of inclination equal to 0º. The moments of these forces relative to the point O are equal to each other: $M_p = M_R = 0$

The center of gravity is projected at point O, which is 5 cm in front of the calcaneal tubercle.

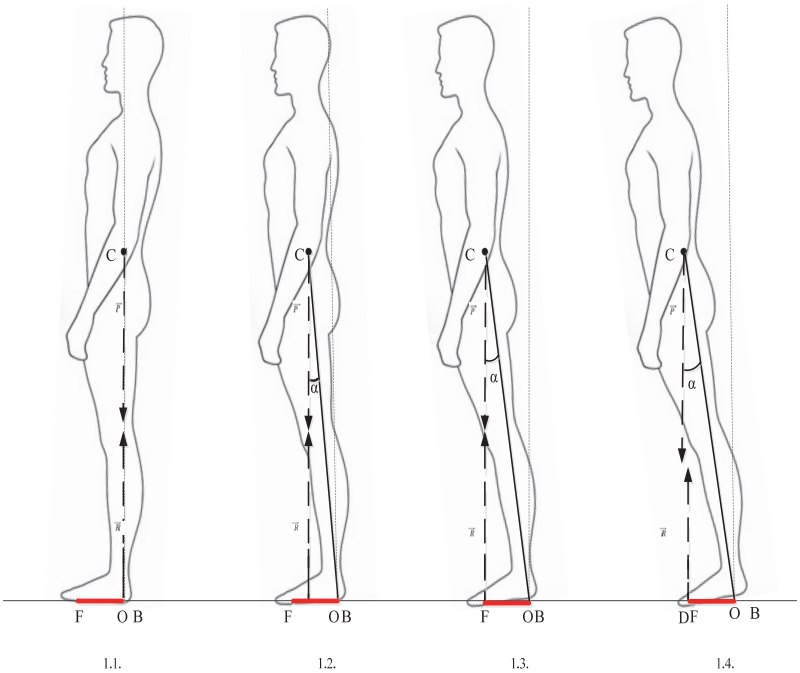
Fig. 1B demonstrate the angle increase within $0 < \alpha \leq \alpha°$ – conditionally, the center of gravity is projected forward from the point O.

In fig. 1B, $\alpha > \alpha°$, $OD > OF$ and, accordingly, the center of gravity is projected at point D, which is located outside the supporting area (foot).

As one can observe, the passage of the vertical axis of its common center of gravity within the supporting area of the body is the prerequisite for maintaining body balance. If the vertical of the center of gravity of the support comes out of the supporting area, the body loses balance and falls.

The mathematical substantiation of this process is presented below.

The sagittal size of the supporting area in the norm always prevails over the frontal size, therefore, the displacement of the vertical line of the center of gravity is easier to the right and left than backward, and especially difficult when moving forward. The formula can determine the limiting angle of deviation forward (fig. 1B).



A

1a $M_P = M_R = 0$

1b $M_P = OC \cdot P \cdot \sin(180-\alpha) = OC \cdot P \cdot \sin\alpha = OA \cdot P = OA \cdot R = M_R$

1c $M_P = OC \cdot P \cdot \sin(180-\alpha_{limit}) = OC \cdot P \cdot \sin\alpha_{limit} = OF \cdot P = OF \cdot R = M_R$

1d $M_R = OF \cdot R \cdot \sin 90^0 = OF \cdot R = OF \cdot P < OD \cdot P = M_P$

Generally, the moment of force is determined by the formula: $\vec{M}_F = \vec{r} \times \vec{F} = [\vec{r}, \vec{F}]$. The absolute value (module) of the moment of force is determined as follows:

$|\vec{M}_F| = M_F = |\vec{r}||\vec{F}|\sin(\vec{r}, \vec{F}) = rF\sin(\vec{r}, \vec{F})$.

1.1) $M_P = OC \cdot P \cdot \sin(\vec{OC}, \vec{P}) = OC \cdot P \cdot \sin 180^0 = 0$. (1)

$M_R = 0 \cdot R = 0$. (2)

Thus, it follows from (1) and (2) that $M_P = M_R = 0$ (see Fig. 1a).

1.2) $M_P = OC \cdot P \cdot \sin(\vec{OC}, \vec{P}) = OC \cdot P \cdot \sin(180-\alpha) = OC \cdot P \cdot \sin\alpha = OA \cdot P$ (3)

$M_R = OA \cdot R \cdot \sin(\vec{OA}, \vec{R}) = OA \cdot R \cdot \sin 90^0 = OA \cdot R = OA \cdot P$ (4),

because $\vec{P} = -\vec{R}$.

Thus, it follows from (3) and (4) that $M_P = M_R$ (see Fig. 1a).

1c) $M_P = OC \cdot P \cdot \sin(\vec{OC}, \vec{P}) = OC \cdot P \cdot \sin(180-\alpha_{limit}) = OC \cdot P \cdot \sin\alpha_{limit} = OF \cdot P$ (5)

$M_R = OF \cdot R \cdot \sin(\vec{OF}, \vec{R}) = OF \cdot R \cdot \sin 90^0 = OF \cdot R = OF \cdot P$ (6),

because $\vec{P} = -\vec{R}$.

Thus, it follows from (5) and (6) that $M_P = M_R$ (see Fig. 1c).

1.4) $M_P = OC \cdot P \cdot \sin(\vec{OC}, \vec{P}) = OC \cdot P \cdot \sin(180-\alpha) = OC \cdot P \cdot \sin\alpha = OD \cdot P$ (3)

$M_R = OF \cdot R \cdot \sin(\vec{OF}, \vec{R}) = OF \cdot R \cdot \sin 90^0 = OF \cdot R = OF \cdot P$ (4),

because $\vec{P} = -\vec{R}$.

Thus, it follows from (3) and (4) that $M_P > M_R$, because $OD > OF$ (see Fig. 1d).

$$\alpha_{limit} = arctg\left(\frac{OF}{h_{grav.center}}\right).$$

Similarly, one can determine the maximum angle of deviation backward:

$$\beta_{limit} = arctg\left(\frac{OB}{h_{grav.center}}\right).$$

The displacement of the vertical line of the center of gravity backward occurs at the value of angle β with a degree measure, much smaller than the degree of angle α (Fig. 1), because $OB < OF$.

B

Fig. 1. Schematic representation of the migration of the center of gravity: scheme (a), formula (b).

The survey results were analysed using the MS Office 2010 software package. The correlation between the indices was determined using the Spearman coefficient (R).

Results of the study and their discussion. The diaphragm is known to be the main respiratory muscle, and the abdominal and thoracic cavities, affected by this muscle, are also involved in torso stability and postural control. The diaphragm also has properties associated with maintaining the stability of the lumbar spine. The postural function of the diaphragm stabilises the human spine when performing tasks requiring repetitive movement.

Based on the claims about the spiroid structure of muscular kinematic chains, it was found that muscles contract in isolation and participate in the joint movements of spirals through aponeuroses, fascia, and intermuscular septa. Muscular spirals are functional associations of muscles that provide rotational movements. The basis of muscular spirals is a chain of skeletal muscles, whose essence is the transfer of force from link to link. In this context, each spiral possesses a certain set of muscles, and some of them can participate in other spirals.

Since the diaphragm is connected to the cervical spine indirectly through the fascia and interfascial spaces of the body and also through the fibromuscular levers, it attaches to the bones of the torso inside the skeleton of the thorax and the spine (fig. 2). The spiroid muscular chains maintain the balance of the body in gravity from the outside, we believe that the diaphragm is a complex biomechanical formation of muscle spirals of the human body. The uterus is attached to the pelvic bones and the diaphragm with the help of the osseous-elastic-muscular complex, which we consider the internal lever mechanism of the external muscular spirals of the pregnant woman's body.

Fig. 2. The location of muscular spirals of external and internal rotation in the human body

These factors lead to the adjustment of balanced activity of these systems to maintain the position of the body in a variety of settings and conditions. It is the subject of sensorimotor integration – a process during which the nervous system, receiving information from all sensory receptors (touch, proprioception, smell, sight, hearing, taste), organizes an adaptive response to perform a certain action, adopting an appropriate body position and the like.

Using the questionnaire method, we found that 6 women (12 % of respondents) had a history of reproductive loss.

During pregnancy, 2 women (4 %) experienced involuntary falls in the first and third trimesters, respectively, and therefore sought medical advice.

Inconveniences (difficulty) in the transition from standing to sitting (and vice versa) position during pregnancy in the study group were estimated at an average of 3.06±1.8 points (on a ten-point scale). The respondents rated inconveniences (difficulty) when walking on an uneven surface at an average of 2.78±2.19 points (on a ten-point scale). These parameters did not correlate with the BMI of patients (R=0.04077, p=0.7786 and R=0.08839, p=0.5416, respectively). In this group of subjects, no strong correlations were found between the postural control disorders and the level of reactive (situational) anxiety (R=0.2588, p=0.696). In general, a low level of reactive (situational) anxiety in the group of subjects was found in 76% of respondents and a moderate level – in 24 % of subjects. 30 % of the surveyed patients performed sets of physical exercises for pregnant women as recommended by a doctor (18 %).

Conditions for maintaining a static state of human equilibrium include the migration in the projection of the center of gravity of a person with an increasing inclination angle forward or backward. The passage of the vertical axis of its common center of gravity within the supporting area of the body is the prerequisite for maintaining body balance. If the vertical of the center of gravity of the support comes out of the supporting area, the body loses balance and falls. The limiting angle of inclination, at which the body still maintains a state of equilibrium, becomes available for measurement based on the projection of the center of gravity and the parameters of the foot.

After analyzing the data from foreign studies, we found that the postural function of the diaphragm is to stabilize the human spine when performing tasks that require repetitive movement. The abdominal and thoracic cavities, acting on the diaphragm, are involved in the stability of the torso. Muscles not only contract in isolation but also participate in the joint movements of spirals through aponeuroses, fascia, and intermuscular septa. Transmitting energy, skeletal muscle chains provide rotational movements of the human body. The diaphragm, connecting with the cervical spine indirectly through the fascia and interfascial spaces of the body, is a complex biomechanical formation of the muscle spirals of the human body. Since the movement of the diaphragm occurs not only during respiration, but also during childbirth, and changes in the postural balance of pregnant women were previously revealed, we can consider the uterus as part of the muscle spirals.

The study found that 90 % of the surveyed women experience discomfort when moving from a standing position to a sitting position, as well as when walking on an uneven surface. The study of the psychological and emotional state of women, conducted using the Spielberger-Khanin test and the FAM (Feeling. Activity. Mood) questionnaire did not find strong correlations between the postural control disorders and the level of reactive (situational) anxiety (R=0.2588, p=0.696). A low level of reactive (situational) anxiety in the group of subjects was found in 76 % of respondents, and a moderate level – in 24 % of subjects. At the same time, 30 % of the surveyed patients performed physical exercises for pregnant women. The effect that these physiological changes cause on the postural stability of the pregnant woman's body has not been quantitatively studied for a long time.

Studies on the quantitative indices of the impact of pregnancy on the postural control of a pregnant woman’s body are associated with the use of postural stability tests, which, in turn, can help to identify pregnant women at high risk of falls. Therefore, we consider it necessary to use the incremental tests for further correction of postural control of pregnant women using physical rehabilitation. Such rehabilitation should be done according to individual programs aimed at kinematic muscle chains.

If in the process of building dynamic models the average location of the center of gravity is necessary for a group of people or even for the same person for a certain period, a simple system of equilibrium and scaling is sufficient. One percent error in a simple equilibrium system will be of the same magnitude order as the error caused by the respiratory cycle.

This assumption is confirmed in a study by Ewan CG et al. [10], which allowed the researchers to measure the dynamic changes in the diaphragm length based on the evaluation of the mechanics of the diaphragm contraction using ultrasonography. The study proved the involvement of the diaphragm in postural control with the sudden forced movement of the upper limb. The relationship between the diaphragm thickness and imbalance has also been proven [1].

Since the function of muscles, their power potential and functionality depend on the activity of the endocrine system, we can assume that the function of the diaphragm in maintaining the incremental balance may be subject to the mechanisms of circadian rhythms [8].

Since the diaphragm moves during respiration and childbirth, we can consider the uterus as part of the muscle spirals. Particular attention should be paid to the studies on changes in the postural control of the body in women during pregnancy. The scholars revealed changes in the dynamic stability of women, in particular, slowing down of walking pace, reduction of stride width, and weakness in the transition from sitting to standing position, in particular with closed eyes or on an unstable surface [8, 9]. Changes in the postural control of women were observed from the beginning of the second trimester to 6-8 weeks after delivery [7, 13]. There were also correlations between postural control disorders in pregnant women and the level of anxiety; there was a decrease in the frequency of falls in pregnant women who performed a set of exercises as compared to women who led a sedentary lifestyle during pregnancy [6].

Adaptation of muscles, bones and joints in a woman's body during pregnancy causes discomfort or pain, changes the postural balance of the body and increases the risk of falls. Studies show that the incidence of hospitalization due to falls in pregnant women is 2.3 times higher than in non-pregnant women of an appropriate reproductive age. Out of 3.997 women who participated in the study, 26.7 % reported at least one fall during pregnancy, and 35 % of these women reported two or more falls. The highest frequency of falls occurred at 6-7 months of pregnancy, and 66.3 % of them occurred due to rapid movement, walking on slippery surfaces, or walking with an armload [14].

An epidemiological study by Dunning et al. [9] confirms the data on a high risk of injury due to falls in pregnant women with a frequency of 27 % among all subjects, which approaches the value of the risk of falls in women above the age of 70 years (28 %). Moreover, from 17 to 39 % of pregnant women were delivered to the hospital with injuries, caused by accidental falls [12].

Conclusions

1. In this regard, it is possible to assume that the uterus is a muscular-elastic-collagen system of levers involved in stabilizing a woman's posture during pregnancy, being in an uncharacteristic state due to changes in the connective tissue elements of both the uterus and extrauterine structures. With the enlargement of the uterus during pregnancy, the restoration of the typical posture changes due to modifications in its musculo-elastic apparatus and in its elastic-collagen connections with the pelvic bones. It is important that the dense area of the ligaments is a collagen structure and is the least elastic component of this chain.

2. The uterus is attached to the pelvis from the inside. In contrast, the areas of the external spiroid dynamic muscle chains are attached from the outside, thus entwining the body both homolaterally and heterolaterally. Based on the above, we hypothesize that these are synergistic and mutually competing biomechanical structures. Disturbance in the balance of these structures can lead to a suboptimal condition of the pregnant woman's body in statics and dynamics.

Prospects for further research are to develop a biomechanical model for the postural balance of the human body according to the input parameters; to study of changes in the postural balance of women with a history of uterine surgery, including extirpation;development, to provide the research of efficiency and practical implementation of programs of physiotherapeutic influence on muscular spirals for the purpose of stabilization of postural balance in women of the above-stated categories.

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