Examination of childhood spine deformities among small schoolchildren: determining the shape of the spine and stance stability tests

Abstract of Ph.D Thesis

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1. INTRODUCTION

The care and treatment of children with posture disorders and spinal deformities is an important field of child orthopaedics. Customized therapeutical gymnastics and corrective gymnastic therapy play an important role in prevention, but in school-based physical education, it is also a decisive factor to take age-appropriate specificities into consideration. To this end, it is essential to record the shape of the spine numerically. X-ray images are only allowed to be made in case of suspected structural deformities (e.g. scoliosis, Scheuermann's disease); this is not accepted in case of a postural disorder. Based on the recommendation by the International Scientific Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT), non-invasive measurement systems also play an important role in the follow-up of children with scoliosis, therefore the use of alternative instruments not entailing any radiological exposure should be focussed on. Known non-invasive testing instruments can define the curvatures of the spine through the skin, without any radiological exposure. The Zebris ultrasound-based motion analysis system (Zebris Medizintechnik GmbH, Isny, Germany) is a widespread measuring instrument, which can determine not only the characteristics to describe the motions of the upper and lower limbs, but – using the WinSpine software package – it can also define the spatial position of spinous processes, wherefrom the values of spinal curvatures can be calculated.

2. OBJECTIVES

The main objective of my research is to find out how indolent posture in childhood affects spinal curvatures and balancing ability. A part of the research is to verify the Zebris non-invasive spine analysis method in case of children of correct posture and those treated with scoliosis, and to determine the normal values of spinal curvatures. At the beginning of the research, I set the following objectives in respect of the children involved in testing:

1. Study of the reliability of the Zebris ultrasound-based spine analysis method and of the repetition accuracy of measurements in case of children with correct posture and suffering from scoliosis, respectively.
2. Validation of the Zebris ultrasound-based spine analysis method using spinal curvature values determined on standard X-ray images using the Cobb method.
3. Determination of the spinal curvature values of school-aged children in the sagittal plane using the Zebris ultrasound-based spine analysis method (analysis of age and height in respect of spinal curvatures in the sagittal plane).
4. Analysis of the impact of indolent posture in childhood on stance stability.

3. SUBJECTS AND METHODS

Tests were performed on several groups.

- The reliability of the Zebris ultrasound-based spine analysis method and the repetition accuracy of measurements were tested by the involvement of 20 children with correct posture and 23 girls suffering from scoliosis.
- The validation of the Zebris ultrasound-based spine analysis method using spinal curvature values determined by the Cobb method on traditional X-ray images was performed with the involvement of 19 children treated with scoliosis.
- Determination of the spinal curvature values of school-aged children in the sagittal plane using the Zebris ultrasound-based spine analysis method was carried out with the involvement of 129 lower-grade primary school children.
- The impact of indolent posture in childhood on stance stability was tested with the involvement of 113 children with correct posture and 68 children with indolent posture.

The measurement instruments required for complex testing were available at the Biomechanical Laboratory of MÁV Hospital in Szolnok, operating as a hospital specialized in musculoskeletal diseases.

3.1. Physical orthopaedic test

Clinical physical tests were performed at the Biomechanical Laboratory, conducted by an orthopaedist. Specialist findings always mentioned posture features and the state of the feet. Physical orthopaedic tests performed by a specialist always preceded tests using the Zebris ultrasound-based spine analysis method.

3.2. Radiological tests (only in case of children treated for scoliosis)

Standard biplanar (posterior-anterior and lateral) digital X-ray images were taken of the full spine by digital X-ray equipment (Siemens Luminous Fusion Digital X-ray 2015/31030) at Szolnok MÁV Hospital. On occasion of taking posterior-anterior (PA) radial X-ray images, children were asked to stay in a natural straight standing position and to keep their arms loosely at the sides of their trunk.

In order to evaluate curvatures in the sagittal plane, lateral X-ray beams were directed from left to right while taking X-ray images. The children examined were asked to raise their arms forward to 45° in the sagittal plane, and then to hold their elbows of the opposite side with their hands. The Cobb method was used for the evaluation of X-ray images.

3.3. Determination of the value of sagittal and frontal spinal curvatures to characterize the shape of the spine using the Zebris ultrasound-based spine analysis method

3.3.1. Presentation of measuring instruments

In order to determine angle values characterizing the shape of the spine, the spatial positions of spinous processes were recorded – while standing in a natural upright posture – by an ultrasound-based Zebris CMS-HS motion analysis system (Zebris Medizintechnik GmbH, Isny, Germany) the parts of which are as follows: a T-shaped measuring head emitting ultrasound signals from its three points; a central unit for producing ultrasound; a reference marker containing an ultrasound receiver for filtering the hip’s movements; a pointer stick comprising two ultrasound-based receivers for specifying the spatial position of spinous processes; a computer and a printer to process and print data (Figure 1).

The sensors in the measuring head emit ultrasound signals in specified intervals, which are recorded by the receivers. The measuring frequency is 100 Hz. The distance between each sensor and the transmitters of the measuring head can be calculated from the known ultrasound velocity corresponding to the given temperature and from the measured propagation time. The spatial coordinates of receivers can be calculated at each moment of the measurement from the spatial coordinates of the three transmitters of the measuring head and from the distance between the receivers and the three sensors of the measuring head, using the method of triangulation. The calculation method can be performed for each sensor. The spatial positions of the sensors – and therefrom the spatial positions of spinous processes – are recorded and stored numerically by the WinSpine measurement control (Zebris Medizintechnik GmbH, Isny, Germany).

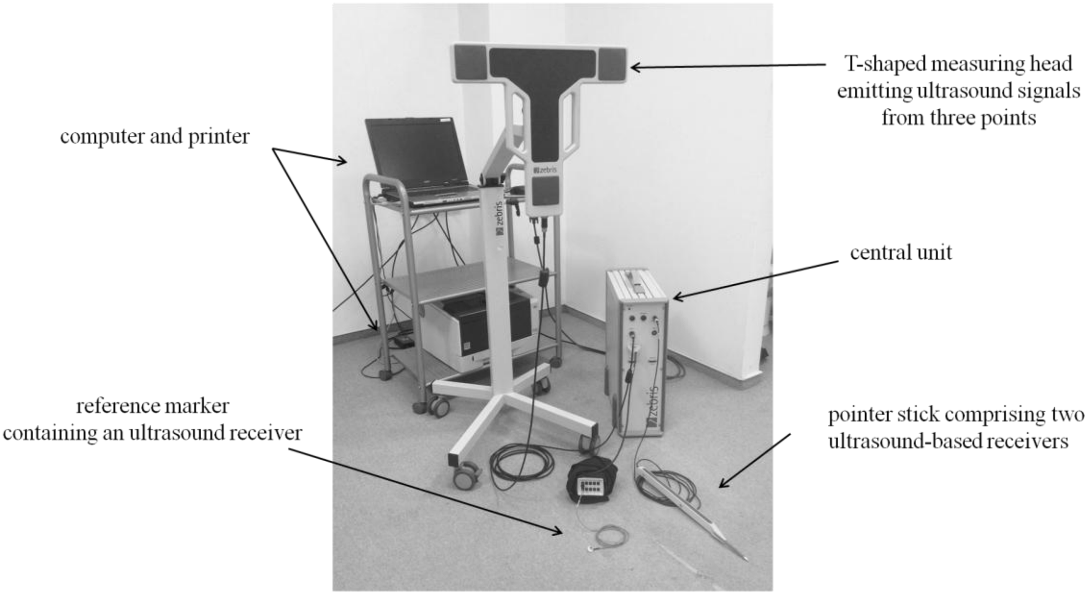

Figure 1.

Parts of the Zebris CMS-HS ultrasound-based motion analysis system

3.4. Impact analysis of indolent posture in childhood to the stability of standing

3.4.1. Presentation of measuring instruments

In the course of static standing, the body weight is distributed between the two lower limbs, and the distribution of body weight can be measured even within one foot. The ground reaction force is opposite – but equal in value – to the force exerted to the ground by human body weight; a force plate (pedograph) was used for measuring it (based on Newton's third law). Pressure distribution below the soles can be determined by the capacitive force sensors built in the force plate, which convert the pressure of sole points on the sensors into electric signals. The surface area of the Zebris PDM-S (Zebris GmbH, Isny, Germany) pressure distribution measuring plate used by us is 320x470 mm and includes a total of 1504 capacitive sensors. The measuring frequency of static tests is 100 Hz. The tests were only performed with the eyes open and standing on two legs (Figure 2).

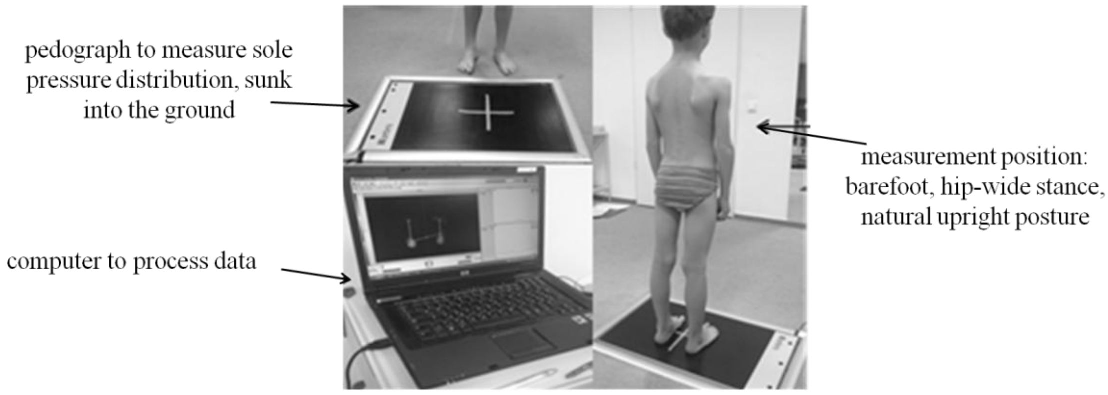

Figure 2.

Sole pressure distribution measurement

4. RESULTS

4.1. Study of the reliability of the Zebris ultrasound-based spine analysis method and of the repetition accuracy of measurements in case of children with correct posture and suffering from scoliosis, respectively

4.1.1. Children with correct posture

Based on the results of regression analyses, correlation is excellent both in case of *TK* (0.90-0.97) (Figure 3) and *LL* (0.96-0.99), which is also supported by slope values close to one (dorsal kyphosis: 0.83–1.11; lumbar lordosis: 0.89–1.06). In case of *LL*, significant differences were found between two tests by examiner A on day 1 (p= 0.01). Altogether this shows that ultrasound-based spine tests are reliable for determining dorsal kyphosis and lumbar lordosis angle values to describe the shape of the spine.

The repetition accuracy of the *TK* and *LL* parameters – calculated from the values measured by the same examiner and from the values measured by the two examiners – is excellent (*ICC*≥ 0.934). *SEM* values are also low (*SEM*≤ 1.743°), which again demonstrate the excellence of repetition accuracy.

The lowest repetition accuracy was found when determining the value of lateral inclination (*ICC*≥ 0.204, *SEM*≤ 0.655). In case of *TTI*, correlation was average (0.37–0.74), while it was weak in case of *LI* (0.005–0.66), which suggests that the maintenance of the children's centre of gravity in a constant position is inappropriate. The average and weak correlation found in the case of *TTI* and *LI* also appears in the slope values of regression lines (*TTI*: 0.52–0.99, *LI*: 0.004–0.69). On the basis thereof, *TTI* and *LI* values should always be contemplated critically; particular attention should be devoted to the inspection of taking up the correct posture.

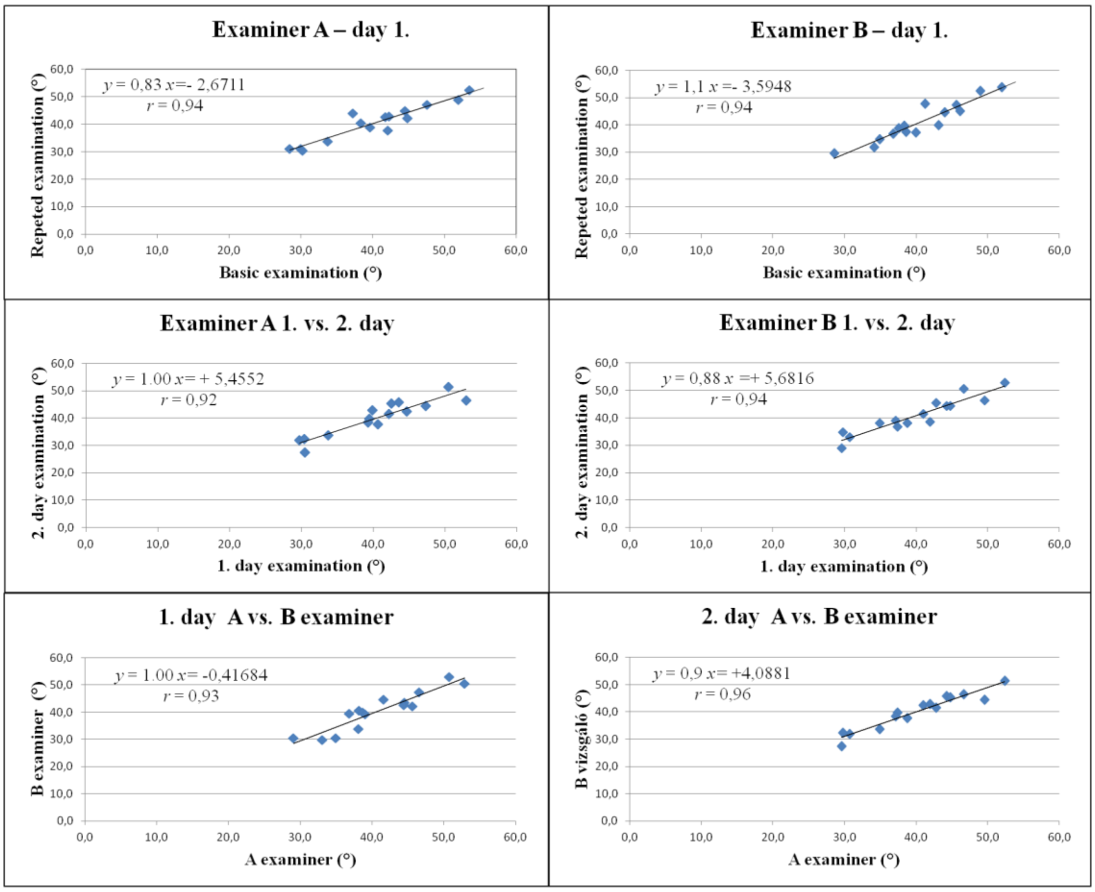

Figure 1.

Reliability analysis of the *TK* angle in case of children with correct posture (data pairs with regression lines and their characteristics)

4.1.2. Children suffering from scoliosis

The repetition accuracy of the *TK*, *LL*, *TTI* and *LI* parameters – calculated from the values measured by the same examiner and from the values measured by the two examiners – is excellent (*ICC*≥ 0.793). *SEM* values are also low (*SEM*≤ 3.865°), which again demonstrate the excellence of repetition accuracy. The lowest repetition accuracy was found when determining the value of lumbar lordosis (*ICC*≥ 0.793, *SEM*≤ 2.127°).

4.2. Validation of the Zebris ultrasound-based spine analysis method using spinal curvature values determined on standard X-ray images using the Cobb method

There were significant differences in the *TK* (-2.6°, p= 0.02) and *LSC* (3.2°, p= 0.02) parameters; at he same time, no significant differences were found in case of the parameters *LL* (2.5°, p= 0.16) and *TSC* (3.0°, p=0.05) parameters. The results of comparisons by the Bland–Altman method were analysed separately in the sagittal (*TK*, *LL*) and frontal (*TSC*, *LSC*) planes, respectively. In case of *TK*, the slope value of the regression line is 1.00 and the intercept value of the regression line is below 5°. The correlation between the *TK* values specified by the two methods is significant (p= 0.000) and excellent (r_{TK}= 0.95) (Figure 4). However, the intercept value of the regression line fitted to the *LL* parameter significantly differs from zero (1.27°, p= 0.002), its slope value is close to one (0.97, p= 0.000), and correlation is very good (r_{LL}= 0.76) (Figure 4).

The correlation between the *TSC* and *LSC* values specified by the two methods is significant (p= 0.000) and excellent (r_{TSC}= 0.85, r_{LSC}= 0.84), with a slope value below 1 (0.79 and 0.71); the intercept value of the regression line is below 5°.

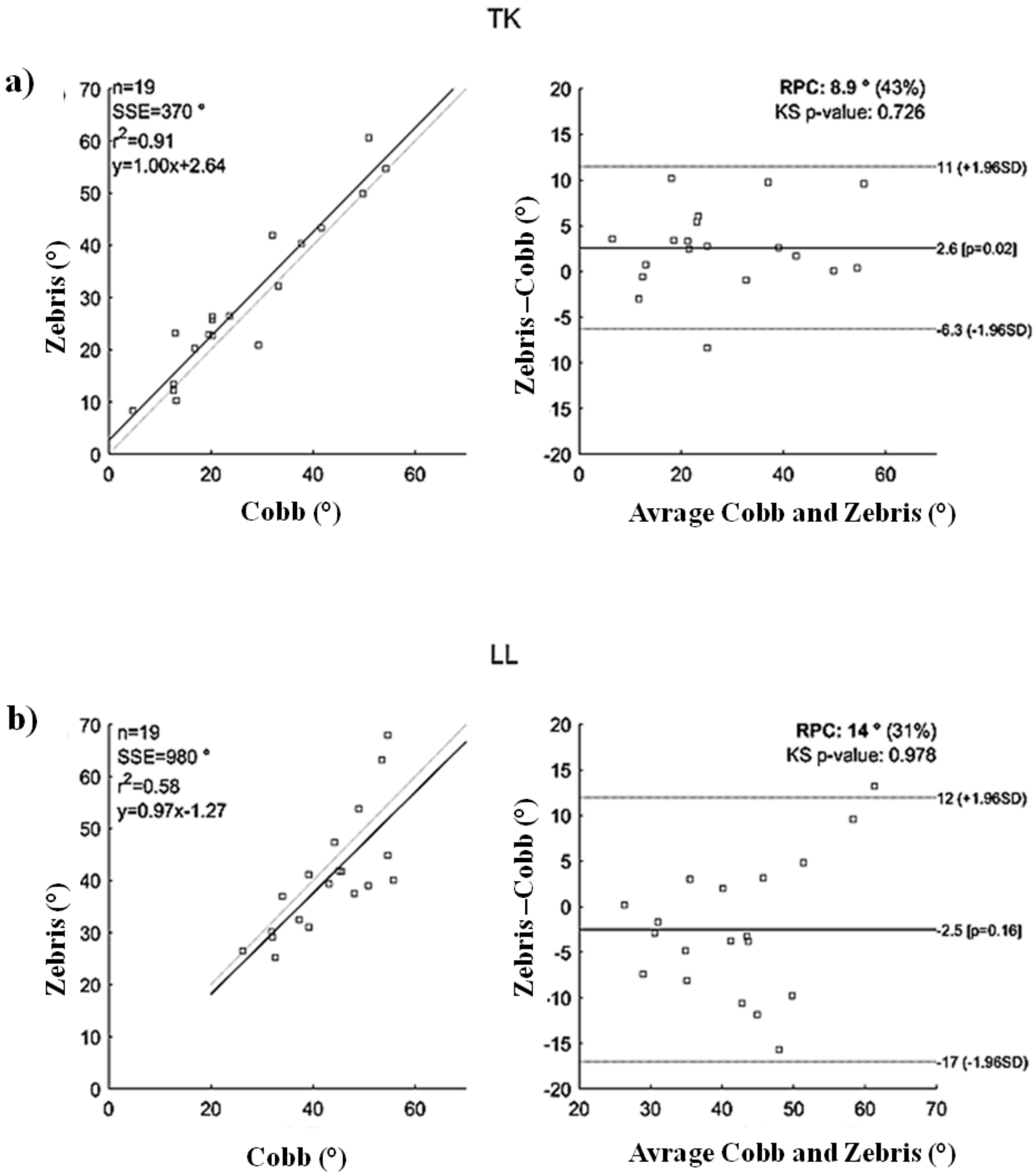

Figure 4.

Bland-Altman figure of spinal curvatures in the sagittal plane, determined by the two measurement methods

a) *TK*: thoracic kyphosis, b) *LL:* lumbar lordosis

4.3. Determination of the spinal curvature values of school-aged children in the sagittal plane using the Zebris ultrasound-based spine analysis method

4.3.1. Results of gender-based analysis

Independent of posture, age and height, it can be established by investigating the impact of genders that the average values of the four angles examined (*TK*, *LL*, *TTI* and *LI*) significantly differ in the case of boys and girls. On the basis thereof, boys and girls will be treated as separate groups subsequently.

4.3.2. Differences between the test results of the group with correct posture and with indolent posture, respectively

When examining the two groups, boys and girls were treated as separate groups, but still independent of age and height.

In case of *girls* with correct and indolent posture, there is a significant difference in *TK* ($F(1.563)= 4.794$, $p< 0.05$) and *LL* ($F(1.563)=5.50$, $p< 0.05$) values. In the group with indolent posture, the value of *TK* (41.188±0.566) is significantly higher than the average value of children with correct posture (39.58±0.469). In case of *LL*, the average of the group with correct posture (34.157±0.582) is significantly higher than the average of the group with indolent posture (32.017±0.703). In case of *TTI* ($F(1.563)= 0.022$, $p= 0.881$) and *LI* ($F(1.563)= 0.002$, $p= 0.964$) values, there is no significant difference between the two groups.

In case of *boys* with correct and indolent posture, very similar results to those of girls are yielded: there is a significant difference in *TK* ($F(1.356)= 6.773$, $p< 0.05$) and *LL* ($F(1.356)= 14.323$, $p< 0.05$) values. In the group with indolent posture, the value of *TK* (43.846±0.669) is significantly higher than the average value of the group with correct posture (41.479±0.616). For the *LL* angle, the average of the group with correct posture (30.084±0.847) is significantly higher than the average of the group with indolent posture (25.346±0.922). In case of *TTI* ($F(1.356)= 0.035$, $p= 0.853$) and *LI* ($F(1.356)= 0.454$, $p= 0.501$) values there is no significant difference.

4.3.3. Results of tests by age

In order to perform tests by age, 6 age groups were established from children between 6 and 15 years of age. The first group consisted of children aged 7 or lower, and the last group was made up of 12-year-olds and older; the ages in between were grouped per year.

In case of girls, the values of *TK* and *LI* angles were significantly influenced, while the values of *TTI* and *LL* angles were not significantly influenced by age in terms of both the group with correct posture and the group with indolent posture. In case of both correct and indolent posture, the values of *TK* and *LI* angles are significantly influenced by age: the values of *TK* angles are significantly reduced as age progresses, while the values of *LI* angles are significantly increased as age progresses. *TTI* angle values (correct posture: $p= 0.446$, indolent posture: $p= 0.284$) and *LL* angle values (correct posture: $p=0.290$, indolent posture: $p= 0.917$) are not significantly influenced by age.

In case of boys, the values of *TK* angles (correct posture: $p= 0.815$, indolent posture: $p=$ 0.678,) and the values of *LL* angles (correct posture: $p= 0.196$, indolent posture: $p=$ 0.114) are not significantly influenced by age. In the group of children with correct posture, the *TTI* and *LI* angles increase significantly as age progresses, while in the group of children with indolent posture, these two angle values are not significantly affected by age (*TTI:* $p= 0.065$, *LI:* $p= 0.978$).

4.3.4. Examination of height data by gender and diagnosis, regardless of age

In case of girls with correct posture, the value of the *TTI* angle ($F(7.327)= 0.971$, $p= 0.452$) is not significantly influenced by body height. The value of the *TK* angle shows a decreasing tendency as the height increases, but it is not significant ($F(7.327)= 1.949$, $p=0.061$). The values of *LL* ($F(7.327)= 2.857$, $p<0.05$) and *LI* ($F(7.327)= 2.128$, p<0.,05) angles significantly depend on body height. The *LL* angle values of children shorter than 130 cm significantly differ from the values of other height groups. *LI* angle values increase as the height increases; two homogeneous groups significantly differing from each other can be formed – the groups of children of up to 150 cm height and those taller than 150 cm height.

In case of boys with correct posture, tests contradict all the above. The value of the *TK* angle ($F(7.186)= 2.764$, $p< 0.05$) is significantly influenced by body height. The value of the *TK* angle significantly increases as the height increases, except for the group taller than 160 cm height, the values of which are significantly lower than the values of the other groups. The values of *LL* ($F(7.186)= 1.143$, $p= 0.338$) and *LI* ($F(7.186)= 1.867$, $p= 0.077$) are not affected significantly by body height. The values of *TTI* angles ($F(7.186)= 6.042$, $p<0.05$) increase as the height increases, but the change is not significant.

In case of girls with indolent posture, the values of *TK* angles decrease as the height increases, but the change is not significant – *TK* ($F(7.222)= 1.795$, $p= 0.089$). Differences in height groups as regards *LL* angles ($F(7.222)= 0.817$, $p= 0.574$) are not significant, either. The values of *LI* angles increase as the height increases, but the change is not significant – *LI* ($F(7.222)= 1.294$). The *TTI* angle ($F(7.222)= 2.091$, $p< 0.05$) is the only angle which is significantly influenced by body height in case of girls with indolent posture. The values of the *TTI* angle increase as the body height increases; significant differences can be observed in case of children lower than 135 cm and children taller than 160 cm.

4.4. The impact of indolent posture in childhood on stance stability

As regards the COP parameters of the groups with correct posture and with indolent posture, significant differences were found between the difference of load distribution between the two feet (*LDD*) ($p= 0.021$) and in the high and medium medio-lateral frequency performance proportion (*ML MHR*) ($p= 0.002$). There were no significant differences in case of the rest of the parameters ($p\geq 0.108$). It can be observed from the gender comparison that few parameters indicate a difference; however, the length of the COP track is significantly larger in the case of girls with indolent posture ($p= 0.041$).

5. CONCLUSIONS, UTILISATION OF THE RESEARCH WORK IN SPORTS SCIENCES

Based on the results and the assessment of the series of tests conducted, the following new scientific findings can be stated, by taking the objectives into consideration:

1. In case of children with correct posture and those suffering from scoliosis, the repetition accuracy of spinal curvature angles characterizing static posture as determined by the Zebris ultrasound-based spine analysis system is excellent. On the basis thereof, the method is reliable and can be used with appropriate accuracy for follow-up. The repetition accuracy of *TTI* and *LI* is lower, probably because children cannot yet minimize the displacement of their centre of gravity, therefore attention should be paid to maintaining the correct posture when conducting tests.
2. The Zebris ultrasound-based spine analysis method was validated on children suffering from AIS during static stance, by comparing sagittal and frontal spinal curvatures as determined by the Cobb method on two-way spinal X-ray images. Based on the results, the Zebris spine analysis method as a non-invasive method is suitable for assessing the efficiency of the therapy and for the follow-up of changes. This is supported by the small difference (≤3.5°) yielded in the course of comparisons with X-ray images as the gold standard method (in case of sagittal and frontal curvatures). Based on a less accurate determination of lumbar lordosis in the sagittal plane, it can be recommended that the Zebris spine analysis method should be used for the assessment of posture changes, rather than for the measurement of absolute degrees. The size of the thoracolumbar / lumbar curvature in the frontal plane is systematically underestimated, primarily due to the rotational and osteal deformities of vertebrae with scoliosis.
3. Indolent posture significantly influences the values of sagittal spinal curvatures (*TK* and *LL*). Normal ranges are expedient to be specified in a group breakdown

according to gender and body height, since the values of all four angles ((*TK*, *LL*, *TTI* és *LI*) are affected by both the children's gender and body height.

4. As a consequence of indolent posture, certain differences can already be observed in posture control; however, significant deviations are shown only by *LDD* and *ML-MHR* parameters. Based on the results, the spatial-temporal parameters characterizing stance stability do not deteriorate significantly. The impact of changed posture is continuously corrected by the central nervous system, which is indicated by a significant change in the frequency-based *ML MHR* parameter. As a consequence of an incorrect position, the asymmetric load between the two sides – also indicated by a significant difference of *LDD* – muscular balance is further impaired. The correction of indolent posture is an important task of physiotherapy, improving both posture and balance.

Studies of the reliability of the Zebris ultrasound-based spine analysis method and of the repetition accuracy of measurements in case of children with correct posture and suffering from scoliosis, respectively, have made it clear that this test method can be used reliably for determining spinal curvature values characterizing posture in childhood.

The use of the ultrasound-based device does not entail any radiological exposure, it does not have an oncogenic effect, therefore measurements can be repeated at discretionary intervals in case of children and sportsmen. This makes it possible to conduct status surveys by this non-invasive testing method even several times a year. It can help reveal conditions representing indications for therapeutical gymnastics and corrective gymnastic therapy. The effect of physical education, therapeutical gymnastics and corrective gymnastic therapy can be followed up on an on-going basis, and provides assistance in the development of customized exercises as well.

Even in the case of children with correct posture, the gender of the children examined significantly influences sagittal spinal curvature values (*TK*, *LL*). In case of girls with correct posture, the value of the *TK* angle shows a decreasing tendency as the height increases, but there are no significant differences in height groups in terms of *TK* and *TTI* angles. The values of *LL* angles significantly depend on body height – groups of up to 130 cm height and otherwise can be discerned. The values of *LI* angles also significantly depend on body height; here, height groups of shorter than 150 cm and taller than 150 cm can be formed, respectively. In case of boys with correct posture, the values of *TK* angles significantly increase as the height increases. There are no significant differences in height groups in case of the *LL*, *TTI* and *LI* angles. This highlights the fact that the aspects of physical education should be differentiated according to gender and height even in the case of healthy children with correct posture. Groups of physical education, therapeutical gymnastics and corrective gymnastic therapy should be formed on the basis of body height, rather than according to age, and in a breakdown by gender, if possible. Also in the case of children with indolent posture, the gender of the child examined significantly influences sagittal spinal curvature values (*TK* and *LL*) describing the shape of the spine as well as angle values characterizing posture (*TTI* and *LI*). Both genders show an increasing tendency of angle values characterizing posture (*TTI* and *LI*) as their height increases; however, these are not significant. A significant difference can be observed between the height groups of lower than 135 cm and higher than 160 cm only in the case of girls with indolent posture. In this case as well, gender and body height should be used for grouping as opposed to age. In case of indolent posture, the most sensitive angle values are those characterizing posture (*TTI* and *LI*), which indicate posture changes both for boys and girls in the analysis of the effect of therapeutical gymnastics and corrective gymnastic therapy. In order to check for the effect of conservative treatment, the 95% *CI* – specified by gender and body height as a result of our investigations – can be used and changes can be analysed.

Indolent posture also changes stance stability. Some parameters show significant changes. In case of children with indolent posture, it is also important and essential to improve balancing ability.

In summary, it can be stated that the results of regular non-invasive tests determining the shape of the spine and describing balancing ability can be properly used for the design and follow-up of customized therapeutical gymnastics and corrective gymnastic therapy. This is particularly important in the case of sportsmen.

6. LIST OF OWN PUBLICATIONS

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