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The use of characteristics and indicators of body construction as predictors in the identification of the angle values of the physiological curves of the spine in sequential objective testing - mathematical models

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Abstract

Introduction: The physiological curvatures of the spine in the sagittal plane are constantly evolving along with changes in the structure and proportions of the body and physical activity. The aim of this study is to identify and assess the strength of the influence of body features and indices on the values of lumbar lordosis and thoracic kyphosis angles with the use of a mathematical model. In the years 2006–2016, 1,314 female students aged (± SD 19.7 ± 0.4) (min.–max. 18.1–22.5) were examined.

Materials and Methods. The following measurements were made: body mass (BM), body height (BH), waist circumference (WC), hips circumference (HC), body fat (%Fat), total body water (%TBW), the value of thoracic kyphosis angles (THKA) and lumbar lordosis angles (LLA). The body mass index (BMI), the body adiposity index (BAI), the waist–hip ratio (WHR) and the waist circumference (WC) were analyzed.

Results: WC is the predictor for changes in the value of the angle of thoracic kyphosis, and the BAI is a predictor for changes in the value of angle of lumbar lordosis.

Conclusion: The presented mathematical models are a method of non-invasive control of the values of the angles of thoracic kyphosis and lumbar lordosis and support the monitoring of the process of compensation, correction and therapy.

Keywords

anthropometry, physiological curvatures of the spine, lumbar lordosis and thoracic kyphosis, modeling and estimation, regression equation

Cover Page Footnote

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Article

The use of characteristics and indicators of body composition as predictors in the identification of the angle values of the physiological curvatures of the spine in sequential objective testing – mathematical models

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Abstract: Introduction: The physiological curvatures of the spine in the sagittal plane are constantly evolving along with changes in the structure and proportions of the body and physical activity. The aim of this study is to identify and assess the strength of the influence of body features and indices on the values of lumbar lordosis and thoracic kyphosis angles with the use of a mathematical model. In the years 2006–2016, 1,314 female students aged ($\overline{x}$ ± SD 19.7 ± 0.4) (min.–max. 18.1–22.5) were examined. Materials and Methods. The following measurements were made: body mass (BM), body height (BH), waist circumference (WC), hips circumference (HC), body fat (%Fat), total body water (%TBW), the value of thoracic kyphosis angles (THKA) and lumbar lordosis angles (LLA). The body mass index (BMI), the body adiposity index (BAI), the waist–hip ratio (WHR) and the waist circumference (WC) were analyzed. Results: WC is the predictor for changes in the value of the angle of thoracic kyphosis, and the BAI is a predictor for changes in the value of angle of lumbar lordosis. Conclusion: The presented mathematical models are a method of non-invasive control of the values of the angles of thoracic kyphosis and lumbar lordosis and support the monitoring of the process of compensation, correction and therapy.

Keywords: anthropometry, physiological curvatures of the spine, lumbar lordosis and thoracic kyphosis, modeling and estimation, regression equation.

1. Introduction

One of the goals of scientific exploration in the field of health sciences is to identify risk factors that directly or indirectly affect the occurrence of diseases and pathologies. The available literature includes studies that identify, group, and classify various factors, and then analyze them in order to create mathematical risk models [1–5]. It is common to use features and indicators characterizing the composition and structure of the body, such as the body mass index (BMI), the waist-to-hip ratio (WHR), the waist circumference (WC), the body adiposity index (BAI) in the assessment of overweight and obesity as well as fat distribution, which, as has been shown many times, it is associated with the risk of cardiovascular diseases [6–7].

Thus, identification of obesity with a use of anthropometry as a non-invasive method and on this basis estimating the risk of cardiometabolic diseases is currently one of the directions of scientific exploration, which is reflected not only in the data of the World Health Organization (WHO) [8–12]. Nevertheless, musculoskeletal ailments which are often a consequence of pathobiomechnical disorders and the emerging imbalance of spine curvatures are an equally significant problem today [13]. One of the risk factors for the occurrence of Low Back Pain [LBP] is overweight and obesity, which in turn is often associated with a sedentary lifestyle [13–17]. It has been shown that obesity is a factor that significantly influences the shape of the spine curvature in the sagittal plane, expressed as an angular value, especially in lumbar lordosis, which is characterized by high phyllo and ontogenetic variability [18–21].

The body structure and composition are immanent parts of the body posture which are based on the geometry of the spinal curvatures. Thus, features and indicators identifying body structure and composition appear to be important in estimating body posture sagittal balance. In functional and clinical terms, sagittal balance is the key parameter of the spine geometry, the basis of which is lumbar lordosis [22–25]. Some researchers argue that sagittal balance disorders have a destructive effect on the value of the kyphosis and lordosis angle, implying the acceleration of pathoanatomical changes [26–31], and others indicate that it is the lumbar segment that is most often the target of surgical and physiotherapeutic interventions [24, 25]. Therefore, special attention is required in searching for and identifying the determinants of this pathology in order to support preventive and prophylactic activities more effectively.

At the same time, it should be noted that the physiological curvatures of the spine in the sagittal plane that define the human body posture, i.e. the way of holding on, are labile and constantly evolving with age and changes in the body structure and proportions as well as physical activity in the postnatal period [32].

The aim of the study was to identify the prediction of body features and indices in relation to the size of the angles of lumbar lordosis [°] and thoracic kyphosis [°]. It was assumed that the secular trend observed in ten-year prospective studies for features and indicators of body composition and body structure affects the size of the angles of lumbar lordosis and thoracic kyphosis in young women. At the same time, the operational goal was to build a mathematical model determining the strength of the influence of the variability of structure and composition features on the curvature of the spine of young women.

2. Materials and Methods

2.1. Participants/Inclusion and Exclusion Criteria

The examinations were carried out between 2006 and 2016 involving female first-year students (N = 1314, mean age 19,7 ± 0.4) at Faculty of Management of the University of Economics in Katowice (see Table 1).

Table 1. Structure of the study group of women in the period between 2006 and 2016.

Date of examination	Number and age			Characteristics of body composition		
	N	Age M ± SD	Min–Max	BH ± SD	BM M ± SD	BMI M ± SD
2006	139	19.3 ± 0.5	17.8–20.7	166.8 ± 6.4	58.1 ± 7.6	20.9 ± 2.3
2007	230	19.7 ± 0.77	17.4–22	167 ± 6.2	58.2 ± 8.1	20.9 ± 2.7
2008	131	19.5 ± 0.67	17.8–23.2	166.6 ± 5.9	58.5 ± 8.3	21 ± 2.9
2009	99	19.9 ± 0.9	18.2–24.5	167.3 ± 6.3	59.6 ± 10.8	21.3 ± 3.7
2010	167	19.6 ± 0.6	18.3–23.1	166.9 ± 6.1	58.6 ± 9.9	21 ± 3.2
2011	163	19.1 ± 0.6	18–22	168.8 ± 5.8	56.1 ± 6.9	19.7 ± 2.1
2012	137	19.1 ± 0.7	18–23	163.2 ± 5.4	62 ± 9.5	23.2 ± 2.8

Date of examination	Number and age			Characteristics of body composition		
	N	Age M ± SD	Min–Max	BH ± SD	BM M ± SD	BMI M ± SD
2013	62	19.6 ± 0.7	18.2–22.1	164.7 ± 4.2	59 ± 8.6	21.8 ± 3
2014	59	20.1 ± 0.6	18.8–20.9	165 ± 4.6	64.5 ± 8.8	23.7 ± 2.6
2015	75	20.3 ± 1.0	17.7–24.8	167.6 ± 6.6	62.8 ± 12	22.3 ± 3.8
2016	52	20.3 ± 0.6	18.7–21.5	166.5 ± 5.7	62.7 ± 13.0	22.6 ± 4.6
Total	**1314**	**19.7 ± 0.4**	**18.1–22.5**	**166.8 ± 6.1**	**58.7 ± 8.8**	**23.6 ± 6.7**

N – number of the participants, BH – body height, BM – body mass, BMI – body mass index, M – arithmetic mean, SD – standard deviation

The surveyed students, representing an average young Caucasian population, were people who were involved in various forms of physical activity, but none of them was actively involved in sport. Furthermore, during the research, they did not report any pain or other diseases that would prevent conducting the research and disturb the homogeneity of the studied group. The exclusion criteria concerned persons who had any locomotor system dysfunction or another disease preventing them from active participation in physical education classes at university.

The examinations were carried out in the morning in separate rooms on the university premises, and they were always carried out by the same two examiners. The students who participated in the examinations gave their written consent. The study participants could withdraw from the test procedure at any time without giving reasons. The subjects were wearing sportswear, without shoes and socks. Beforehand, they were instructed about the purpose of the study and fasted for 2 hours before the measurements.

The research was carried out for the following 10 years at the same university (every year in October), and the same research procedures were used for first-year students. The first two years of the research were a pilot study, and the collected data are included in the analyses of the research project "Diagnostics of students' body composition, body posture and physical fitness", which was approved by resolution of the local bioethics commission No. 5/2008 of 29 April 2008. The research was conducted in accordance with the standards contained in the 2008 Declaration of Helsinki.

2.2. Measurement Procedures

The examinations were conducted in the morning. This was a cohort-sequential design cross-sectional analytical study, and the participants were measured only once. Two examiners performed the measurements in order to minimize inter-observer differences (see Fig. 1). Two types of measurements were carried out.

2.2.1. Spine curvature measurement

Anteroposterior spinal curvatures were evaluated by means of the Rippstein plurimeter. The plurimeter allows for quick, accurate and inexpensive examinations of children and adolescents' posture in the sagittal and transverse planes in order to complement physical examinations (e.g. in orthopedics and pediatrics) and rehabilitation. The apparatus enables quick and easy measurements and ensures reproducibility of the results, even when the examinations are carried out by different examiners. Two values of angular deflection are obtained (read directly from the device): the angle of thoracic kyphosis, measured between the kyphosis peak Th12 and Th1, and the angle of lumbar lordosis, measured between L5 and Th12. A V-plurimeter was employed to measure thoracic kyphosis and lumbar lordosis, with the patient standing without any postural correction [13, 18–19]. The value of 30 ± 5 was considered normal kyphosis and lordosis [33, 34].

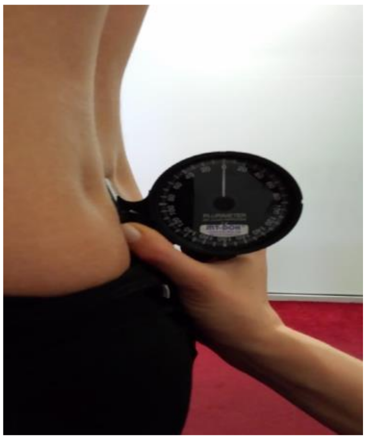

Fig. 1. Spine curvature measurement.
Source: Own photograph.

2.2.2. Anthropometric measurements

The body height (BH [cm]) and the waist and hip circumference (WC and HC [cm]) were measured. The body mass (BM [kilograms]) was determined using a Tanita BC 420SMA stand-on bioimpedance analyzer (Tanita Corporation, Japan). The study was performed according to a standard protocol recommended by the manufacturer. The participant started examinations after fasting, in light clothing, shoeless and without socks, with clean feet. The device samples periods of 5-second resistance values (Rx) and the reactance of their volume (Xc). These data are used as a basis for calculating body composition by a computer software relative to age, sex and body height [29]. BH measurements were performed using a wall-mounted stadiometer with standard scales and the accuracy of 0.5 cm. BH was measured to the nearest mm. An anthropometric tape was used over light clothing to measure WC and HC [35]. WC was measured between the iliac crest and the rib cage (minimum circumference) whereas hip girth was measured over the greater trochanters (maximum width).

2.3. Statistical analysis

The collected material was subjected to statistical analysis. Arithmetic means and standard deviations were calculated. The Shapiro-Wilk test was used to test the data for normal distribution, whereas the homogeneity of variance was evaluated by means of Levene's test. The ANOVA analysis of variance with repeated measures was employed to determine intergroup differences.

To determine the predictors of kyphosis and lordosis, a regression analysis was performed considering BH [cm], BM [kg], WC [cm], HC [cm], TBW [%], FAT [%] and BMI [kg/m^2] indices, BAI [%], WHR, determining the regression equation model. A significance level of $p < 0.05$ was adopted in all statistical analyses.

3. Results

The multivariate Anova analysis during the 10-year follow-up confirmed statistically significant differentiation for all variables in the following years, except for BMI (Table 2).

Table 2. Differentiation of features and indicators of body composition and posture of young women in 2006–2016.

	N = 1314			
	$\bar{x}$ ± SD	Min–max	F	*p*
BH [cm]	168 ± 6.1	151.0–189.5	7.578	**0.001**
BM [kg]	58.7 ± 8.8	39.4–108.5	5.650	**0.001**
WC [cm]	70.9 ± 6.4	59–112	19.053	**0.001**
HC [cm]	95.7 ± 6.6	78–132	13.615	**0.001**
TBW [%]	54.1 ± 4.3	36–71	6.300	**0.001**
Fat. [%]	23.6 ± 6.7	2.2–50.8	8.141	**0.001**
BAI [%]	26.0 ± 3.64	46.0–14.9	25.005	**0.001**
BMI [m/kg]	21.1 ± 2.9	14.1–41.3	1.234	0.218
WHR	0.7 ± 0.4	0.1–1	15.183	**0.001**
THKA [°]	35.7 ± 8.5	15–62	170.103	**0.001**
LLA [°]	34.4 ± 8.6	10–60	19.653	**0.001**

Statistical significance p <0.001, BH – body height, BM – body mass, WC – waist circumference, HC – hip circumference, TBW – total body water, Fat – body fat content, BAI – body adiposity index, BMI – body mass index, WHR – waist-to-hip ratio, KTHA – thoracic kyphosis angle, LLA – lumbar lordosis angle.

Detailed analysis with the post-hoc test confirmed this differentiation in all subsequent years between the studied groups of women for the values of the thoracic kyphosis angle and lumbar lordosis. On the other hand, for the features characterizing the body structure and composition, statistically significant differentiation was confirmed only for the years 2012, 2015 and 2016 at the level of statistical significance $p < 0.01$ and $p < 0.05$ (Tables 3 and 4).

Table 3. The significance of differences for thoracic kyphosis in the analyzed years 2006–2016 at the level of $p < 0.001$ and $p < 0.005$.

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
2006		**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	1.000	**0.001**	**0.001**
2007	**0.001**		**0.001**	**0.000**	**0.001**	**0.001**	**0.001**	0.996	**0.001**	**0.001**	**0.001**
2008	**0.001**	**0.001**		0.980	**0.001**	0.125	0.060	**0.001**	**0.001**	0.997	0.996
2009	**0.001**	**0.001**	0.980		**0.001**	**0.004**	**0.002**	**0.001**	**0.001**	0.665	1.000
2010	**0.001**	**0.001**	**0.001**	**0.001**		**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
2011	**0.001**	**0.001**	0.125	**0.004**	**0.001**		1.000	**0.001**	**0.001**	0.937	0.058
2012	**0.001**	**0.001**	0.060	**0.002**	**0.001**	1.000		**0.001**	**0.001**	0.820	**0.030**
2013	**0.001**	0.996	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**		**0.004**	**0.001**	**0.001**
2014	1.000	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.004**		**0.001**	**0.001**
2015	**0.001**	**0.001**	0.997	0.665	**0.001**	0.937	0.820	**0.001**	**0.001**		0.842
2016	**0.001**	**0.001**	0.996	1.000	**0.001**	0.058	**0.030**	**0.001**	**0.001**	0.842	

Statistical significance p < 0.01; p < 0.05

Table 4. The significance of differences for lumbar lordosis in the analyzed years 2006–2016 at the level of $p < 0.001$ and $p < 0.005$.

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
2006		0.138	**0.001**	**0.001**	**0.001**	**0.001**	**0.000**	**0.015**	0.889	0.072	**0.015**
2007	0.138		**0.001**	0.288	**0.001**	0.091	**0.021**	**0.001**	0.057	0.995	0.781
2008	**0.001**	**0.001**		0.973	0.068	0.944	0.999	**0.001**	**0.001**	0.402	0.982
2009	**0.001**	0.288	0.973		**0.001**	1.000	1.000	**0.001**	**0.001**	0.991	1.000
2010	**0.001**	**0.001**	0.068	**0.001**		**0.000**	**0.003**	**0.001**	**0.001**	**0.001**	**0.018**
2011	**0.001**	0.091	0.944	1.000	**0.001**		1.000	**0.001**	**0.001**	0.978	1.000
2012	**0.001**	**0.021**	0.999	1.000	**0.003**	1.000		**0.001**	**0.001**	0.846	1.000
2013	**0.015**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**		0.935	**0.001**	**0.001**
2014	0.889	0.057	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	0.935		**0.021**	**0.005**
2015	0.072	0.995	0.402	0.991	**0.000**	0.978	0.846	**0.001**	**0.021**		0.999
2016	**0.015**	0.781	0.982	1.000	**0.018**	1.000	1.000	**0.001**	**0.005**	0.999	

Statistical significance $p < 0.01$; $p < 0.05$

The relationship between the features characterizing the body structure and composition and the value of the thoracic kyphosis angle KTHA [°] analyzed by means of the Pearson test of the showed a moderate, directly proportional correlation with WC ($r = 0.5$; $p < 0.05$). However, in the case of the lumbar lordosis angle LLA [°], there was a correlation with HC ($r = 0.7$; $p < 0.05$). Other features of the body composition did not show a statistically significant correlation with the values of KTHA and LLA [°].

Detailed regression analysis of the collected data in 2006–2016 indicated that in subsequent years, the most common predictors of a change in angular values of lumbar lordosis and/or thoracic kyphosis are features and indicators such as: WC, HC, %FAT, %TBW and BAI. However, the analysis of the whole group (n=1314) showed that WC is the most important predictor for changes in the angle of thoracic kyphosis in the population of Caucasian young women, and the BAI index for the angle of lordosis. As a result, this allowed building two regression models for the values of the thoracic kyphosis (YTHKA) and lumbar lordosis (YLLA) angles of young Caucasian women, which took the form of the kyphosis angle:

$$\mathbf{1.}\quad \mathbf{Y_{THKA} = 32.965 + 0.055 * WC}$$

It has been shown that the predictive value [°] of thoracic kyphosis will fail change by 0.0550 when the value of WC changes by one unit, which is expressed in centimeters. In the examined Caucasian population of young women in the years 2006–2016, the value of WC was in the range of 59–112 cm, therefore the projected model value of the variable is in the range of 37.255 to 40.225 degrees (Table 5).

Table 5. Predictors of thoracic kyphosis identified in the years 2006–2016 and estimation of the range of the norm of the angle of thoracic kyphosis in the studied group of young women.

Year	Independent variable	n	β	B	Constant	Range of the norm THKA
2006	WC [cm]	139	0.185	0.172	13.304	23.452–32.568
2007	%FAT	230	0.192	0.075	43.703	43.868–47.513
2008	%TBW	131	0.148	0.030	36.696	37.323–40.758
	BAI [%]		0.147	0.042		
2009	HC [cm]	99	-0.302	-0.032	44.068	46.564–48.292

Year	Independent variable	n	β	B	Constant	Range of the norm THKA
2010	%TBW %FAT	167	-0.171 -0.180	-0.176 -0.117	48.447	55.0404–60.943
2011	BAI [%]	163	-0.088	-0.274	44.292	48.374–56.896
2012	BAI [%] %TBW	163	0.190 -0.188	0.612 -0.105	49.962	56.3118–80.448
2013	%FAT	62	0.234	0.146	27.656	27.9722–35.0728
2014	HC [cm]	59	-0.471	-0.546	77.649	42.588–72.072
2015	% TBW	75	0.231	0.265	54.450	64.5708–86.6762
2016	BAI [%]	52	-0.204	-0.387	50.790	56.5563–68.592

N – number of participants, β – beta for lumbar lordosis, B – value of the variable changes, LLA – lumbar lordosis angle, BH – body height, BM – body mass, WC – waist circumference, HC – hip circumference, TBW – total body water, Fat – body fat content, BAI – body adiposity index, BMI – body mass index, WHR – waist-to-hip ratio.

However, in the case of the value of the lumbar lordosis angle, the form of the model is as follows:

$$2. \quad Y_{LLA} = 29.851 + 0.213 * BAI$$

It has been shown that the predictive value of the lumbar lordosis angle [°] will change by 0.2130 when the BAI value changes by one unit, and this is expressed as a percentage [%]. In the studied population in 2006–2016, the BAI value ranged from 14.9% to 50.8%, so the projected model value of the variable ranges from 33.025 to 39.649 degrees (Table 6).

Table 6. Predictors of the value lumbar lordosis identified in the years 2006–2016 and estimation of the range of the norm of the angle of lumbar lordosis in the studied group of young women.

Year	Independent variable	n	β	B	Constant	Range of the norm LLA
2006	BAI	139	0.167	0.481	18.785	25.9519–40.911
2007	BAI	230	0.082	0.189	28.389	31.2051–37.083
2008	BAI	131	0.151	0.398	7.262	13.1922–25.57
2009	%TBW BAI	99	0.118 0.112	-0.166 0.218	39.426	36.6982–37.668
2010	WHR %TBW	167	-0.190 -0.155	-45.281 -0.305	113.738	15.5081–66.936
2011	BM [kg]	163	0.083	0.097	30.824	34.646–41.3485
2012	WHR	137	-0.094	-15.542	48.256	49.8102–63.798
2013	HC [cm]	62	-0.240	-0.294	41.510	59.236–83.226
2014	BH [cm]	59	-0.226	-0.307	79.275	46.357–58.1765
2015	WC [cm]	75	-0.215	-0.131	47.713	55.442–62.385
2016	WHR HC [cm] %TBW	52	0.196 0.344 0.224	-0.369 -0.369 -0.425	73.180	41.5332–53.395

N – number of participants, β – beta for lumbar lordosis, B – value of the variable changes, LLA – lumbar lordosis angle, BH – body height, BM – body mass, WC – waist circumference, HC – hip circumference, TBW – total body water, Fat – body fat content, BAI – body adiposity index, BMI – body mass index, WHR – waist-to-hip ratio.

4. Discussion

So far, defining the influence of body composition on the body posture has been limited to identifying the correlation between anthropometric features and their indices and the angular values of spine curvatures [36–40]. Such explorations were carried out with the use of various measurement techniques, methods and in various age and sex groups [32]. Some of them indicate a correlation of some features and indicators of the posture and body composition with the angular value of lumbar lordosis and/or thoracic kyphosis [36–37, 39], others indicate their lack [38].

The present research results not only confirm the existence of the relationship between the identified predictors of the values of lumbar lordosis angles and thoracic kyphosis but also allow for their measurable estimation. This makes it possible to effectively estimate the value of the lumbar lordosis angle and thoracic kyphosis with dynamically changing features and indicators.

The significant correlation of WC with KTHA and HC with LLA found in this study is confirmed in the analyzed literature. An increase in BMI and HC resulted in a directly proportional increase in LLA in the study of Indonesian students, despite the fact that the study group came from a different part of the world [37]. Although the BMI index, which was assessed for increased body weight, is not calculated from the width parameters, and in the case of overweight and obesity, the distribution of adipose tissue is unknown, but the increase in HC had a direct proportional effect on the LLA value. A similar relationship was found in studies in South Africa, which confirmed the existence of a significant correlation between overweight and obesity and the value of the lumbar lordosis angle. The increased body weight was again measured by the BMI index [35]. In both cases, these were studies conducted on young people for one year. It is different in this study, where the research was conducted over the course of a decade.

The above corresponds to the studies by Saludes et al. [41] in which the impact of increased body weight (overweight, obesity) on lumbar lordosis was assessed. The studied group was older (50.5 ± 19.7, n = 179, $p < 0.001$) than the presented one, but the same trend should be noticed. The authors found that the accumulation of abdominal fat influences the increase in the value of the lumbar lordosis angle, and its modification is related to the accumulation of fat in the abdominal cavity [41]. Overweight was determined by the BMI index, and abdominal obesity was measured by the WC index. The research of Jankowicz-Szymańska confirms this, showing that the increase in fat, especially abdominal fat, increases the risk of developing lumbar hyperlordosis [40].

An assessment of the influence of obesity on the value of pedestrian kyphosis was done by Gonzalez-Sanchez et al. The authors found that there were significant differences in thoracic kyphosis between people with normal weight and obese people, and the angle values were measured using an electromagnetic device. It turns out that despite different methodologies for assessing the same features of the body structure and posture, the obtained results are convergent [42].

The analysis of the results of the present research in individual years shows predictors from individual years also related to the change in body composition, %TBW or %FAT, which increase the tissue volume and thus increase the width parameters, including hip [HC] and waist [WC] circumferences. The BAI index as an identified predictor of the value of the lumbar lordosis angle for the whole group gives a different quality of this relationship, as does the WC for estimating the value of thoracic kyphosis. Until now, it was presented in a linear relationship and did not create the possibility of calculating the relationship between the changing parameters.

Additionally, one of the significant findings of this study is that the BMI index, as the only one among the 11 tested parameters, showed no statistically significant correlation with the value of the angle of thoracic kyphosis and lumbar lordosis (F = 1.234; $p = 0.218$).

The studies of children and adolescents where the authors indicated such relationships are in some opposition. Perhaps, in this case, the variable differentiating these results is a different stage of the respondents' physical development. Nevertheless, previous studies by Zwierzchowska et al. [18] confirm such a trend in a group of adults, where no significant statistical correlation was found between the BMI index and the value of the lumbar lordosis angle. On the other hand, a linear increase in the angular value of lumbar lordosis was demonstrated with an increase in the fatness index BAI in overweight and obese people. At that time, the analyses did not take into account the changes in the time series.

This study do not provide normative values for the physiological curvature of the spine for the general human population, but nevertheless it indicates a very dynamic model and pattern for setting the norm. The authors are convinced that mathematical models can give such a direction to further scientific exploration. The proposed equations of regression models for researchers may be an inspiration for a different view on the concept of the "norm" of the two largest sections of the spine. The authors propose that the concept of the "norm" of the curvature of the spine should depend on the parameters of the body structure and composition. So far, the size of the norm in relation to the angular values of the physiological curvatures of the spine has been treated very individually, but it did not take into account the width and height parameters of the body structure and the indicators built on their basis. This is a significant intellectual innovation resulting from this research.

Strengths and weaknesses

The strength of this research is the size of the group, its homogeneity and repeatability of the procedures and techniques of conducting the research (always by the same two researchers within 10 years of data collection). In addition, the originality of this study is the construction of a mathematical model that is used to predict the size of kyphosis angles and lumbar lordosis using anthropometric features and indicators of body structure.

The interpretation of the results of this research is a limitation, as so far a relationship has been proven between some features and indices of body structure and the size of the angles of thoracic kyphosis and lumbar lordosis; however, no predictors of posture traits have been determined using a similar statistical methodology.

5. Conclusions

The results of the study allowed the identification of predictors of the angular size of thoracic kyphosis and lumbar lordosis in the studied population of young women. It was shown that among the analyzed body features and indices, waist circumference [WC] is a predictor of the final value of thoracic kyphosis, while the BAI index is a predictor of the angular value of lumbar lordosis.

The constructed mathematical models for thoracic kyphosis angle (YTHKA = 32.965 + 0.055 * WC) and lumbar lordosis (YLLA = 29.851 + 0.213 * BAI) may be effective in estimating their value in changing conditions of the body structure and composition.

Mathematical models are a theoretical construct, but used with caution they can be helpful in monitoring the compensation process and spine correction.

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