Monitoring changes in the shape of the spine in children with postural disorders

Monitorowanie zmian kręgosłupa u dzieci z zaburzeniami postawy ciała

Arkadiusz Żurawski, Zbigniew Śliwiński, Grażyna Nowak-Starz, Wojciech Piotr Kiebzak

Jan Kochanowski University, Kielce, Poland

Abstract

Introduction: Due to numerous complications of an abnormal shape of the spine, it is extremely important to systematically monitor its shape. A precise and routine method of measurement enables comparison of the scores obtained over time and possible early intervention to avoid complications.

Aim of the research: To present the pattern for monitoring changes in the shape of the spine in children with postural deformities.

Material and methods: The study group consisted of patients with diagnosed shape of the spine deformity, who underwent a 4-month therapy, supervised by a physiotherapist. The control group comprised children with no shape of spine deformity. The children in the study group underwent a 3-dimensional computer analysis of the shape of the spine. The DIERS test was performed in both groups. In the study group it was performed 4 times. It involved the measurement of complete assessment of body posture.

Results: Statistically significant scores of the Friedman test for imbalance, pelvic tilt, kyphosis angle, lordosis angle, and lateral deviation were observed. Therefore, a series of post-hoc analyses were performed using Dunn-Bonferroni tests. It was observed that changes in individual parameters analysed in the authors’ study arise at different speeds.

Conclusions: Detailed monitoring of the parameters describing the position of the spine makes it possible to control the course of the treatment process of patients with disorders of the position of the spine. The dynamics of changes taking place within the spine position varies for the individual parameters analysed.

Key words: physiotherapy, posture defects, photogrammetry, monitoring the treatment process.

Słowa kluczowe: fizjoterapia, wady postawy, fotogrametria, monitorowanie procesu leczenia.
Introduction
Gradual change in the shape of the spine is an adaptation mechanism to the changing conditions and motor needs that accompany a person during their growth [1]. The shape of the spine is formed by many factors, both internal and external; it changes throughout life, under the influence of age and the type of performed work, but also the emotional state and physical fatigue [2, 3]. It should be emphasized that disorders in the shape of the spine often occur as a result of bad habits [4]. The aforementioned habits may result in the adoption of a non-physiological body posture in everyday activities, influencing the shaping and preserving an abnormal body shape [4], which consequently negatively affects many body systems [5–13]. Some of these disorders, despite apparent regression, reappear later in life, most often as weakening of manual skills and graphic functions, as well as disorders in the development of eye-hand coordination, visual analysis, and synthesis [14]. All these factors may lie behind psychosocial problems [15]. Due to numerous complications of an abnormal shape of the spine, it is extremely important to systematically monitor its shape. A precise and routine method of measurement enables the comparison of the scores obtained over time and possible early intervention to avoid the complications described above.

There are many ways to categorize the shape of the spine, ranging from visual assessment methods [16, 17], through the use of simple instruments [18–20], to complex computer systems [21–29]. The most frequently used method of visual assessment does not meet the criteria of objectivity and repeatability; therefore, it is worth implementing more effective methods of conducting tests in children [30]. X-ray radiation continues to play an important role in diagnostics because it enables the observation of morphological changes in the vertebrae, as well as calculation of the angle of spine curvature (according to Cobb [31]). Performing a radiological examination, however, is associated with the patient’s exposure to ionizing radiation and therefore cannot be performed as a preventive examination. With respect to preventive examination and systematic monitoring of treatment effects, it is better to use photogrammetric systems, which are non-invasive and do not require large financial outlays [32].

Aim of the research
The aim of the work is to present a pattern for monitoring changes in the shape of the spine in children with posture disorders.

Material and methods
Participants subjects
Children aged 8–12 years were assessed. The study group consisted of patients diagnosed with spine shape deformity. The children in the study group underwent a 4-month therapy conducted under the supervision of a physiotherapist. The control group consisted of children who did not have any posture defect in preventive medical examination or physiotherapeutic assessment. The research was carried out at the Clinical Rehabilitation Centre of the Świętokrzyskie Centre of Paediatrics, Poland.

The study group consisted of 211 children – 53% girls and 46.92% boys. The mean age in the study group was 10.72 years (SD = 1.44), body height 1.39 m (SD = 0.16), body weight 34.7 kg (SD = 11.84), and BMI 20.15 (SD = 2.35).

The control group consisted of 101 children – 50% girls and 50% boys. The mean age in the control group was 10.69 years (SD = 1.44), body height 1.39 m (SD = 0.13), body weight 38.69 (SD = 8.03), and BMI 20.02 (SD = 2.52).

Inclusion criteria
– Age 8–12 years,
– Diagnosed defect of shape of the spine (applies only to the study group),
– Good general health (≤ 2 according to the ECOG scale),
– A legal guardian’s consent to participate in the study.

Exclusion criteria
– Comorbidities that may affect the shape of the spine disorder,
– Interruption or non-compliance with the recommendations included in the therapeutic procedure (applies only to the study group),
– Body mass index (BMI) below the 10th and above the 90th percentile.

Participation in the research was voluntary, combined with ensuring anonymity. The legal guardians of the children participating in the study gave their informed consent.

Study project
The children in the study group were subjected to a 3-dimensional computer analysis of shape of the spine and a physiotherapeutic functional assessment. Based on the obtained results, a rehabilitation program was chosen, which assumed: 1) the child performing specific therapeutic activities at home twice a day under parental control, and 2) the use of a mirror to properly correct body posture. The examination was conducted and the choice of therapy was made by a physiotherapy specialist. The patients were rehabilitated according to 2 systems. A combination of proprioceptive neuromuscular facilitation (PNF) and Vojta’s techniques, with individual therapeutic sessions consisting of a combination of global patterns based on Vojta’s method (reflex creeping
and the first phase of reflex rolling), a combination of patterns for the limbs and the shoulder and pelvic girdles according to the PNF concept, and patient education regarding the need to assume an optimal body posture for the rehabilitation process. The study protocol assumed 4 appointments at 4-week intervals. During each appointment, the analysed parameters were measured and a functional test was performed. Based on these, the therapy was chosen. The parents were thoroughly trained by the physiotherapist in the recommended techniques, which they would then perform with the children until the subsequent appointment.

In the control group, the measurement of the analysed parameters and the functional test were performed once.

The study was approved by the Bioethics Committee at the Faculty of Medicine and Health Sciences, the Jan Kochanowski University in Kielce (Approval No. 1/2016, issued 15.01.2016). All methods were performed in accordance with the relevant guidelines and regulations.

**Body posture assessment**

The shape of the spine was assessed in static conditions in a standing habitual position, with the back to the camera, with eyes directed straight ahead. The DIERS Formetric 4D system was used to assess the posture. The system enables precise assessment of the shape of the spine [29]. The DIERS test was performed in both groups (study and control). In the study group it was performed 4 times (before the first and after the second, third, and fourth therapeutic sessions). It involved the measurement of 7 parameters enabling a complete assessment of body posture [33].

**Parameters assessed**

1. Trunk imbalance VP-DM [mm] – shows the deviation of the VP (spinoous process of the 7th cervical vertebra) from the DM (the midline connecting the right and left dimples of Venus).
2. VP-DM [mm] lateral deviation – means the maximum deviation of the spine midline from the VP-DM line in the frontal plane (value at the top of the curve).
3. Pelvic tilt [mm] – means the difference in the height of lumbar dimples in relation to the horizontal plane (cross-section).
4. Pelvic torsion [°] – calculated from the mutual torsion of the planes at the points of lumbar dimples (vertical component).
5. Surface rotation [°] – maximum trunk rotation on the symmetry line.
6. Kyphosis angle [°] – the angle measured between VP and the estimated position of Th12.
7. Lordosis angle [°] – the angle measured between the estimated position of Th12 and DM.

**Intervention**

In the rehabilitation program for children from the study group, global patterns chosen on the basis of functional and computer testing were used, based on 2 recognized therapeutic methods. The planned therapeutic program was realised by the treated children under their parents’ supervision. The therapeutic session was about 20 min long and was based on elements of the PNF and Vojta methods [34–36].

**Ethical approval and consent to participate**

The study was approved by the Bioethics Committee at the Faculty of Medicine and Health Sciences, the Jan Kochanowski University in Kielce (Approval No. 1/2016, issued 15.01.2016). All methods were performed in accordance with the relevant guidelines and regulations. Participation in the research was voluntary, combined with ensured anonymity. The legal guardians of the children participating in the study gave their informed consent.

**Statistical analysis**

Statistical analyses were performed with IBM SPSS Statistics 23 package. The basic descriptive statistics were analysed: the mean, the median, standard deviation, skewness, kurtosis, and the smallest and the largest distribution value. The sample size necessary to draw conclusions about the entire population was estimated [37], based on available epidemiological studies [38]. To assess normality of the distribution of variables, the non-parametric Kolmogorov-Smirnov test was used [39]. Percentage differences between the measurements were calculated. To assess the significance of differences between the parameters in the study and control groups, the Mann-Whitney U test was used due to the fact that most of the analysed variables adopted non-normal distribution [40]. The analysis of changes occurring between consecutive measurements in the study group was conducted using the Friedman test [41]. This test was used because it allows us to determine the differences between the 4 measurements simultaneously. Statistically significant scores of the Friedman test underwent post-hoc tests using the Dunn-Bonferroni test to counteract the problem of multiple comparisons, consisting of reducing the nominal significance level of each set of related tests [42].

**Results**

Basic descriptive statistics of tested quantitative variables were calculated together with the Kol-
Monitoring changes in the shape of the spine in children with postural disorders

To check the normality of the distribution of these variables, the analyses were performed separately for the study group and the control group. Most measurements adopted distributions different from the normal distribution. Hence, to maintain the consistency of the scores, in this work, statistical analyses were performed using non-parametric tests.

The minimum value/number necessary to infer about the entire population of children aged 8–12 years with spinal posture defect in Poland is 296; therefore, the study population of 312 meets the assumed criteria.

Table 1. Comparison of the study and control groups in terms of the level of body posture rates

| Parameter                  | Measurement | Study group (n = 211) | Control group (n = 101) | U    | Z     | P-value | r     |
|----------------------------|-------------|-----------------------|-------------------------|------|-------|---------|-------|
|                            | M   | SD   | M   | SD   |      |       |        |       |
| Trunk imbalance [mm]       | I   | 9.09 | 6.09 | -0.39 | 4.83 | 2053.5 | -11.550 | < 0.001 | 0.65 |
|                            | IV  | 4.24 | 4.13 | -0.39 | 4.83 | 4645.0 | -8.094  | < 0.001 | 0.46 |
| Pelvic tilt [mm]           | I   | 3.55 | 3.45 | 0.21  | 3.54 | 5059.0 | -7.747  | < 0.001 | 0.44 |
|                            | IV  | 2.80 | 2.74 | 0.21  | 3.54 | 5708.0 | -6.893  | < 0.001 | 0.39 |
| Pelvic torsion [°]         | I   | 2.51 | 1.84 | 0.70  | 2.54 | 5749.5 | -5.601  | < 0.001 | 0.37 |
|                            | IV  | 2.17 | 1.65 | 0.70  | 2.54 | 6479.5 | -8.094  | < 0.001 | 0.39 |
| Kyphosis angle [°]         | I   | 41.37| 9.60 | 39.45 | 8.28 | 9695.0 | -1.288 | 0.198  | 0.07 |
|                            | IV  | 38.92| 8.28 | 39.45 | 8.28 | 10135.0| -0.698 | 0.485  | 0.04 |
| Lordosis angle [°]         | I   | 37.05| 9.55 | 38.33 | 8.59 | 9593.0 | -1.425 | 0.154  | 0.08 |
|                            | IV  | 38.10| 8.13 | 38.33 | 8.59 | 10352.5| -0.406 | 0.684  | 0.02 |
| Surface rotation [°]       | I   | 4.56 | 2.18 | 3.66  | 1.99 | 7776.0 | -3.862 | < 0.001 | 0.22 |
|                            | IV  | 4.10 | 2.10 | 3.66  | 1.99 | 9265.0 | -1.865 | 0.062  | 0.11 |
| Lateral deviation [mm]     | I   | 4.51 | 2.91 | 2.10  | 0.71 | 3857.5 | -9.118 | < 0.001 | 0.52 |
|                            | IV  | 3.97 | 2.58 | 2.10  | 0.71 | 5100.5 | -7.451 | < 0.001 | 0.42 |

M – mean, SD – standard deviation, U – Mann-Whitney U test score, Z – standardised value, p – statistical significance, r – effect size.
was close to statistical significance for surface rotation index. However, such a score did not enable a post-hoc analysis. No statistically significant score for pelvic torsion was achieved. Detailed data are presented in Table 2.

### Discussion

The applied DIERS measurement system enables detection of even small changes in tested parameters describing the position of the spine in space. The analysis of the scores shows that the computer system makes it possible to observe differences of a few millimetres or degrees in size. Their clinical value may be of varying importance in long-term observation. Thus, regular monitoring of specific parameters in objective manner enables precise comparison of the criteria of the dysfunction image at each stage of its treatment. This is especially important due to the risk of progression of a dysfunction, which is a phenomenon considered typical in children with shape of spine disorders [3, 43].

In our study of the treatment process, a change in most parameters was recorded: trunk imbalance was reduced by 4.85 mm (53%), pelvic tilt by 0.75 mm (21%), and thoracic kyphosis angle by 2.45° (6%), which reached a physiological value, just like the lordosis angle, which increased by 1.05° (3%). The rotation angle decreased by 0.46° (10%), and im-

### Table 2. Changes in the level of body posture rates during the therapy. Dunn-Bonferroni Test

| Parameter                  | Measurement | M       | SD       | Statistic       |
|----------------------------|-------------|---------|----------|-----------------|
| **Trunk imbalance [mm]**   | 1           | 9.09^a  | 6.09     |                 |
|                            | 2           | 7.61^b  | 5.99     | $\chi^2(3) = 127.82$ |
|                            | 3           | 6.48^c  | 5.11     | $p < 0.001$     |
|                            | 4           | 4.24^d  | 4.13     |                 |
| **Pelvic tilt [mm]**       | 1           | 3.55^a  | 3.45     |                 |
|                            | 2           | 3.59^a  | 3.43     | $\chi^2(3) = 12.79$ |
|                            | 3           | 3.31^a  | 3.45     | $p = 0.005$     |
|                            | 4           | 2.80^b  | 2.74     |                 |
| **Pelvic torsion [°]**     | 1           | 2.51    | 1.84     |                 |
|                            | 2           | 2.40    | 1.72     | $\chi^2(3) = 4.63$ |
|                            | 3           | 2.36    | 1.71     | $p = 0.201$     |
|                            | 4           | 2.17    | 1.65     |                 |
| **Kyphosis angle [°]**     | 1           | 41.37^a | 9.60     |                 |
|                            | 2           | 40.12^a | 9.63     | $\chi^2(3) = 17.34$ |
|                            | 3           | 40.42^a | 9.46     | $p = 0.001$     |
|                            | 4           | 38.92^a | 8.28     |                 |
| **Lordosis angle [°]**     | 1           | 37.05^a | 9.55     |                 |
|                            | 2           | 37.97^a | 9.35     | $\chi^2(3) = 18.34$ |
|                            | 3           | 38.28^a | 9.61     | $p < 0.001$     |
|                            | 4           | 38.10^a | 8.13     |                 |
| **Surface rotation [°]**   | 1           | 4.56    | 2.18     |                 |
|                            | 2           | 4.41    | 2.40     | $\chi^2(3) = 7.81$ |
|                            | 3           | 4.60    | 2.44     | $p = 0.050$     |
|                            | 4           | 4.10    | 2.10     |                 |
| **Lateral deviation [mm]** | 1           | 4.51^a  | 2.91     |                 |
|                            | 2           | 4.48^a  | 2.77     | $\chi^2(3) = 15.38$ |
|                            | 3           | 4.76^a  | 3.03     | $p = 0.002$     |
|                            | 4           | 3.97^a  | 2.58     |                 |
balance was reduced by 1.54 mm (12%). Pelvic torsion was the only parameter describing body posture that did not change significantly in our study - reduction by 0.36° (14%) p = 0.201 (Table 1).

The shape of spine correction effect is also described by other researchers. Lee, who used the PNF technique, achieved a considerable reduction in the frontal curvature within 3 weeks [44]. Weiss, using the combination of PNF and Schrot techniques with postural re-education, described the reduction of abnormal curvature in the frontal plane and considerable improvement in thoracic kyphosis angle and spine rotation [43]. Reduction of lateral deviation, thoracic kyphosis angle, lumbar lordosis angle, rotation angle, and trunk imbalance after 4 weeks of rehabilitation was shown [45]. Misik et al. points out that the application of PNF-based therapy 3 times a week results in a significant reduction in pelvic tilt after 6 weeks [46]. Stepien et al. using the PNF technique, described positive effects of her actions in the area of lumbar lordosis angle, spine rotation, and pelvic torsion after 6 months of treatment [34]. Steffan, combining the methods of Vojta and Schrot, also indicates the reduction of spine abnormal shape parameters [47]. In the authors’ observations, an important advantage of the methods described is that they are easy to learn and perform in home conditions.

It should be emphasized that changes in individual parameters analysed in our study appear at a different pace. It was found that parameters such as trunk imbalance and pelvic torsion improved systematically with each appointment. For pelvic tilt, improvement was not observed until the third examination. Kyphosis angle, surface rotation, and lateral deviation make an interesting group of described parameters, where, during examination 2, visible improvement was observed, and during examination 3 – deterioration against the second, and examination 4 had the best result of all the measurements. Another observation implies that lordosis angle, which improved in examinations 2 and 3, slightly deteriorated in 4 compared to 3 (Table 2).

The fact that the authors describe the effects of therapy after the treatment cycle had finished, without analysing them during its course, should be critically assessed. The lack of publications describing changes in the parameters of the spine position during treatment does not allow us to compare our observations with the results of other authors. During the examination, special attention should be drawn to the spinal curvature in the sagittal plane, i.e. kyphosis angle and lordosis angle, because, as our observations show [45, 48, 49] and other authors report, it is these parameters that imply a change in the shape of the spine in the other 2 planes [50–52].

The abovementioned irregular changes in the spine position parameters during long-term rehabilitation may be the consequence of various factors that can disturb the observation process. Natural changes in the spine during the growth period may affect the pace of shaping its curves [1, 3]. Adopting a specific body position in everyday activities also influences the shaping and preserving of the figure [3, 53]. In view of negative changes, sedentary lifestyle, which contributes to the loss of lumbar lordosis, is particularly unfavourable in the treatment of scoliosis [3]. Reducing physical activity and frequently exceeding of the body’s energy demand is also indicated as the cause of the deterioration of body posture among children and adolescents [3, 54].

Considering the variability of effects achieved in the treatment process and, as described in the literature, a number of factors influencing the rehabilitation process of patients with shape of spine disorders, the authors recognize the need for continuous and objective monitoring of the achieved effects. Reliable assessment of the effects of therapy needs suitable tools, especially because most physiotherapists examine the patient only subjectively [54]. Raster stereography is one such suitable tool. Due to the lack of radiation emission, it is a sensitive and safe tool for monitoring therapeutic effects [45, 55]. The versatility and fidelity of the 3-dimensional model generated by the DIERS system enables reliable information to be obtained about the patient’s morphology throughout the treatment process [45], enabling a precise match of therapeutic activities to existing dysfunction. It is very important to be able to notice even discrete disturbances in the development of the antigravity system, perform qualitative analysis of postural and motor compensation patterns, and predict their consequences [56, 57]. Our observations suggest that systematic and objective monitoring of the treatment process is a condition for an effective and personalized treatment process.

Limitations: The presented study did not include variables describing physical activity or the quality of nutrition of the subjects during the rehabilitation process, which should be considered in further analyses.

Clinical implications: Ongoing assessment of changes in the parameters describing the position of the spine in space allows careful monitoring of the course of the treatment process and enables quick correction of conducted activities, which can significantly improve the effectiveness of the entire therapeutic process. Systematic assessment should include changes occurring in all planes, because, as this study has shown, individual parameters change at different paces. A reliable evaluation process allows the results of the implemented measures to be forecast and a long-term study on the improvement of therapeutic protocols to be conducted.

Conclusions

Detailed monitoring of parameters describing the position of the spine makes it possible to control
the course of the treatment process in patients with spine position disorders. Photogrammetric systems are very sensitive in detecting changes, so they are a good tool for ongoing monitoring of the treatment process of patients with spine alignment disorders. The dynamics of changes happening within the spine alignment is different for the individual parameters analysed.

Acknowledgments

Project financed under the program of the Minister of Science and Higher Education called “Regional Initiative of Excellence” in the years 2019-2022, project no. 024/RID/2018/19, amount of financing 11,999,000.00 PLN. The funding included translation costs and a publication fee. The authors were not paid for the preparation of the manuscript. The founder had no influence on the data collection or the content of the manuscript.

We would like to thank the patients for their contributions to our study, without whom it would have been impossible.

Conflict of interest

The authors declare no conflict of interest.

References

1. Pizzigalli L, Cremasco MM, Cremona E. Human postural adaptation to earthy and atypical gravitational environment effects of sport training on stablimetric parameters. Adv Anthropol 2013; 3: 229-236.
2. Biernat M, Baks-Sosnowska M. The impact of body posture on self-image and psychosocial functioning during adolescence. Paediatr Family Med 2018; 14: 282-285.
3. Kowalski IM, Protasiewicz-Faldowska H, Joziwicki-Grabyńska D, Kiebzak W, Zarzycyki D, Lewandowski R, Szarek J. Environmental factors predisposing to pain syndromes among adolescent girls with diagnosed idiopathic scoliosis. J Elementol 2010; 15: 517-530.
4. Górecki A, Kiewski J, Kowalski J, Marczyński W, Nowotny J, Rybicka M. Prophylactics of postural deformities in children and youth carried out within the teaching environment – experts recommendations. Pol Ann Med 2009; 16: 168-177.
5. Dyck M, Piek J. How to distinguish normal from disordered children with poor language or motor skills. Int J Lang Commun Disord 2010; 45: 336-344.
6. Zwicker JG, Missiuna C, Boyd LA. Neural correlates of developmental coordination disorder: a review of hypotheses. J Child Neurol 2009; 24: 1273-1281.
7. Dainese R, Serra J, Azpiroz F, Malagelada J. Influence of body posture on intestinal transit of gas. Gut 2003; 52: 971-974.
8. Peeters G, Burton NW, Brown WJ. Associations between sitting time and range of symptoms in mid-age women. Prev Med (Baltim) 2013; 56: 56-66.
9. Simao SSS, Romero CV, Baraldi K, Oda AL, Viana CF, de Magaiaes Leal Chiappetta AL, Pieri A. Clinical evaluation of the relationship of posture, breathing and swallowing in chronic-state post-stroke patients: case report. Rev CEFAC 2013; 15: 1371-1378.
10. Lin F, Parthasarathy S, Taylor SJ,ucci D, Hendrux RW, Makhsoous M. Effect of different sitting positions on lung capacity, expiratory flow, and lumar lordosis. Arch Phys Med Rehabil 2006; 87: 504-509.
11. Landers M, Barker G, Wallentine S, McWhorter JW, Peel C. A comparison of tidal volume, breathing frequency, and minute ventilation between two sitting positions in healthy adults. Physiother Theory Pract 2003; 19: 109-119.
12. Dunsiri S, Smyser C, Liao S, Inder T, Pineda R. Defining the nature and implications of head turn preference in the preterm infant. Early Hum Dev 2016; 96: 53-60.
13. Dey A, Barnsley N, Mohan R, McCormick M, McAuley JH, Moseley GL. Are children who play a sport or a musical instrument better at motor imagery than children who do not? Br J Sports Med 2012; 46: 923-926.
14. Esch T, Stefano GB. Endogenous reward mechanisms and their importance in stress reduction, exercise and the brain. Arch Med Sci 2010; 6: 447-455.
15. Punt M, Jong MDE, de Groot E, Hadders-Algra M. Minor neurological dysfunction in children with dyslexia. Dev Med Child Neurol 2010; 52: 1127-32.
16. Mrozkowiak M, Szark-Eckardt M, Żukowska H, Zukiow W. Prevention of flat feet in preschool children. J Health Sci 2012; 2: 25-40.
17. Kotwicki T, Chowańska J, Kinel E, Czaprowski D, Tomaszewski M, Janusz I. Optimal management of idiopathic scoliosis in adolescence. Adolesc Health Med Ther 2013; 4: 59-73.
18. Grivas TB, Vasiliosis ES, Polyzoios ED, Mouzakis V. Trunk asymmetry and handedness in 8245 school children. Pediatr Rehabil 2006; 9: 259-266.
19. Stolinski L, Kotwicki T. Trunk asymmetry in one thousand school children aged 7-10 years. Stud Health Technol Inform 2012; 176: 259-263.
20. Sule M, Wendt M, Przydeńek J, Bartkowiak P, Waszak M, Cieślak K, Lewandowski J. Evaluation of the effects of musculoskeletal therapy on the degree values for physiological spine curvatures, altered due to long-term kick-boxing training. Archives of Budo 2015; 11: 209-215.
21. Piriyaprasarth P, Morris ME, Winter A, Białorckowski AE. The reliability of knee joint position testing using electrogoniometry. BMC Musculoskelet Disord 2008; 9: 6.
22. Skomudek A, Szczegielniak J, Skomudek W. The possibiliy of using thermal imaging in the diagnosis of the rehabilitation process after cardiology by-pass surgery. Acta Biooptica et Informatica Medica 2013; 19: 32-39.
23. Kowalski IM, Protasiewicz-Faldowska H, Dwornik M, Pierożyński B, Raistenskis J, Kiebzak W. Objective parallel-forms reliability assessment of 3 dimension real time body posture screening tests. BMC Pediatr 2014; 14: 221.
24. Saltikov JA, van Schaik P, Bell JA, Warren JG, Wojcik AS, Papastefanou SL. 3D back shape in normal young adults. Stud Health Technol Inform 2004; 88: 81-85.
25. Mardjetko S, Knott P, Rollet M, Baute S, Riemenschneider M, Waszak M, Muncie L. Evaluating the reproducibility of the formetric 4D measurements for scoliosis. Eur Spine J 2010; 19: 241-242.
26. Chowańska J, Kotwicki T, Rosadziński K, Śliwiński Z. School screening for scoliosis: can surface topography replace examination with scoliometer? Scoliois 2012; 7: 9.
Monitoring changes in the shape of the spine in children with postural disorders

28. Rosa K, Muszkieta R, Zukow K, Napierala M, Cieślicka M. The incidence of defects posture in children from classes I to III Elementary School. J Health Sci 2013; 3: 107-136.

29. Massimiliano M, Raimondi P, Paoloni M, Pellana S, Di Michele A, Di Renzo S, Vanadia M, Dimaggio M, Murgia M, Sarilli V. Vertebral rotation in adolescent idiopathic scoliosis calculated by radiograph and back surface analysis-based methods: correlation between the Raimondi method and rasterstereography. European Spine J 2013; 22: 367-371.

30. Weiss HR, Werkmann M: Treatment of chronic low back pain in patients with spinal deformities using a sagittal re-alignment brace. Scoliosis 2009; 4: 7-10.

31. Śliwiński Z, Kufel W, Halat B, Michalak B, Śliwińska D, Śliwiński G. Radiological progress report of curing scoliosis according to the fed method based on own material. Scoliosis 2014; 9: 14.

32. Lee BK. Influence of the proprioceptive neuromuscular facilitation exercise programs on idiopathic scoliosis patient in the early 20s in terms of curves and balancing abilities: single case study. J Exercise Rehabil 2016; 12: 567-574.

33. Wilczyński J. A body posture in the sagittal plane measured among girls aged 12 to 15 from the świetokrzyskie province. Studia Medyczne 2009; 13: 37-39.

34. Stepień A, Fabian K, Graff K, Podgurniak M, Wit A. An immediate effect of PNF specific mobilization on the angle of trunk rotation and the Trunk-Pelvis-Hip Angle range of motion in adolescent girls with double idiopathic scoliosis – a pilot study. Scoliosis and Spinal Disorders 2017; 12: 29.

35. Adler S, Beckers D, Buck M. PNF in Practice. Springer, Chicago 2014.

36. Kinel E, Gajewska E, Surowinska J, Lisinski P. Proposition of functional examination according vojta’s concept in children with scoliosis. Scoliosis 2014; 9: O17.

37. Charan, J, Biswas T. How to calculate sample size for different study designs in medical research? Indian J Psychol Med 2013; 35: 121-126.

38. Maciałczyk-Paprocka K, Dudzińska J, Stawińska-Witoszyńska B, Krzyżanik A. Incidence of scoliotic posture in school screening of urban children and adolescents: the case of Poznań, Poland. Anthropropol Rev 2018; 81: 341-350.

39. Razali NM, Wah YB. Power comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors and Anderson-Darling tests. J Statistical Modeling Analytics 2011; 2: 21-33.

40. Winter J, Dodu D. Five-Point Likert Items: t test versus Mann-Whitney-Wilcoxon. Practical Assessment Research Evaluation 2012; 15: 11.

41. Benavoli A, Corani G, Mangili F. Should we really use post-hoc tests based on mean-ranks? J Machine Learning Res 2016; 17: 1-10.

42. Dunn OJ. Estimation of the medians for dependent variables. Ann Mathem Stat 2017, 30: 192-197.

43. Weiss HR, Klein R. Improving excellence in scoliosis rehabilitation: a controlled study of matched pairs. Pediatr Rehabil 2006; 9: 190-200.

44. Lee BK. Influence of the proprioceptive neuromuscular facilitation exercise programs on idiopathic scoliosis patient in the early 20s in terms of curves and balancing abilities: single case study. J Exerc Rehabil 2016; 12: 567-574.

45. Zmyslińska A, Kiebzak W, Żurawska A, Pogorzełska J, Koteła I, Kowalski TJ, Śliwiński Z, Śliwiński G. Effect of physiotherapy on spinal alignment in children with postural defects. Int J Occup Med Environ Health 2019; 32: 25-32.

46. Misuk C, Wontae G. The effects of dynamic exercise using the proprioceptive neuromuscular facilitation pattern on posture in healthy adults. J Phys Ther Sci 2017; 29: 1070-1073.

47. Steffan K. Physical therapy for idiopathic scoliosis. Ortophade 2015; 44: 852-8.

48. Kiebzak W, Dwornik M, Żurawska J, Żurawski A. sEMG assessment of the activity of the rectus abdominis and multifidus muscles in different sitting postures. FP 2017; 17: 52-62.

49. Weiss HR, Werkmann M. Unspecific chronic low back pain – a simple functional classification tested in a case series of patients with spinal deformities. Scoliosis 2009; 4: 4-10.

50. Nakano H, Kihara H, Nakano J, Konishi Y. The influence of positioning on spontaneous movements of preterm infants. J Phys Ther Sci 2010; 22: 337-344.

51. Franojne MR, Darr N, Held SL, Kott K, Young BL. The performance of children developing typically on the pediatric balance scale. Pediatr Phys Ther 2010; 22: 350-359.

52. Górecki A, Kwierski J, Kowalski J, Marczyński W, Nowotny J, Rybicka M. Prophylactics of postural deformities in children and youth carried out within the teaching environment – experts recommendations. Pol Ann Med 2009; 16: 168-177.

53. Van Loon PJ, Kühbauch BA, Thunnissen FB. Forced lordosis on the thoracolumbar junction can correct coronal plane deformity in adolescents with double major curve pattern idiopathic scoliosis. Spine 2008; 33: 797-801.

54. Perriman DM, Scarvell JM, Hughes AR, Lueck CJ, Dear KB, Smith PN. Thoracic hyperkyphosis: a survey of Australian physiotherapists. IJPR 2012; 17: 167-178.

55. Koch S, Arnold S, Zeckay R, Śliwiński G, Thiele C, Kufel W, Śliwiński Z, Malberg H. Analysis of the distribution of pressure patterns in children with postural deformities. Biomed Engineering 2012; 57: 1082-1085.

56. Wilczyński J, Bieniek K, Margiel K, Sobolewski PK, Wilczyński J, Zieleński R. Correlations between variables of posture and postural stability in children. Medical Studies 2022; 38: 6-13.

57. Kowalski IM, Protasiewicz-Faldowska H, Jozwiak-Grabyśa D, Kiebzak W, Zarzycki D, Lewandowski R, Szarek J. Environmental factors predisposing to pain syndromes among adolescent girls with diagnosed idiopathic scoliosis. J Elementol 2010; 15: 517-530.

Address for correspondence:
Dr Arkadiusz Żurawski
Jan Kochanowski University
Kielce, Poland.
Phone: +48 787339222
E-mail: azurawski@onet.eu