Original paper

Analysis of the impact of lumbar lordosis on selected balance parameters in women

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Abstract

Introduction: Scientific research in the literature confirms a direct influence and relationship between increased parameters of lumbar lordosis of the spine, and changes and deviations from the norm within equivalent reactions.
Aim of the research: The aim of the study was to analyse selected parameters in a group of women based on their depth of lumbar lordosis.
Material and methods: The research was carried out from January until October 2023. The study group totalling 75 women consisted of female students of the Collegium Medicum, aged 18–26 years. The tests were carried out in a static form using the DIERS Posture Lab system. The following parameters were fed into the calculation sources: "lordosis angle", "pelvic inclination", "CoP lateral movement", "COP area", "CoP total anterior/posterior movement". In addition, the following Harzmann parameters were considered: "lateral deviation", "surface rotation", "pelvic obliquity", "pelvic torsion", "vertical deviation" and foot load parameters: "rear force distribution", "front force distribution", "left side force distribution", "right side force distribution", "maximum pressure on the left side", "maximum pressure of the right side", "contact area of left feet", "contact area of right feet".
Results and conclusions: There was no statistical significance of correlation between lordosis and equivalent reactions and pelvic tilt in the group of young adult women. The impact of lumbar lordosis on young adult women does not directly affect the tested parameters. The parameter of the lordosis angle and pelvic inclination were higher than usual; therefore, the distribution of forces in the foot was also characterised by a different load distribution.

Introduction

Scientific research in the literature confirms a direct influence and relationship between increased parameters of lumbar lordosis of the spine, and changes and deviations from the norm within equivalent reactions in different age ranges compared to the group whose degree of lordosis is reduced. The authors refer to the relationship between pelvic nutation and lumbar deepening, which influences the equivalent reactions [1–7]. When there is an anterior pelvic tilt, changes in the muscles also occur, i.e. their shortening and tension, known as muscle imbalance. When analysing the area of the lumbar spine, the erector spinae, the quadratus lumborum, and the lower part of the latissimus dorsi muscle have a greater tone - together cums to shorten the iliopsoas muscle and the rectus femoris muscle. It is assumed that the last two mentioned muscles are responsible for nutation of the pelvis. The antagonist muscle group is then "inhibited" by signals from the central nervous system. There is a weakening and lengthening of, among others, abdominal muscles – rectus abdominis, gluteal muscles, i.e. gluteus maximus and minimus, and the entire group of hamstring muscles – biceps femoris, semitendinosus, semimembranosus [8]. Local muscles that position, control and stabilise the area of lumbar lordosis include multifidus, transverse abdominis, internal obliques, pelvic floor muscles, and autochthonous muscles that rotate the spine and are not dependent on human activity, as well as those influencing the physiological extension of the spine: semispinalis, spinalis, rotatores [9]. Of course, when discussing the topic of balance, it can be considered in terms of the balance of the spine area, i.e. the balance between external forces affecting the spine and the response of the central stabilization muscles guided by sensory-neural regulation in order to maintain a stable vertical position, both static and dynamic, and looking more broadly, as the balance of the entire organism. Pizones *et al.* [10] describe balance as "a dynamic concept that shows how the body can adjust its centre of mass while moving and standing". Agonistic and antagonistic forces are designed to maintain our body. If for some reason we fall out of the balance cone zone, the muscles will begin to work vigorously and counteract. In addition to proper muscle work in terms of tension time, motor control, and strength, it is important to note that there is no balance without a properly functioning nervous system. It describes balance also of the coordination of sensorimotor stimuli to stabilise the centre of gravi ty of the body centre of pressure (CoP) [6]. The authors of numerous scientific publications assume a direct impact of the pelvic nutation on the lumbar section, where the lordosis angle deepens and increases [1]. This is related to the relationship of the biokinematic chain, where disruption of one part of a given region may affect other links and the phenomenon of tensegrity [8]. This second relationship explains how the tensegrity theory works in living matter and is present at every level of organisation of the organism – it can be found both in a single cell and in the entire spinal column. According to the assumptions of biotensegrity, the body constitutes a whole, where individual elements are interdependent and influence each other [11]. Mazzocchi [12] described CoP as the coordinate of the resultant force that is applied by the feet on a given surface. It is the point of the vertical ground reaction force vector. It is the average of all forces acting on the surface connecting to the ground.

Aim of the research

The aim of the study was to analyse, in a group of women, selected balance parameters based on their relationship with the depth of lumbar lordosis.

Material and methods

The study was conducted from January to October 2023 at the Jan Kochanowski University in Kielce.

The study group consisted of female students at the Medical College aged 18–26 years. A total of 75 women were examined, with mean age 21.57 ±2.54 years. The study was conducted in a standing position using the DIERS Posture Lab system – a computer system for non-invasive, radiation-free spine and body posture analysis with the additional use of a treadmill recording movement in the sagittal plane and the transverse plane (recording equivalent reactions) [13, 14]. The study time was 6 s. Each person was appropriately prepared for the study – the back was completely exposed, from the cervical spine to the middle of the buttock. The subjects were left without shoes for the purpose of performing the tests using a pedoscan. Each subject assumed a habitual posture.

Results

Descriptive statistics

Table 1 presents the results of descriptive statistics for the variables included in the statistical analysis. The mean for the lordosis angle parameter in the women's group was 44.573°. The standard value for the lumbar lordosis angle is 32–37°, which shows that this parameter in the study group was higher than the norm. The standard deviation was 8.323°. The pelvic inclination variable had a mean value of 25.718°, the norm for the female gender is 20° [13].

For the parameter "deflection of the trunk from the vertical VP-DM" in the group of women, the average was 0.015 mm with a standard deviation of 12.831 mm. For the parameter "pelvic obliquity DL-DR", the average was 0.076 mm with a standard deviation result of 5.639 mm. The variable "pelvic twist" had an average of 0.023° with a standard deviation of 3.021°. For the parameter "pelvic inclination", the mean and standard deviation had a result of 25.718 mm with a standard deviation of 8.436 mm. Force distributions for percentage load on both the right and left feet had similar mean scores. For the right foot 49.558% and for the left foot 50.441%, with the same standard deviation with a value of 7.704%. Force distributions for the forefoot and heel also showed values close to the norm (40% to 60%) – the average for the forefoot was 43.218% and for the heels 56.781%. For the remaining balance variables, i.e. "lateral movement (max.)", the mean score was 7.884 mm with a standard deviation of 13.61 mm. "Total lateral movement" was 64.425 mm with a standard deviation of 136.845 mm. The variable "total front/back movement" had a mean of 75.676 mm with a standard deviation of 219.06 mm. For "COP area", the result for the variable was 1075.359 mm^2 with a standard deviation of 6326.405 mm^2. The parameters of the lordosis angle and pelvic inclination were higher than usual; therefore, the distribution of forces in the foot was also characterised by a different load distribution.

Not all parameters had a normal distribution; hence, non-parametric tests were used for further analysis.

Correlations

Table 2 shows the correlations between the angle of lumbar lordosis and spine and pelvis variables. None of the variables tested showed strong correlation. Despite the increased angle of lumbar lordosis, the variable had no significant correlation with the pelvic tilt variable.

Tables 3 A and 3 B present correlations between spine variables and the variables of equivalent reactions. The following variables were characterised by strong correlations: "torso deviation from vertical VP-DM" and "total front/back movement CoP" with a correlation strength of 0.345 and "CoP surface" with a strength of 0.311; the variable "surface rotation (rms)" had strong correlations with the variables "lateral movement (max.) CoP" with a value of 0.2604, "total lateral movement CoP" with a value of 0.2807, and "area CoP" with a value of 0.279. The last variable was the rotation of the surface to the left with the "CoP surface" with a force of –0.236. The above examined correlations suggest that changes in the spine

Table 1. Descriptive statistics of variables

Variable	Descriptive statistics		
	Mean	**Std. dev**	**Median**
ITL-DM lordosis angle [°C]	44.573	8.323	44.15
Torso deviation from vertical VP-DM [mm]	0.015	12.831	–0.35
Pelvic obliquity DL-DR [mm]	–0.076	5.639	0.2
Pelvic twist DL-DR [°]	0.023	3.021	0.8
Pelvic inclination (dimples) [°]	25.718	8.436	25.6
Surface rotation [ms] [°]	3.628	2.921	2.885
Surface rotation [+max] [°]	3.501	4.669	4.3
Surface rotation [–max] [°]	–6.019	5.674	2.328
VP-DM lateral deviation [rms] [mm]	6.306	8.496	–4.395
Lateral deflection VP-DM [+max] [mm]	9.786	13.498	6.5
Lateral deflection VP-DM [–max] [mm]	–4.386	11.269	–2.1
Force distribution left side [%]	50.441	7.704	50.655
Force distribution right side [%]	49.558	7.704	49.344
Front force distribution [%]	43.218	8.872	43.366
Rear force distribution [%]	56.781	8.872	56.633
Maximum left side [N]	7.521	3.144	7.333
Maximum right side [N]	7.323	3.050	7.512
Area left [cm^2]	89.760	31.932	96.933
Area right [cm^2]	90.316	31.948	96.218
Lateral movement (max.) [mm]	7.884	13.610	4.234
Total lateral movement [mm]	64.425	136.845	32.72
Total front/back movement [mm]	75.676	219.060	36.163
COP area [mm^2]	1075.359	6326.405	100.734

in the form of deviations of the trunk from the vertical projection of the centre of gravity and rotation of the vertebrae may influence the balance variables, increasing the range of deflection CoP values, both in frontal and sagittal plane motion.

Tables 4 A and 4 B present the correlations between spine variables and foot load force variables. None of the correlated variables showed a sufficiently strong correlation.

Tables 5 A and 5 B present the correlations between spine variables and foot loading force variables in percentage terms. As in the case of Tables 4 A and 4 B, also none of the variables subjected to correlation demonstrated strong enough interdependence.

Statistical analysis

The statistical analysis was performed using the Statistica program Stat Soft 21. Parameters that were used for analysis included the following: lordo-

Table 2. Correlations between the angle of lumbar lordosis and variables of the spine and pelvis

Variables	Angle of lordosis [ITL-DM°]
Pelvic inclination (dimples) [°]	0.092
VP-DM lateral deviation [rms] [mm]	0.052
Lateral deflection VP-DM [+max] [mm]	–0.043
Lateral deflection VP-DM [–max] [mm]	0.124
Pelvic obliquity DL-DR [mm]	–0.194
Pelvic twist DL-DR [°]	–0.129
Torso deviation from vertical VP-DM [mm]	0.088
Surface rotation [rms] [°]	0.024
Surface rotation [+max] [°]	–0.191
Surface rotation [–max] [°]	0.033

Table 3. A – Correlations between spine and balance reaction variables. **B** – Correlations between spine and balance reaction variables

A

Variables	Lateral movement (max.) CoP	Total lateral movement of the CoP
Pelvic inclination (dimples) [°]	0.013000	0.097000
VP-DM lateral deviation [rms] [mm]	–0.021000	0.003000
Lateral deflection VP-DM [+max] [mm]	0.050000	0.167000
Lateral deflection VP-DM [–max] [mm]	–0.115000	–0.087000
Pelvic obliquity DL-DR [mm]	0.075000	0.077000
Pelvic twist DL-DR [°]	–0.114000	–0.150000
Torso deviation from vertical VP-DM [mm]	0.209000	0.228000
Surface rotation [rms] [°]	0.260400	0.280700
Surface rotation [+max] [°]	–0.087000	–0.013000
Surface rotation [–max] [°]	–0.201000	–0.103000
Angle of lordosis [ITL-DM°]	0.205000	0.112000

B

Variables	Total fore/aft movement CoP	Area CoP
Pelvic inclination (dimples) [°]	0.041000	–0.068000
VP-DM lateral deviation [rms] [mm]	0.007000	0.001000
Lateral deflection VP-DM [+max] [mm]	0.124000	0.091000
Lateral deflection VP-DM [–max] [mm]	0.096000	–0.049000
Pelvic obliquity DL-DR [mm]	0.023000	0.034000
Pelvic twist DL-DR [°]	–0.204000	–0.200900
Torso deviation from vertical VP-DM [mm]	0.345000	0.311000
Surface rotation [rms] [°]	0.288000	0.279000
Surface rotation [+max] [°]	–0.058000	–0.0123000
Surface rotation [–max] [°]	–0.223000	–0.236000
Angle of lordosis [ITL-DM°]	0.203000	0.105000

sis angle, pelvic inclination, CoP lateral movement (max.), CoP total lateral movement, COP area, and total front/back movement of the CoP. The analysis also considered the following Harzmann parameters: lateral deviation VP-DM (rms), surface rotation (rms), pelvic obliquity DL-DR, pelvic torsion DL-DR, torso deviation from the vertical VP-DM, and parameters determining the load on the feet: rear force distribution [%], force distribution front [%], force distribution left side [%], force distribution right side [%], maximum left side, maximum right side, area left, and area right. Tests for normality distribution were also performed (Shapiro-Wilk, a test used to assess the normality distribution of collected studies and the c^2 goodness-of-fit test, used to test the relationship between two variables expressed on a nominal scale), and correlations were tested using the Spearman test (analysis thanks to which variables can be correlated with each other on an ordinal scale and quantitative ones that do not have a normal distribution).

Discussion

In the conducted research, the lordosis angle in the group of women was above 37°, the average was 44.573° – the selected study group had increased lumbar lordosis. Deviations from the norm in the spine, such as curvatures or rotations, affect the dynamics and statics of the entire body. There is a statistically significant correlation between disorders in the curvature of the spine and the efficiency of equivalent reactions. As a result of impaired muscle function, especially those stabilising the spine – deep back muscles mm. multifidus, rotator and inter-transverse (tonic sounds that become shortened) [9] – a disorder occurs in the mechanism of regaining balance. The above-mentioned muscle groups play an impor-

Table 4. A – Correlations between spine variables and foot load forces. **B** – Correlations between spine variables and foot load forces

A

Variables	Maximum left side [N]	Maximum right side [N]
Pelvic inclination (dimples) [°]	–0.225000	–0.133000
VP-DM lateral deviation [rms] [mm]	–0.095000	–0.151000
Lateral deflection VP-DM [+max] [mm]	–0.111000	–0.039000
Lateral deflection VP-DM [–max] [mm]	0.076000	0.151000
Pelvic obliquity DL-DR [mm]	–0.038000	0.005000
Pelvic twist DL-DR [°]	–0.126000	–0.174000
Torso deviation from vertical VP-DM [mm]	0.063000	0.078000
Surface rotation [rms] [°]	–0.102000	–0.096000
Surface rotation [+max] [°]	–0.047000	–0.091000
Surface rotation [–max] [°]	0.083000	0.083000
Angle of lordosis [ITL-DM°]	–0.070000	–0.034000

B

Variables	Area left [cm^2]	Area right [cm^2]
Pelvic inclination (dimples) [°]	–0.015000	–0.033000
VP-DM lateral deviation [rms] [mm]	–0.129000	–0.137000
Lateral deflection VP-DM [+max] [mm]	–0.102000	–0.033000
Lateral deflection VP-DM [–max] [mm]	0.075000	0.155000
Pelvic obliquity DL-DR [mm]	–0.113000	–0.108000
Pelvic twist DL-DR [°]	0.022000	–0.131000
Torso deviation from vertical VP-DM [mm]	–0.038000	0.102000
Surface rotation [rms] [°]	–0.049000	–0.009000
Surface rotation [+max] [°]	–0.124000	–0.187000
Surface rotation [–max] [°]	0.160000	0.146000
Angle of lordosis [ITL-DM°]	–0.019000	–0.016000

tant role in the process of regaining balance, and at the same time they are sensitive to the stretch reflex [5]. There are disorders that directly affect the shape of the spine. These may be one-dimensional disorders in which the spine curvatures deepen or flatten in the sagittal plane due to the mechanism of changes in muscle tension or through changes in the attachment sites of given muscles. Izzo [15] also distinguished three-element disorders. The above elements include: the nervous system – receiving information, controlling, and transmitting stimuli; the spine – a passive system, and the muscles as an active system responsible for movement and joint stability. Disturbance of one of the elements affects to changes in the functioning of the others. When failure occurs, the work of the remaining elements increases, and it leads to compensation. According to the authors, the pelvis is the basis determining the shape and depth of lumbar lordosis, which also translates into the shape of the entire spine. The pelvic inclination corresponds to the angle between the perpendicular to the upper level of the S1 vertebra, passing through its centre and the axis of the heads of the femurs [1]. According to Izzoa [15], in healthy people and in cases of pathophysiology, the curvature of the spine in the sagittal plane is related to the so-called geometry of the pelvic position – the angle of the sacrum in relation to the pelvis, the inclination of the sacrum, and pelvic tilt. The results of our own research do not cover this, in line with the results presented by Izooa, in their own research despite changes in the sagittal plane, i.e. deepening of lumbar lordosis, there were no changes in the pelvic inclination. Lum [16] in their study proved the connection between lumbar lordosis and pelvic inclination – as in the case of Izzoa's research, in our own research, no statistically significant correlation was found between these variables. Le Huec [17] demonstrated a strong correlation between

Table 5. A – Correlations between spine variables and foot load forces in percentages. **B** – Correlations between spine variables and foot load forces in percentages

A

Variables	Front force distribution [%]	Rear force distribution [%]
Pelvic inclination (dimples) [°]	0.02900	–0.02900
VP-DM lateral deviation [rms] [mm]	–0.00600	0.00600
Lateral deflection VP-DM [+max] [mm]	0.04900	–0.04900
Lateral deflection VP-DM [–max] [mm]	0.04000	–0.04000
Pelvic obliquity DL-DR [mm]	–0.06500	0.06500
Pelvic twist DL-DR [°]	0.16200	–0.16200
Torso deviation from vertical VP-DM [mm]	–0.03100	0.03100
Surface rotation [rms] [°]	–0.06800	–0.06800
Surface rotation [+max] [°]	0.04300	–0.04300
Surface rotation [–max] [°]	0.13400	–0.13400
Angle of lordosis [ITL-DM°]	0.02300	–0.02300

B

Variables	Front distribution right side [%]	Front distribution left side [%]
Pelvic inclination (dimples) [°]	–0.06200	0.06200
VP-DM lateral deviation [rms] [mm]	–0.01200	0.01200
Lateral deflection VP-DM [+max] [mm]	0.02400	–0.02400
Lateral deflection VP-DM [–max] [mm]	0.06100	–0.061000
Pelvic obliquity DL-DR [mm]	–0.04720	0.047200
Pelvic twist DL-DR [°]	–0.15100	0.15100
Torso deviation from vertical VP-DM [mm]	0.19900	–0.19900
Surface rotation [rms] [°]	0.08200	–0.08200
Surface rotation [+max] [°]	–0.10700	010700
Surface rotation [–max] [°]	–0.04100	0.04100
Angle of lordosis [ITL-DM°]	–0.01200	0.01200

the sacrum inclination and lumbar lordosis ($r = 0.86$, $p < 0.001$). The relationship between the sacrum inclination and the pelvic inclination explains the relationship between the pelvic inclination and lumbar lordosis, where the whole creates a biomechanical whole and a correlation between the selected parameters. Pizones [10] and other authors [18–21] also confirm this correlation in their work. The research results listed above and the authors' works cannot be confirmed in this work. The results of our own research and those published by other authors turn out to be significantly different. Statistical analysis calculations do not reveal any correlation between the parameters of the lordosis angle and pelvic inclination in the group of women whose depth of lumbar lordosis was greater, the correlation between the variables was 0.09 (Table 2); therefore, the authors hypothesis cannot be confirmed. In the authors' research [2–4], the results show the existence of a correlation between the parameters of the lordosis angle and the distribution of ground reaction forces on the feet, as well as changes in the equivalent reactions. As part of our own research, the correlation between spinal variable settings and foot load was analysed. The results of our own research did not reveal any statistically significant correlations between the spinal alignment variables and the distribution of ground reaction forces. The authors found statistically significant results in terms of changes in equivalent reactions, which coincides with their own results presented in the work. The research of Drzał-Grabiec [12] shows that body posture, i.e. the shape of the spine curvatures in the sagittal position and rotations, affects the balance system and the responses occurring in it to stimuli. The above research results only partially cover this with your own results presented in the work. The shape of the spine in the sagittal position did not have significant correlations with balance reactions, but Harzmann parameters, among others, rotation within the spine, had strong correlations – the "surface rotation" variable had strong correlation results with maximum lateral movement, with a score of 0.26; total lateral movement, result 0.28, and with the CoP surface, result 0.27. The variable "torso deviation from the vertical" from "total "forward/backward movement" had a correlation value of 0.34 and a CoP area of 0.31 (Table 3). Some researchers [22, 23] define the CoP movement as the result of the base of support, assuming that the posture is the dynamic stability of the body constantly in rocking movements.

According to Yamanda [23], CoP is a fluctuation of a chaotic process. According to the authors, the depth of lumbar lordosis curvature significantly correlates with the CoP field value and the average CoP velocity. According to Azevedo [6], an increase in the lumbar lordosis parameter was associated with an increase in the total lateral displacement, leading to a decrease in balance. The results of our own research cannot confirm the results presented by Azevedo and Yamanda. As part of our own research, the correlations between the depth of lumbar lordosis of the spine and equivalent reaction variables were analysed. The analysis of the resulting correlations (Tables 3 A and 3 B) shows that the previously mentioned variables do not have statistically significant correlations with each other, which contradicts the hypotheses adopted by the authors. Despite increased lumbar lordosis compared to accepted standards, no correlation with parameters was found in each study group around equivalent reactions.

The study did not consider the division into foot types. This is an important factor that should be included in future studies.

Conclusions

In the conducted research, increased lumbar lordosis did not directly affect the results of equivalent reactions and variable foot loads. There was no significant statistical correlation between the lordosis angle and pelvic inclination in the study group. The parameters of lordosis angle and pelvic inclination were higher than usual; therefore, the distribution of forces in the foot was also characterised by a different load distribution.

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Ethical approval

The study protocol was approved by the Bioethics Review Committee, appointed in accordance with applicable statutory restrictions at the Faculty of Medicine and Health Sciences, Jan Kochanowski University in Kielce, Poland, approved on 30 June 2023 (Ethical Approval Decision Number 34/2023).

Conflict of interest

The authors declare no conflict of interest.

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