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Examining relationships of the anterior pelvic tilt angle with the anterior-posterior curvatures and elongation of the spine

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Purpose: A pelvic tilt may lead to body posture disturbances. The aim of the study was to determine relationships between the anterior pelvic tilt angle and the curvature and mobility of lumbar lordosis and thoracic kyphosis. *Methods*: The angles of anterior pelvic tilt, lumbar lordosis, thoracic kyphosis and spinal elongation were measured with the use of Posturometr-S device. The posturometric measurements were carried out with the pointing stick of the device moving along spinous processes (from C7 to L5) and marking the selected anthropometric points. *Results*: In the studied group of boys, the angles in a free-standing position and the thoracic kyphosis angle during elongation were significantly greater than the corresponding lordosis angles. In all measured variables the range of measured angles was characteristically wide. The greatest individual differences were found in the lumbar lordosis angles. All the boys featured a significant increase in body height during linear elongation. The measurements of angles at baseline and during elongations of lumbar lordosis and thoracic kyphosis in a standing position in the entire study group revealed that the anterior pelvic tilt had no significant impact on lumbar lordosis in a free-standing posture and its elongation. In the case of thoracic kyphosis, the correlation was statistically significant, although it was not strong. *Conclusions*: The anterior pelvic tilt angle is correlated with the subject's age, body mass, body height and the size of thoracic kyphosis.

Key words: *children, lumbar lordosis, thotacic kyphosis, elongation, body shape, Posturometr-S*

1. Introduction

The vertebral column is an interlinked biokinematic chain, extending from the sacrum situated at the back part of the pelvic cavity, through its particular sections, to the atlanto-occipital joint. The spine functions in all movements of the body as well as movements of the head, neck and trunk. It is an important structure that carries the majority of body weight, transfers this weight to the lower limb through the pelvis and maintains the balance of the body [14].

Elongation measurements enables the assessment of the mobility of individual spinal segments. Indirect assessment of efficiency and mutual dynamic relations of postural muscle. The skeleton is stabilized by the attached musculo-ligamentous-fascial system. A tilt of any part of this interconnected structure may have a significant impact on the shape and dynamics of another part, not necessary in its close proximity. Determining the primary cause of such disorders is rather difficult. According to Lewit [12] and Chaitow [3], a sagittal pelvic tilt triggers an imbalance of the pelvic floor muscles. The resulting changed position of the

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pelvis is referred to as the lower crossed syndrome in which the increased anterior pelvic tilt facilitates the hip flexors and lumbar extensors and inhibits the gluteal and abdominal muscles. A pelvic tilt may thus lead to body posture disturbances. Mayers [15], Snijders et al. [23], and Vlemming et al., [27], [28] showed that muscle imbalances disturb the entire musculo-ligamentous-fascial system, which can have a direct effect on the spatial distribution of the skeletal elements of the locomotive system.

Researchers have emphasized the significance of two anatomy trains: superficial back line (SBL) and back functional line (BFL), which play a crucial role in maintaining the pelvis in the correct position in the sagittal plane. There have been multiple models of myofascial chains affecting the skeletal components of the locomotor system. Struyff-Denys [24], Paul Chauffour [4] and Busquet [2] have underlined that myofascial imbalances lead to a faulty body posture as well as dysfunctions and pathologies of the joints and periarticular tissues, and found close relationships between soft and bone tissues. Studies of structural integration have also indicated other aspects of such interactions. It appears that different forms of functional and structural chains of specific parts of the locomotive system make it impossible to determine precise correlations between individual system parts. Spinal sagittal curves appear progressively with growth and are well established when the standing position and walking are possible. It is just at the end of the skeleton growth that the morphology of the spino-pelvic setting is fixed [22]. Posture correction during the anti-gravity work decreases the anterior-posterior curvatures of the spine. However, there is no clear data on the pelvis and lumbar lordosis positioning during the same exercises. The study attempts to determine relationships between the anterior pelvic tilt angle and the curvature and mobility of lumbar lordosis and thoracic kyphosis. It was assumed that active spinal elongation in the upright position reduces the anterior-posterior curvatures of the spine and the anterior pelvic tilt.

2. Materials and methods

The study was carried out in 2014–2015 in the Oleśnica district in Poland, on a randomly selected group of 1,152 boys aged 7 to 9 years. Before the study, a visual inspection of all boys was conducted to exclude those whose examination would not guarantee the reliability of the results. The exclusion criteria were developmental defects, locomotive system disorders, hyperactivity, apathy, recent traumas, and obesity preventing marking anthropometric points.

The inclusion criterion was the parent's or legal guardian's written consent for the boy to take part in the study.

The selection process was as follows:

– 7-year-old boys: 353 randomly selected, 319 qualified;
– 8-year-old boys: 418 randomly selected, 389 qualified;
– 9-year-old boys: 381 randomly selected, 358 qualified.

Altogether, 1066 boys were qualified for the study. Each participant's record file contained such data as first name, surname, calendar age, body height (*b* – *v*) [cm] to the nearest 0.01 cm, and body mass [kg] to the nearest 1 g.

The angles of anterior pelvic tilt, lumbar lordosis, thoracic kyphosis and spinal elongation were measured with the use of Posturometr-S device [25] consisting of two coupled systems:

– mechanical – involving measurements between marked points or lines using a pointing stick;
– electronic – calculating the positioning of the marked points or lines.

The measurement station consisted of measuring devices, a platform for measuring spinal elongation in a free-standing position, a specially designed seat for measuring spinal inclinations, weighing scales, a PC, and a printer (Fig. 1).

Fig. 1. The station used for spinal elongation measurement

The study consisted of a calculation of positions of selected anthropometric points. The body posture

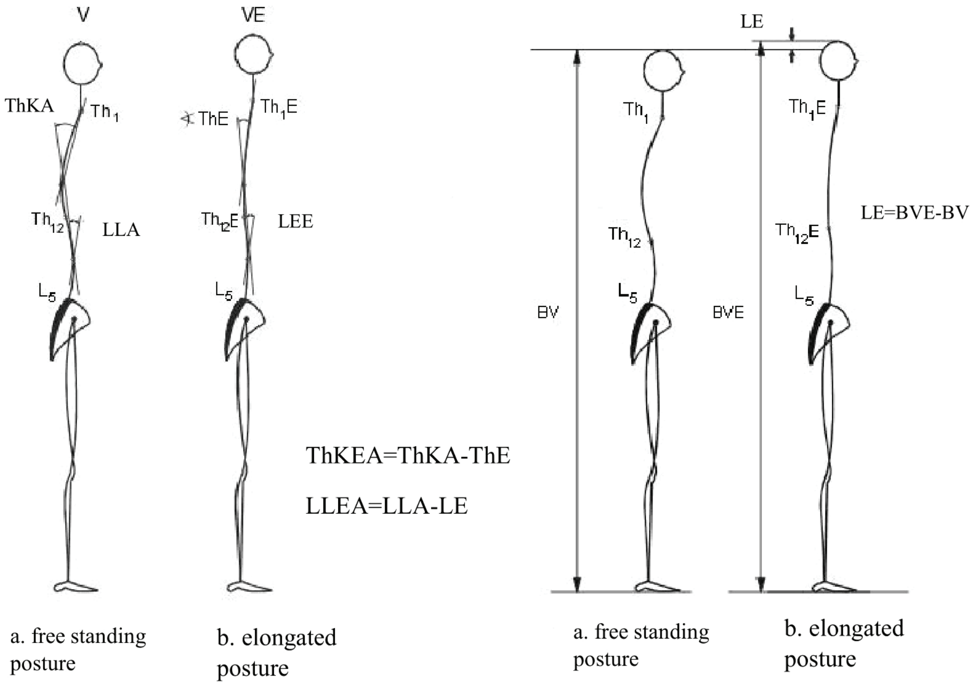

Fig. 2. Measurements of angular elongation, thoracic kyphosis and lumbar lordosis angles (ThKA, LLA), and linear elongation (EL)

parameters were registered automatically, and the software was used to calculate linear and angular parameters following the established sequence of measurements. The posturometric measurements were carried out with the pointing stick of the device moving along spinous processes (from C_7 to L_5) and marking the selected anthropometric points.

The measurements took place between 9 a.m. and 12 a.m. in spacious well-lit rooms ensuring full concentration and guaranteeing intimacy.

Each participant stood on the platform with his back towards the examiner, with straight legs slightly astride with the distance between the medial malleoli of about 10 cm. The arms were placed alongside the body, with the feet parallel to each other, the big toes on the same line on the measurement platform, and the head in the Frankfurt plane. Both the pelvis and the head were stabilized. One and the same examiner marked the tips of the spinous processes from C_7 do L_5 and the middle of the line connecting the posterior superior iliac spines with the upper edge of the pubic symphysis. Two consecutive measurements were performed on each participant: in a free-standing position and during body elongation following the command "Straighten up!". The participants were not given any additional instructions, or expressed any opinions about the body posture during measurements. The upright body posture was maintained for 5 seconds [5]. The measurements of lumbar lordosis and thoracic kyphosis in a free-standing posture and during elongation are shown in Fig. 2.

The following angles were calculated:

- thoracic kyphosis angle (ThKA) in a free-standing position, between a straight line linking the tip of the Th_1 spinous process and the peak of thoracic kyphosis, and a straight line linking the peak of thoracic kyphosis and the Th_{12} spinous process;
- thoracic kyphosis elongation angle (ThKEA) in a standing position, between a straight line linking the tip of the Th_1 spinous process and the peak of thoracic kyphosis, and a straight line linking the peak of thoracic kyphosis and the Th_{12} spinous process, during elongation of the spine;
- lumbar lordosis angle (LLA) in a free-standing posture, between a straight line linking the Th_{12} spinous process with the peak of lumbar lordosis, and a straight line linking the peak of lumbar lordosis and the tip of L_5 spinous process;
- lumbar lordosis elongation angle (LLEA) in a standing position, between a straight line linking the Th_{12} spinous process with the peak of lumbar lordosis, and a straight line linking the peak of lumbar lordosis and the tip of L_5 spinous process during elongation of the spine;
- anterior pelvic tilt angle (APTA), between a line passing through the middle of the line connecting the posterior superior iliac spines with the upper edge of the pubic symphysis, and a horizontal line. The APTA is expressed as the tangent of the tilt angle.

– linear elongation is the difference between the elongation (BVE) and the free-standing (BV) positions of the top of the head during elongation.

The angles were measured to the nearest 1°, and the linear variables to the nearest 0.1 cm.

The reliability assessment showed that the differences between the conducted measurements on a group of 20 controls were statistically non-significant ($p \leq 0.05$). The absolute error in marking the positions of the anthropometric points did not exceed 1 mm on all axes of coordinates. The statistical analysis revealed the error to be no greater than 2.5 mm for the X and Z axes, and 3 mm for the Y axis. The impact of human error on the measurements was minimalized by marking the anthropometric points by one and the same examiner and by stabilizing the pelvis and the head in the Frankfurt plane.

The normality of distribution of the measurable variables was checked with the Shapiro–Wilk test. The critical level of statistical significance was set at $p \leq 0.05$. The statistical analysis revealed no grounds for rejection of the normal distribution hypothesis. The statistical calculations included arithmetic means, standard deviations, and coefficients of variation. The significance of differences between the variables was checked with the analysis of variance (ANOVA) and least significant difference (LSD) tests.

The correlation between the anterior pelvic tilt angle, baseline angles (free-standing posture), and lumbar lordosis and thoracic kyphosis elongation was determined with Pearson's correlation coefficient. The statistical calculations were made for the entire study group using the Statistica v.12.0 (StatSoft) software package.

3. Results

The analysis of morphological parameters in the study group revealed their regular increase, and the differences between the ages were statistically significant. The SD values, however, indicated large differences between particular results (Tables 1, 2).

Table 1. Morphological variables in participants' age groups

Variable	Age [years]	N	$\bar{x}$	S	v
BH [cm]	7	319	131.16	5.77	4.44
	8	389	134.51	6.42	4.78
	9	358	139.56	6.57	4.71
BM [kg]	7	319	27.42	4.19	15.27
	8	389	30.18	5.08	16.82
	9	358	34.80	7.36	21.15

BH – body high; BM – body mass.

Table 2. Differences in mean variables in participants' age groups – LSD test

Variable	ANOVA		Means in age groups			post-hoc LSD test – p-value		
	F	p	7 Y	8 Y	9 Y	7–8 Y	7–9 Y	8–9 Y
BH [cm]	1.9	0.000	131.6	134.51	139.56	0.000	0.000	0.000
BM [kg]	144.56	0.000	27.42	30.18	34.80	0.000	0.000	0.000

BH – body high; BM – body mass; Y – years, $p < 0.05$.

Table 3. Statistical characteristics of spinal curvatures in particular age categories of boys.

Variable	Years	$\bar{x}$	S	v
ThKA [°]	7	25.74	4.00	15.56
	8	25.80	4.31	16.71
	9	26.53	4.15	15.66
ThKEA [°]	7	10.41	4.67	44.88
	8	9.80	4.21	42.92
	9	9.72	4.21	43.31
LLA [°]	7	5.92	8.07	136.28
	8	7.37	8.52	115.59
	9	7.16	8.55	119.46
LLEA [°]	7	1.78	6.62	371.09
	8	2.84	6.79	239.07
	9	2.00	6.91	346.12
APTA [°]	7	44.90	4.01	8.92
	8	45.39	3.84	8.46
	9	45.79	4.01	8.75
EL [cm]	7	10.87	5.75	52.93
	8	11.06	5.94	53.68
	9	12.18	6.35	52.12

ThKA – thoracic kyphosis angle; ThKEA – thoracic kyphosis elongation angle; LLA – lumbar lordosis angle; LLEA – lumbar lordosis elongation angle; APTA – anterior pelvic tilt angle; EL – elongation.

In the studied group of boys, the angles in a free-standing position and the thoracic kyphosis angle

Table 4. Differences in mean angles in particular age categories of boys – post-hoc LSD test

Variables	ANOVA		Means in age groups			post-hoc LSD test – *p*-value		
	F	*P*	7 Y	8 Y	9 Y	7–8 Y	7–9 Y	8–9 Y
ThKA [°]	3.94	0.0196	25.74	25.80	26.53	0.8484	**0.0139***	**0.0169***
KETh [°]	2.52	0.0811	10.41	9.80	9.72	0.0646	**0.0390***	**0.7910***
LLA [°]	2.93	0.0539	5.92	7.37	7.16	0.0227	**0.0563***	**0.7307***
LLEA [°]	2.48	0.0841	1.78	2.84	2.00	0.0392	**0.6825***	**0.0895***
APTA [°]	4.30	0.0138	44.90	45.39	45.79	0.1058	**0.0034***	**0.1579***
EL [mm]	4.84	0.0080	10.87	11.06	12.18	0.6619	**0.0047***	**0.0117***

$p < 0.05$*; ThKA – thoracic kyphosis angle; ThKEA – thoracic kyphosis elongation angle; LLA – lumbar lordosis angle; LLEA – lumbar lordosis elongation angle; APTA – anterior pelvic tilt angle; EL – elongation; Y – years.

Table 5. Relationships between physical and angular variables in the entire studied group of boys ($N = 1066$).

Variable	Age	BH	BM	ThKA	ThKEA	LLA	LLEA	APTA	EL
Age	–	**0.51**	**0.46**	**0.08**	**–0.06**	**0.08**	0.03	**0.09**	**0.09**
BH	**0.51**	–	**0.76**	**0.12**	**–0.06**	**0.13**	–0.00	**0.15**	**0.12**
BM	**0.46**	**0.76**	–	0.06	**–0.06**	**0.13**	–0.03	**0.08**	**0.06**
ThKA	**0.08**	**0.12**	0.06	–	**0.45**	**0.14**	**0.09**	**0.08**	**0.47**
ThKEA	**–0.06**	**–0.06**	**–0.06**	**0.45**	–	–0.02	0.04	–0.00	**0.35**
LLA	**0.08**	**0.13**	**0.13**	**0.14**	–0.02	–	**0.43**	0.04	–0.06
LLEA	0.03	–0.00	–0.03	**0.09**	0.04	**0.43**	–	0.02	0.01
APTA	**0.09**	**0.15**	**0.08**	**0.08**	–0.00	0.04	0.02	–	–0.02
EL	**0.09**	**0.12**	**0.06**	**0.47**	**0.35**	–0.06	0.01	–0.02	–

BH – body high; BM – body mass; ThKA – thoracic kyphosis angle; ThKEA – thoracic kyphosis elongation angle; LLA – lumbar lordosis angle; LLEA – lumbar lordosis elongation angle; APTA – anterior pelvic tilt angle; EL – elongation, $p < 0.05$ in bold.

during elongation were significantly greater than the corresponding lordosis angles. In all variables measured, the range of measured angles was characteristically wide. The greatest individual differences were found in the lumbar lordosis angles. All the boys featured a significant increase in body height during linear elongation (Tables 3, 4).

The measurements of angles at baseline and during elongations of lumbar lordosis and thoracic kyphosis in a standing position in the entire study group revealed that the anterior pelvic tilt had no significant impact on lumbar lordosis in a free-standing posture and its elongation. In the case of thoracic kyphosis the correlation was statistically significant, although it was not strong (Table 5).

4. Discussion

Seven-to-nine-year-old boys have an relatively stable skeletal development, changing body proportions, spinal curvatures and spatial positioning of the pelvis. This development is supported by a relatively weak musculo-ligamentous system [30]. Due to the large water volume in muscle fibers, young muscles are flabby and often unable to produce long and strong contractions. The dynamic growth of the musculo-ligamentous-fascial system is accompanied by the equally intense development of the nervous system, including the vestibular system, which has a significant impact on the body posture in the sagittal plane [16], [20], [21]. This is also a period in which the correct body posture patterns are developed, and errors in shaping these patterns may lead to the formation of future bad [9].

The study focused on finding relationships between the anterior pelvic tilt angle and anterior-posterior curvatures of the spine in a free-standing position and during elongation of spinal sections and the total spine.

The spine functions in all movements of the body as well as movements of the head, neck and trunk. It is an important structure that carries the majority of body weight, transfers this weight to the lower limb through the pelvis and maintains the balance of the body. According to the anatomical segmentation, spine curves are: the cervical lordosis (C1 to C7), thoracic kyphosis (T1 to T12), lumbar lordosis (L1 to L5) and sacral kyphosis (sacrum) [18]. The study results indicate that the positioning of the pelvis was not associated with the size of lumbar lordosis in a free-standing position or during elongation, although this kind of correlation has been proven in many world research. Lack of correlation may be explained by a different measurement methodology. In the study, Lumbar lordosis angle was measured for L1–L5, as opposed to L1–S1 used for some of the other research. Since sacrum is tightly coupled to the pelvic bone, correlation can be expected. A positive correlation was found between thoracic kyphosis and body build parameters. Greater body mass, body height and thoracic kyphosis were associated with a greater anterior pelvic tilt angle. These are not consistent with observations by Legaye and Duval-Beaupere [11], who found a strong correlation between the anterior pelvic tilt angle and all anterior-posterior curvatures of the spine. On the other hand, no correlations or weak correlations were found between the pelvic tilt and spinal curvatures by Youdas [29] and Prushansky et al. [17]. The discrepancy in those study results indicates that the positions of the pelvis and the spine in the sagittal plane are affected by some other factors. In the studied group of boys these factors were age, body height, and body mass. The increasing anterior pelvic tilt angle with age is a physiological variable related to human ontogenetic development [10]. The prominent anterior superior iliac spines were used as anatomical points. But in children these spines are not well developed until about 10 years of age. Rather this anterior pelvic area is a broad gentle curve without a prominent spine as in the adult [6].

Age, body height and body mass are significant determinants of the size of the pelvic tilt angle and the size of the curvatures of the spine and of elongations of spinal sections and the entire spine. It appears, therefore, that the position of the pelvis and the spine in the sagittal plane is not determined by the distribution of component parts of the locomotive organ, but first and foremost, by external factors. The position of the sacrum and spatial orientation as well as the global magnitude of thoracic kyphosis, and lumbar lordosis changes along with growth [1]. Mac-Thiong et al. [13] documented the changes in sagittal spinal and pelvic parameters during growth in 180 normal subjects aged between 4 and 18 years. However, they did not report the correlation between these parameters, although it has been demonstrated that relationships between spinal and pelvic geometries strongly influence spinopelvic balance in adults. The increase in the body height and body mass of studied boys results in changes of the spatial position of the vertebral column and the pelvis. Greater body height and body mass are associated with the increased anterior pelvic tilt angle and anterior-posterior curvatures of the spine. The increase in body mass and body height can affect body posture in a two-fold way. If body mass and body height grow correctly, the body posture will be correct as well. However, in the case of some disorder, e.g., excess weight, the body posture can be changed [20]. The positive correlation found in the present study indicates that excessive body mass leads to an increase in the anterior pelvic tilt angle and the angles of spinal curvatures. This corresponds to the results by Walicka-Cupryś et al. [26], who found significant increases in the anterior-posterior curvatures of the spine in obese children.

However, excess weight is not the only determinant of the shape of the spine, Górniak et al. [7] and Grabara, Pstrągowska [8] proved that also underweight affected the spinal curvatures, in particular, the size of thoracic kyphosis. The present study revealed a correlation between thoracic kyphosis and the anterior pelvic tilt angle. Thus, it can be assumed that both excess weight and underweight affect the shape of the spine supported on the sacrum.

The lack of correlations between the pelvic tilt and the elongation of the thoracic and lumbar spine indicates that the anti-gravity lines of postural muscles do not affect the position of the pelvis. During the anti-gravity work of the muscles, the lengths of the spine and its particular curvatures change significantly, while the anterior pelvic tilt angle remains unchanged. It can be assumed that during the command “Straighten up!” subjects mainly used the spinal erectors, therefore decreasing the anterior-posterior curvatures of the spine, and neglecting to use the side abdominal muscles. Muscles that would stabilize lumbar spine and pelvis.

The results of the present study show that changes in the size of anterior-posterior curvatures of the spine during elongation are not associated with the angle of the anterior pelvic tilt. In the studied group of boys, the shape of spinal curvatures was affected by age, body height and body mass. The diagnosis and prevention of faulty body posture commonly rely on a model focusing on the shape of the pelvis, and it is thus assumed that the correct pelvic shape guarantees the correct shape of anterior-posterior curvatures of the spine. The present study found no direct correlation between that the pelvis positioning and the size of lumbar lordosis, i.e., a spinal curvature adjacent to the pelvis. Current study is insufficient to fully explain this lack of correlation and further work is necessary.

However, it would be recommended to educate subjects on the use of the side abdominal muscles during an anti-gravity work, and putting even more emphasis on them during the "Straighten Up!" command. This should lead to increased use of this muscle group and better stabilization on the spine and pelvis. A slight correlation was found between the pelvic positioning and the size of thoracic kyphosis.

The present study has a number of limitations. The results were analyzed only in specific age groups and conclusions about the sizes and changes of spinal curvatures during elongation may be ambiguous, as reflected by the coefficient of variations for the angles of lumbar lordosis and thoracic kyphosis. Some boys in the study displayed inverted spinal curvatures in a standing position as well as various directions of changes in anterior-posterior curvatures of the spine. In some boys, a deeper lordosis, significantly flat kyphosis or reversed lumbar lordosis with unchanged thoracic kyphosis were observed rather than the flattening of all spinal curvatures. The analysis of correlations, therefore, focused on absolute angle values. However, for practical reasons, the analysis should include new criteria of participants' classification, e.g., according to the quartiles of the size of lumbar lordosis and thoracic kyphosis. The new classification will enable the assessment of changes of the size of the anterior-posterior curvatures in a free-standing position and during elongation in homogenous study groups with similar sizes of the spinal curvatures. Another criterion to consider can be adiposity.

Observed variation in a change of the anterior-posterior curves during "Straighten Up!" command indicates that a study into the muscle tone and the usage pattern of the postural muscles is advised.

5. Conclusions

In the group of boys, the value of rest angles of thoracic kyphosis and lumbar lordosis and the mobility values of these segments are quite similar and the existing differences are statistically insignificant. The results of the present study revealed no correlations between the anterior pelvic tilt angle and the size of lumbar lordosis in a free-standing position and during spinal elongation. Thoracic kyphosis, compared to lumbar lordosis, is characterized by greater elongation, angular mobility.

The anterior pelvic tilt angle is correlated with the subject's age, body mass, body height and the size of thoracic kyphosis.

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