

Kiebzak Wojciech Piotr. Positioning of the sternum and the sacrum in relation to spine curvatures as a way of assessment of body posture while sitting. Kielce: the Jan Kochanowski University Publishing Company; 2018.

4.1. Title of scientific achievement / SUMMARY OF PROFESSIONAL ACCOMPLISHMENTS

4.1.1. Introduction and scientific aim

Good health is one of the most precious human values and it determines the quality of life (Wnuk et al., 2013; Siwek-Jankiewicz & Bartosińska, 2011). Observation of social behaviour in public and private places raises the question whether the correct body posture could be the element which positively affects our well-being? Therefore, the problem is the ergonomic use of the musculoskeletal system while performing daily activities: walking, standing, and, especially, adopting a long-lasting sitting position. For centuries, proper, avoiding bending, upright posture has been a cultural sign of care for how others perceive us. It was not only an indicator of bodily discipline, but it even built an individual image of a person, also contributing to a positive image of one's own person (Gilman, 2014). A "good" or "natural" posture, in relation to the vertical line, distinguished "advanced" people from "primitive" ones and healthy people from the sick. English aristocracy, adopting an impeccable posture, promoted in this way the distinction from the loaded with work, ailing population, stooped, exploited people of the period of the industrial revolution. Thus, the adopted form of the body position, body posture can become an individual image of a person, an indicator of bodily discipline and a modern form of a perfect citizen (Gilman, 2014).

The correct way of sitting is recommended, i.a. for the following reasons: the improvement of the respiratory system function (Landers et al., 2003; Lin et al., 2006; Park & Han, 2015) even compression load on the fibrous ring and maintaining the cushioning properties of the spine (D.E. Harrison et al., 1999a; Scannell & McGill, 2003; Czaprowski et al., 2014), reducing pain in the heart area (Kiebzak et al. 2010; Peeters et al., 2013) and creating positive thoughts improving the quality of life (Wilson & Peper, 2004). However, it should be emphasized that maintaining the said sitting position requires regular education based on verbal and/or manual stimulation and feedback (Claus et al., 2009; Green & Bavelier, 2008; Czaprowski et al., 2014). Awareness of the above information can be socially important because contemporary cultural changes encourage nonchalant behaviour, including the adoption of an incorrect position–body posture. They are especially pronounced as the dominant of forms of adopted body postures when sitting incorrectly.

In Polish terminology, do not exist terms similar to unambiguous terms derived from the English language such as *sagittal alignment* for spinal and pelvic positioning in the sagittal plane, *upright body position*, or the German *aufrechte Körperhaltung*, defining an active, corrected body posture. Likewise, there is no equivalent to the commonly known universal English term *slump position*, which defines a free, passive, incorrect posture. For the purpose of this work and as a contribution to general discussion, the concept of **body posture** was introduced as the determination of the mutual position of the body parts, i.e. chest, pelvis and spine while performing any activities, including while adopting a sitting position. Special interest should be aroused by a posture in a sitting corrected position as an optimum, physiological posture.

Reflections on "sedentary lifestyle" and the quality of adopting various forms of sitting, raise two basic questions:

1) is there an ideal—the most appropriate form of the posture while sitting (Claus et al., 2009; K. O’Sullivan et al., 2010; K. O’Sullivan et al., 2012; Czaprowski et al., 2014) and

2) is it beneficial to maintain the correct curvatures of the spine when maintaining the correct posture while sitting? (Claus et al., 2009).

The answer to these questions can be found in the comparison of the three forms of sitting posture (Caneiro et al., 2010). Of the three postures mentioned below, i.e. free with full bend of the spine, expressively upright, or neutral, i.e. adjusted to the natural spine shape, beneficial, maintained without excessive muscle tone, it is recommended to adopt the latter one more frequently (Czaprowski et al., 2014; D.E.Harrison et al., 1999a; Claus et al., 2009; K. O’Sullivan, P. O’Sullivan et al., 2012; K. O’Sullivan et al., 2010; K. O’Sullivan, McCarthy et al., 2012; D.D. Harrison et al., 1999; Panjabi, 1992; Dankaerts et al., 2006).

Sedentary lifestyle is a form of human behaviour with energy expenditure ≤ 1.5 of metabolic equivalent when taking a semi-recumbent or recumbent position and a sitting position (Tremblay et al., 2017). Spending time in a sitting position has increased significantly in recent years. The highest values of the median of spending time in a sitting position, i.e. 600 minutes, were recorded in Norway, Japan, Hong Kong and Taiwan (Bauman et al., 2011). The author’s own observations of about 1,300 children in grades 1-2 primary school showed that the time spent in a sitting position fluctuates between 7 and 10 hours a day. These behaviours are becoming common, they are marked by adoption of a stooped posture, in which there is so-called passive "suspension on the spine. The reasons for this condition may be the consequence of many factors, including diseases, but the most common mechanism is sensorimotor disorders, changes in kinesthetic and proprioceptive perceptions (Solomonow, 2004) and loss of automatic postural control as a result of behavioural disorders, which results in the emergence of habitual behaviours (Redgrave et al., 2010) and the adoption of an incorrect posture. In search for the pathomechanism of the described disorders, the role of a protein deficit in neurotransmitters in strictly-defined regions of the brain and defects of the brain stem, thalamus and neocortex are enumerated (Lalonde & Strazielle, 2007). However, it should be emphasized that the determination of the cause of the defect is often possible only after a combined clinical and instrumental assessment in specialist proceedings has been conducted (Kowalski, Kotwicki, et al., 2013).

The main image of the described disorders is the bend of the spine in the sagittal plane, which increases the pressure inside the spinal cord (D.E. Harrison et al., 1999c). It is the result of mechanical compression of the anterior structure of the spinal canal, pressure of the spinal cord on the spinal canal and stretching the spinal cord. As a result of this state, a decrease in blood flow and blood perfusion in the spinal cord and disorders of oxidative metabolism in the neuron mitochondria follow (D.E. Harrison et al., 1999c). An incorrect posture results in abnormalities in the microcirculation of nerve fibers, axonal transport irregularities and nerve conduction (Shacklock, 1995). The described condition of spinal overload is directly recorded by the nervous system which, under these circumstances, may generate pain in the spinal area and/ or pain radiating to other body parts (Shacklock, 1995; Butler, 1989; K. O’Sullivan et al., 2010; D.E. Harrison et al., 1999a).

As a result, accompanying overload of the spine structures may result in: change in respiratory kinematics (Lee et al., 2010), decrease in breathing capacity, minute volume of lung ventilation (Landers et al., 2003), reduction of forced expiratory volume in 1 second and forced vital capacity (Lin et al., 2006; Melam et al., 2014), lumbar spine pain (Chen et al., 2009, Al-Eisa et al., 2006; Morvan et al., 2011), especially in men (Kluszczyński et al 2017), intercostal neuralgia (Kiebzak et al., 2010), fatigue and depression (Peeters et al., 2013), deterioration of social interactions due to inadequate perception of the environment caused by head movement

limitations (Roussouly & Nnadi, 2010), vision deterioration (Peeters et al., 2013), malocclusion (Gogola et al., 2015), problems with swallowing food (Simão, Sináira et al. 2013), intestinal motility disorders (Peeters et al., 2013; P.W. Hodges & Gandevia, 2000) and intestinal gas passage (Dainese et al., 2003), as well as musculoskeletal pain of the upper body quadrant, which is a common health problem in young people (Brink et al., 2015).

In the planning of preventive and curative treatment, various factors with varying degrees of effectiveness are considered. In consequence, detailed instructions with the given angles of the lower limbs, upper limbs and upper body position, which muscles should be shaped and flexed, recommendations to have a perfectly matched chair with a desk and continuous conscious control of the posture turn out to be ineffective. Especially, the commonly recommended "sit up straight" with upper body activity, the so-called "drawing the shoulder blades together," causes improper reactions in the form of less activation of local stabilizing muscles with increased co-activation of phase muscles (P. O'Sullivan et al., 2002; P. O'Sullivan et al., 2006; Czaprowski et al., 2014; Kiebzak et al., 2017). Contrary to the above, the following fact should be considered. Correction of the sagittal plane in preventive and curative activities needs to be a key element in the control of the correct posture (Lee et al., 2010). An important role in this aspect is played by the methods based on neurophysiological mechanisms that enable the creation of global motor models of physiological positioning (in three planes of the body) of the pelvis, head, chest and spine (Vojta & Peters, 2007; Ha & Sung, 2016; Souchard, 2014; Hillier & Worley, 2015; Henry et al., 2016; Wojtkiewicz et al., 2012) and providing simple recommendations facilitating maintenance of a good posture (Kiebzak et al., 2010).

The author's own clinical observations enable clear reflections that the disorder of the spine positioning in the sagittal plane during an individual's activity affects a significant number of people. The disorders can be recognized both in people who are considered healthy and in people who are ill. This fact is associated with changes in the sternal angle and the sacrum positioning, as well as the curvatures of the spine. The point of reference for reflections on the quality of the posture should be its detailed diagnostics and assessment. In order to properly address the above assumption, I have reviewed 618 literature items. I have qualified 280 items for this monograph, including 265 original articles and 15 books and books chapters. Most often, I referred to the scientifically significant names of Peter O'Sullivan, Paul Hodges, Wim Dankaerts—the authors of numerous studies on the issues of musculoskeletal disorders and postural control. Among Polish authors I would enumerate Dariusz Czaprowski, whose three valuable works were cited 15 times in the discussed monograph.

Based on the literature review, I pointed out that different test methods, different criteria and different tools to assess the body positioning in the sagittal plane (*sagittal alignment*) are used. The most frequently used are tests in a standing position using X-rays (Liang et al., 2016; Mac-Thiong et al., 2011; Ghandhari et al., 2013; Labelle et al., 2011; Mac-Thiong et al., 2007; Asai et al., 2017). Roussouly and Pinheiro-Franco in their observations propose lateral x-ray for the assessment of the sagittal plane of the body and finding any disturbances that may occur. The analysis of the collected literature shows that in the radiological assessment of *sagittal alignment*, angles of the pelvis positioning: *pelvic incidence* (PI), *pelvic tilt* (PT), *sacral slope* (SS), and *lumbar lordosis angle* – *lumbar lordosis* (LL) are mainly tested in relation to various combinations of assessed parameters (Liang et al., 2016; Mac-Thiong et al., 2011; Ghandhari et al., 2013; Labelle et al., 2011; Mac-Thiong et al., 2007; Asai et al., 2017; Roussouly & Pinheiro-Franco, 2011; Cho et al., 2015; Lazennec et al., 2013).

An important element of the literature review analysis is the conclusion that in the diagnostic assessment of the spine or the spine and the pelvis, reductions in X-ray exposure should be used (Hui et al., 2016; Roobottom et al., 2010; Leroux et al., 2000; Buchbinder et al.,

2013; Ghasemi et al., 2016). The form of non-invasive examination is currently the commonly used 3D / 4D, i.e. three-dimensional assessment of the posture and its movements using the photogrammetric method. It is recommended that the BMI scores should be considered in the diagnostic procedure, since overstating this parameter may have a negative impact on the quality of the measurement (Peeters et al., 2015).

The Formetric 4D system used in this monograph uses the surface topography to measure the dimensions of the upper body. The measurements show a high repeatability of the obtained results, and the mean standard deviation is $\pm 3^\circ$ (Knott et al., 2010). The Saunders digital inclinometer is another basic or supplementary system in the examination of the positioning of the body sections, including the spine and pelvis while sitting. An inclinometer is a tool which is now widely used in diagnostic procedures. The advantage of the inclinometer is that it is inexpensive, gives reliable measurement results and is easy to use in practice. Assessment of anterior-posterior spine curvatures using a Saunders inclinometer by a single researcher gives the possibility of obtaining good repeatability and reliability of measurements, i.e. $0.9 > \alpha \geq 0.8$, and the measurement error is within the interval of 2.8° - 3.8° (Czaprowski et al., 2012).

The analysis of the literature on discussed issues and the results of the author's own research (Kiebzak et al., 2010; Kiebzak et al., 2017) indicated the necessity of search for biomechanical parameters along with the existing dependencies that will allow to describe the posture while sitting. Consequently, the parameters discovered in the process of the author's own clinical observations and this scientific study allow to show a close dependence of simultaneous movements of particular body parts, i.e. the sternum body and the sacrum, as well as thoracic kyphosis and lumbar lordosis in relation to each other. The Euclidean geometry helped to solve the set tasks (Isayama & Yasukouchi, 1995; Kordos, 2010; Łuczyński & Opal, 1964). On its basis it was shown that common relationships between the specified parts of the body, the so-called "unifying sense" (Kosztolowicz 2001; Wierciński 2011) can be a method of posture assessment while sitting.

The concept of the unifying sense was introduced by Michał Kosztolowicz in 2001. The unifying sense is understood as a common concept for two different concepts which leads to the justification for creation of a different quality of observations (Kosztolowicz, 2001). The exemplification of this concept took place in a publication prepared by Wierciński in Cambridge in 2011 (Wierciński, 2011).

In the author's own studies, in order to define the posture while sitting, simplifying assumptions were made which remain in a specific interdependence. The simplifying assumptions are: the sternum body angle, the sacrum angle, thoracic kyphosis angle and the lumbar lordosis angle. For these assumptions, existing relationships were defined by the concept of the unifying sense. An important element in this concept is the fact that the lines derived from the sternum body and the sacrum can be "inscribed" in a triangle, and the movement of one part of this system triggers the movement of its other parts. The bone of the sternum body in relation to the horizontal line, the sagittal axis of the body "a" forms angle α and the sacrum in relation to the horizontal line, the sagittal axis of the body "b" forms angle β . Angle (γ) is the unifying sense for the sternum body angle (α) and the sacral angle (β) (Fig. 1).

Based on the author's own analytical search for the unifying sense for the angles of the sternum body and the sacrum, their dependencies were illustrated (Fig. 1). Straight lines a and b are the lines parallel to the horizontal line. The author's own observations show that the ABC triangle was constructed by drawing the straight line AC as the extension of the sacrum bone line to the intersection with the AB line as the extension of the sternum body line forming the BAC angle, i.e. angle γ . The base of the triangle is the horizontal line. The ACD angle, i.e. β is

the exterior angle of the ABC triangle. By virtue of the theorem of the Euclidean geometry, the exterior angle of a given triangle equals the sum of the interior angles not adjacent to it, hence, we get: $\beta = \alpha + \gamma$, hence $\gamma = \beta - \alpha$ (1), where γ is the unifying sense for the angle of the sternum body and the angle of the sacrum β as the difference between the positioning of the angles β and α . It follows from the above that the γ angle has a connotation with both angle α as well as angle β , showing common relationships, the so-called unifying sense.

Angle measurements were taken using the Saunders inclinometer. Measured angles are denoted by: α , i.e., the ABC angle for the positioning of the sternum body and β , i.e. the ACD angle for the positioning of the sacrum. Both angles were measured in relation to the horizontal line, the sagittal axis of the body (Fig. 1)

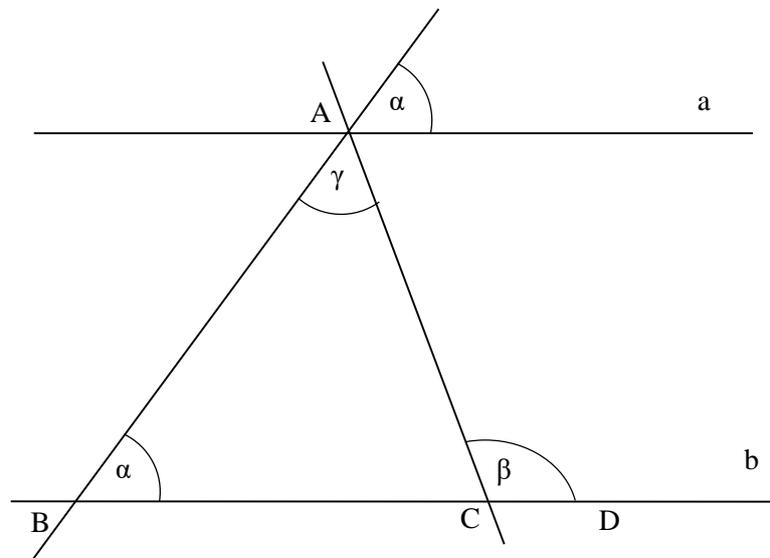


Fig. 1. The arrangement of the line of the sternum body AB and the line of the sacrum AC in the triangle

The consequence of the co-dependence of the sternum body movements in relation to the sacrum is the influence on the changes in the curvature of the thoracic spine ω_1 and lumbar spine ω_2 . In this way, relationships of the unifying sense of the sternum body angle and thoracic kyphosis, i.e. γ_1 , and sacrum bone and lumbar lordosis, i.e. γ_2 are formed (described in the monograph).

Aim of work

Analysis of the relationship between the positioning of the sternum body and the sacrum, and the changes in the curvatures of the thoracic and lumbar spine in the sagittal plane.

Five research hypotheses were formulated for the purpose of the work:

1. The relation of the unifying sense: $\gamma = \beta - \alpha$, i.e. the body sternum body position and the sacrum position (β), is the basis for the interpretation of the research results.
2. The arithmetic mean of the measurement and the median are fixed values in the test of the skewness of distribution of measurement results.
3. The results of the unifying sense of the corrected posture:
 - a. $\gamma = \beta - \alpha$, are close to the normal distribution regarding the sternum body and sacrum positioning,

- b. $\gamma_1 = 180^\circ - (\alpha + \omega_1)$ are close to the normal distribution regarding the positioning of the sternum body and thoracic kyphosis,
 - c. $\gamma_2 = 180^\circ - (\beta + \omega_2)$ are close to the normal distribution regarding the positioning of the sacrum and lumbar lordosis.
4. The corrected posture constitutes a model for the assessment of the measurement results while sitting.
 5. Constrained and passive postures are anti-models for evaluating the measurement results while sitting.

4.1.2. Subjects of the research, methodology and research results

Material, subjects of the research

The observations were conducted on 277 students of the Jan Kochanowski University (UJK), the Faculty of Medicine and Health Sciences (WLiNoZ), aged 19-23. Eventually, healthy people were qualified for the study, $20 < \text{BMI} < 30$, without any reported pain, with the proper structure of the chest and spine. Exclusion criteria were: pregnancy, back pain, difficulties in establishing the location of the sacroiliac joint, neuromuscular diseases, participation in a specialized treatment of postural disorders, diagnosed scoliosis, previous surgical procedures in the spinal area and taking painkillers. Each subsequent person consenting to participate in the experiment was informed about the course of the proceedings. The purpose of the research, security issues and privacy issues, including the use of photographs, and the research procedure were explained to the participants. All individuals expressed their voluntary written consent to participate in the experiment.

Based on the inclusion and exclusion criteria, 159 individuals were qualified for the research, including 83 males, 76 females, first and second year students at the Faculty of Medicine and Health Sciences (WLiNoZ), UJK, aged 19 to 23. The research was conducted in 2015–2017. In Annex 1 of the monograph, it was shown that the given number of men and women included in the statistical study are a representative sample of the population.

Test methods

During the physical examination, the examined individual was in a sitting position, evenly loading the ischial tuberosities, on the horizontally positioned seat of variable height, with the lower limbs bent in the hip and knee joints up to the 90 angle. The feet were set flat on the floor to the width of the hips. Upper limbs were set loosely with palms placed on thighs. The examined individuals adopted each position threefold in order to choose the optimum position, according to the Mork and Westgaard protocol (Mork & Westgaard, 2009).

Using the Saunders inclinometer, angle measurements were taken: α – sternum body position and β – sacrum bone position. The measurements of the kyphosis angle ω_1 and the angle of lumbar lordosis ω_2 were conducted using the DIERS Formetric 4D system. The measurements were taken in three positions: (1) passive, free, without back support and active muscle involvement, with pelvic retinopathy; (2) constrained, active, without back support, following the command "sit up straight – draw your shoulder blades together" and (3) corrected, active, without back support, adopted under the control of the researcher, assessed as a complete, active, physiological spine extension, obtained by lifting the sternum, change of anteversion of the pelvis, retraction of the head with the mandible placed parallelly to the

ground and slight leaning forward of the upper body. All of the subjects performed the same activities. The tests were approved by the Bioethical Committee of WLiNoZ UJK in Kielce, No. 17/2016. Inclusion of the subjects in the study was random.

Statistical methods

Statistical analysis of the measurement results was performed in the range of the following calculations: reliability of measurements, basic descriptive statistics, percent error calculation, skewness of distribution, study of significance of differences between mean scores of measurements, study of correlation between variables and study of confidence interval for mean scores. The calculations were made using the Statistica 13.1 StatSoft. The level of statistical significance was assumed for $p < 0.05$.

Results

The full scope of the results in the form of basic computational statistics is provided in Table 1 in the monograph. In line with the assumptions of the Euclidean geometry and the relation of the unifying sense, it was assumed that the sternum body and the sacrum lines can be "inscribed" in the shape of a triangle. The unifying sense for the angle of the sternum body (α) and the angle of the sacrum (β) is the angle (γ) as the difference between the position of the angles β and α , recorded as an arithmetic operation $\gamma = \beta - \alpha$. The consequence of the co-dependence of movements of the sternum body in relation to the sacrum is the effect on changes in the curvature of the thoracic spine and lumbar spine. The unifying sense for the kyphosis (ω_1) and sternum body (α) angles is the angle: $\gamma_1 = 180^\circ - (\alpha + \omega_1)$, while the unifying sense for the angles of the sacrum (β) and lumbar lordosis (ω_2) is the angle: $\gamma_2 = 180^\circ - (\beta + \omega_2)$.

The correctness of measurements was observed for all of the tested body postures adopted while sitting: passive, constrained and corrected, in the aspect of the unifying sense γ_1 and $(\alpha + \omega_1)$ and γ_2 , as well as $(\beta + \omega_2)$, it was also observed that correlation coefficient is very high and amounts to (-1). Based on the above, it was concluded that if the appropriate sum of angles increases, the corresponding unifying sense γ_1 or γ_2 decreases and vice versa (Table 8 in the monograph).

Statistical analysis of test results showed that only the kyphosis angle ω_1 undergoes correction both in the corrected and the constrained position (Tables 5, 6, 9, 10 in the monograph). This fact is confirmed by the test of significance of the mean scores for the ω_1 chest kyphosis angle, which shows that the U test value is lower than the U_α critical value in both women and men. The score obtained for men: $u = 0.08 < 1.974 = u_{\alpha, 0.05; 164}$ (Table 5 in the monograph) and for women: $u = 0.27 < 1.976 = u_{\alpha, 0.05; 150}$ (Table 6 in the monograph). Based on the above, the H_0 hypothesis was accepted. In the assessment of the other angles in the constrained posture, there is a statistically significant difference compared to the corrected posture. Due to these results the H_0 hypothesis was rejected. This condition causes the lack of harmony, i.e. the complementation of the elements of the chest, spine and pelvis in achieving the desired, effective corrected posture while sitting.

Adoption of passive posture while sitting was recognized as incorrect behaviour. This is confirmed, i.a. by the calculated values of the correlation coefficient between γ_1 and α , which are: for men -0.914 and for women -0.960, and between γ_1 and ω_1 which are: for men -0.957 and for women -0.941, as well as between γ_2 and β for men -0.989 and for women -0.996, and

for γ_2 in relation to ω_2 for men -0.964 and for women -0.957 (Table 8 in the monograph). This is interpreted as high correlation which constitutes the image of the lack of differentiation of the angle α of the sternum body position in relation to the unifying sense γ_1 , and γ_1 in relation to ω_1 , as well as the lack of differentiation of the angle of the sacrum bone β position in relation to the unifying sense γ_2 , and γ_2 in relation to ω_2 .

The constrained posture, similarly to the passive posture, was assessed as incorrect. This is substantiated, e.g. by the calculated correlation coefficient between γ_1 and α for men -0.980 and for women -0.902, and γ_1 and ω_1 for men -0.927 and for women -0.933, as well as between γ_2 and β for men -0.970 and for women -0.941, for the correlation γ_2 in relation to ω_2 for men -0.946 and for women -0.971 (Table 8 in the monograph). This is interpreted as a very high correlation which decides about the lack of differentiation of the unifying sense of γ_1 in relation to α and γ_1 in relation to ω_1 and the lack of differentiation of the angle of the sacral bone β in relation to the unifying sense γ_2 , and γ_2 in relation to ω_2 (Table 8 in the monograph). The constrained posture is characterized by a significantly statistical $p = 0.006555$ bigger difference in the range of the sacrum bone position in women than in men (Table 7 in the monograph).

The observed irregularity of the passive and constrained postures is also confirmed by the higher results of error in the calculation of the empirical median in comparison to the theoretical median. These results, in the assessment of the unifying sense γ_1 , e.g. for men indicate that the error in the passive posture is 57.55% and in the constrained posture 32.30%, while in the corrected posture it is 0.34% (Table 2 in the monograph).

The corrected posture as opposed to passive and constrained postures was assessed as proper. This is evidenced by the fact that there is moderate correlation differentiation between γ_1 and α for men -0.412 and for women -0.457, as well as between γ_2 and β for men -0.458 and for women -0.433, in relation to a very high correlation of γ_1 to ω_1 for men -0.936 and for women -0.979, and for γ_2 to ω_2 for men -0.950 and for women -0.941 (Table 8 in the monograph). The fact of the correct features of the corrected posture is also confirmed by the lowest result of the calculation error of the empirical median compared to the theoretical median, which, e.g. for the unifying sense γ_1 for women in the corrected posture is 0.08%, while in the passive one is 9.85% and constrained one 1.63% (Table 2 in the monograph).

In the conditions of the research, while determining the posture in the corrected position, a high repeatability of obtained measurements was observed, including for the angle of the sternum body and the sacrum (Table 1 in the monograph). Moreover, the proposed corrected sitting posture includes the assumptions of the correct positioning of the body in space.

4.1.3. Discussion of the research results

Based on the bibliography review, the author's attention was drawn to the diversity of assessment of the body positioning in the sagittal plane – *sagittal alignment*. In the search for a reference point to the author's own results, his attention was drawn to similar forms of posture measurements. Thus, one paper was found for the angle of the sacrum positioning, but the parameter measured with the inclinometer was conducted in a standing position (Prushansky et al., 2008). Also, the scientific works were found describing the positioning of the sternal angle, but the measurements differed from the conditions set out in this paper (Hirose, 2005), (Lee et al., 2010), (Suzuki et al., 2016). In the papers review describing the use of non-invasive methods, without X-ray radiation, the authors present various diagnostic solutions for body posture assessment while sitting (Phimphasak et al., 2016), (Brink et al., 2013) (Claus et al., 2016). The tested parameters, due to different diagnostic assumptions, did not allow comparison

of the presented results with the results of the author's own study. The literature review indicates that only the parameters of thoracic kyphosis and lumbar lordosis can be a reference to the author's own studies, despite the fact that the results are presented mainly for the standing position. Considering the obtained results, I found that the subjects in the corrected posture while sitting mostly obtained good and very good scores. However, outside the confidence interval and the extended confidence interval, there remained: for the relationship the sternum body against the sacrum – γ and the relationship the sternum body against thoracic kyphosis – γ_1 4 people in each, for the relationship the sacrum bone and lumbar lordosis – γ_2 5 people in the group of men (Table 11 in the monograph) and for the sternum body against thoracic kyphosis – γ_1 and the relationship the sacrum bone against lumbar lordosis – γ_2 3 people in each in the group of women (Table 12 in the monograph). This fact proves that the presented theoretical way of calculating the common relations of the sternum body, sacrum, thoracic kyphosis and lumbar lordosis is a form of verification of clinical trial results. At the same time, it allows you to obtain information on the quality of adopting the body posture while sitting. The method of analysis based on Tables 11, 12 and 13 (in the monograph) may be used in diagnostic, preventive and therapeutic procedures of adopting the correct body posture while sitting.

The research conducted for the purposes of the presented study and daily clinical activities enable non-invasive monitoring of the simultaneousness of the movement of the sternum and the sacrum bone, as well as the thoracic and lumbar sections of the spine. Recommended in this study determinants of the corrected posture while sitting are characterized by homogeneity of the results (Table 1 in the monograph). These are the parameters developed for a homogeneous healthy population. A common feature of the discussed issue is the fact that the described disorders happen in the sagittal plane (Mac-Thiong et al., 2011; Phimphasak et al., 2016; Czaprowski et al., 2014; Dankaerts et al., 2006; Roussouly & Nnadi, 2010; D.E. Harrison et al., 1999a; Scannell & McGill, 2003; Lee et al., 2014; Le Huec et al., 2011; Straker et al., 2009; Quek et al., 2013; Caneiro et al., 2010; Liang et al., 2016; Kiebzak et al., 2017; Kiebzak et al., 2010), and the arrangement of the individual sections of the spine in relation to each other creates a system of connected vessels. This phenomenon is confirmed by Brügger's observations stating that the alternate course of the centres of gravity of particular parts of the spine, thorax, as well as head and pelvis, leads to the fact that the displacement of any segment entails simultaneous displacement of adjacent sections in opposite directions (Pavlu et al., 2007). This kind of chain reaction is compared to the action of "cogwheel" (Pavlu et al., 2007). The physiological positioning in this plane plays an important role in eliminating shear and compressive forces acting on the spine (Oh & Eun, 2015). Scheduled and prepared calculation models have shown that forces in the lower spine section given in newtons (N) significantly increase, from 550 N in physiological conditions, to values exceeding 5,000 N under overload conditions. At the same time shear forces increase from 200 to 2,000 N. The increase in the forces involved is associated with the prolonged adoption of the bent, passive position of the body – *slump position*. These circumstances become particularly dangerous when, while maintaining defective positions with an incorrect body posture, a sudden, dynamic movement of deep bend appears, often connected to the twist of the upper body (Dreischarf et al., 2016, Rohlmann et al., 2013).

In the process of my observations, I noticed that for an examined person, the angle α of the sternum body position in relation to the sagittal axis of the body is easily controlled and easy to measure. It should be emphasized that for the majority, i.e. 86.67% of the subjects, it is considered easy to adopt (Kiebzak et al., 2017). Considering this observation and considering the simultaneousness of movements of the aforementioned system, positioning the sternum body to the value of angle α should provide an indication for the way to control body posture.

In practical behaviour, the attention of the concerned person is turned away from the determination to "sit up straight" and turned to a specific task.

Concentration of attention of the person undergoing corrective action, on the slight – in the opinion of the subject – elevation of the sternum body to the angle of about 65° in relation to the sagittal axis of the body becomes this specific task. In addition, pelvic retraction is included along with a slight leaning forward of the upper body in conditions without support of the spine (Wolańska & Wolański, 2005; Kiebzak et al., 2010; K. O'Sullivan, McCarthy et al., 2012; Kiebzak et al., 2017), and a slight leaning backward in conditions when the spine is supported (Schüldt et al., 1986).

In most cases, the achievement of active correction of body posture is determined by two opposite features, it is indicated that it is easy and uncomfortable (O'Sullivan, McCarthy et al., 2012; Kiebzak et al., 2017). Encountering these opposing concepts in the author's own clinical practice makes a great challenge for obtaining the desired effects of preventive and curative treatment. This state results from difficulties in creating motivation to work on the body posture (Kiebzak et al., 2017).

In practical actions to strengthen the meaning of provided information, it should be emphasized that the posture is perceived by others (Amoruso et al., 2011) and may reveal the state of mind of the observed person (Ramalingam et al., 2017). Therefore, all corrective actions with proper qualification should be considered from the biopsychosocial perspective in which changes in the parameters of biomechanical factors constitute only one of the elements of the procedure (O'Keeffe et al., 2013, Prins et al., 2008). The aforementioned qualification should exclude from the described procedure the individuals with root pain, special difficulties in maintaining the corrected posture while sitting and in whom the shallowing of thoracic kyphosis is observed. However, it turns out that the consistent "implementation of α angle" in the individual's activity can result in good practical solutions. These solutions may concern the body posture correction while performing various daily activities.

In attempts to position the sternum body to an angle of about 65° in relation to the sagittal axis of the body, it is recommended to frequently practise the positioning of the chest to obtain the desired effect, extended and physiological positioning of the sections of the spine and the entire spine. It should be emphasized that elimination of incorrect behavioral habits is connected with discomfort which, in young people, decreases only after 3-4 months of systematic work (Nowotny-Czupryna et al., 2013). The basis for such activities, i.e. postural control is muscle synergy which depends on the function and structure of the nervous system (Ting & McKay, 2007). It is based on complex processes which involve reflexive segmental reactions and phase activity, precisely adapting to various types of external stimuli (Freyler et al., 2015).

Considering the above, the presented results, the determinant of the sternal angle position may be an accurate proposal for the diagnostics and correction of the posture in the sagittal plane while sitting. This is very important because the data show that the correction of the sagittal plane while sitting may be of fundamental importance for the body's functioning (Lee et al., 2010).

Prevalence of postural disorders being the fact indicates the necessity for raising awareness about body posture, especially among students and teachers (Ramalingam et al., 2017). In skilful planning of preventive and curative activities in the discussed health issue, social media should be used (Lee et al., 2016). Early postural examination will help prevent or at least reduce spine diseases in the subsequent years of life (Ramalingam et al., 2017). Neglecting to popularise corrective actions reinforces changes that may have large implications for general fitness in mature life (Lee et al., 2014; Skaf et al., 2011; Asai et al., 2017).

From the author's own observations and studies, it appears that sedentary lifestyle creates conditions for further developing of thoracic kyphosis and loss or reduction of lumbar lordosis. This condition is a determinant for the development of postural defects, especially of the round back syndrome and overload of the spine structures. Therefore, searching for the right solutions for diagnostics and body posture correction while sitting requires constant research in this area. The results presented in this monograph should have an impact on the implementation and propagation of a new form of scientific reflection on the body posture, and thus on the shaping of body awareness (Danner et al., 2017; Judycki, 2010). One of the elements of this procedure should be learning the image of one's own body posture while sitting and creating a "good" image of one's own body. In addition, it will be valuable to determine how long and how often the corrected position should be adopted and whether the use of corrected posture gives good long-term clinical results.

Reeducation of the body posture, recommended already at an early stage of life (Mikołajczyk et al., 2015) clearly plays an important role in the treatment of spinal pain (Czaprowski et al., 2014; K. O'Sullivan et al., 2012; K. O'Sullivan et al., 2010). However, the results of scientific works concerning the adoption of the "corrected posture" – the physiological extension of the spine in the treatment of various musculoskeletal disorders, i.e. headache, neck and upper chest pain (Caneiro et al., 2010), hip joints (Kiebzak et al., 2016); toe walking (Szopa et al., 2016) or severe cranial and cerebral injuries (Kiebzak et al., 2015) should encourage further in-depth, multidirectional research, i.a. in the assessment of equivalent responses (Wilczyński, 2014).

4.1.4. Practical conclusions of research results

1. According to the properties of the Euclidean geometry and the relation of the "unifying sense", the sternum body and the sacrum lines can be "inscribed" in the shape of a triangle, documenting the co-dependence of their position.
2. Co-dependent movements and the positioning of the sternum body and the sacrum produce the changes in the values of thoracic kyphosis and lumbar lordosis angles. This fact should be an important component of a clinical observation of the body posture while sitting.
3. The constructed model of the "unifying sense" γ (the sternum body in relation to the sacrum), γ_1 (the sternum body and thoracic kyphosis) and γ_2 (the sacrum and lumbar lordosis) enables assessment of the body posture while sitting.
4. Out of the three examined positions, the corrected one showed the interdependence of measured parameters. It was the basis for discovering the pattern defining optimal parameters of body posture while sitting.
5. Implementation of the sternal angle position in relation to the sagittal axis of the body, amounting to about 65° in clinical practice as one of the goals of postural education, can be a target solution for the correction of the body posture while sitting.

Abstract

Positioning of the sternum and the sacrum in relation to spine curvatures as a way of evaluating body posture while sitting

Introduction. Sedentary lifestyle is a form of people's behaviour with energy expenditure $\leq 1,5$ of metabolic equivalent, when adopting semi-recumbent, recumbent or sitting position. The time a person spends in a sitting position has considerably increased in recent years. Even 80% of people's professional life time is spent in this way. The author's own observations of about 1300 (grade 1-2) primary school children, has shown that the time spent in a sitting positions fluctuates around 7 and 10 hours a day. These behaviours are becoming common; they are characterised by adopting a slouched position in which the so called "passive suspension on the spine" appears. The root causes of this state may be the result of many factors, including various diseases, but the most common mechanism is losing automatic posture control with the increase of habitual behaviours. It should be stressed that, in line with Brügger concept, alternate changes of gravity centres of individual spine parts, head, pelvis and thoracic cage trigger chain reaction, which means the change in positioning of one element results in the corresponding change of the remaining elements. Consequently, overloading the spinal structures may result in the disorders of: respiratory and circulatory systems, intestinal peristalsis, sphincter dysfunction, and malocclusions but, primarily, back pain, headaches, chest pain and limb pain. Spinal pain, as a consequence of incorrect sitting position starts as early as at the age of 7-9 years.

Analysis of literature and the results of the author's own studies and experience have indicated the necessity of searching for biomechanical criteria that will allow us to describe a body posture in a sitting position and will facilitate implementation of treatment procedures. The criteria discovered both during the author's own clinical observation and scientific studies, allowed us to show a close relationship of simultaneous relative movement and positioning of particular body parts (that is the sternum body and the sacrum as well as thoracic kyphosis and lumbar lordosis). This dependence was related to the shape of a triangle (basing on the Euclidean geometry) showing that common interactions between specified body parts, the so called "unifying sense" might be a way of evaluating body posture while sitting. The unifying sense shall be understood as a common concept referring to two different concepts, which leads us to the creation of other quality of observations carried out. Reflections on the way a person is sitting constitute a new and important element of the area of preventive medicine.

The aim of the study. Analysing the relation between positioning of the sternum body and the sacrum, and the changes of spine curvatures in thoracic and lumbar parts in sagittal plane.

Materials, participants of the study. The study was conducted on a representative sample (appendix 1) of 159 people, aged 19-23 years (83 men, 76 women). The participants of the study were healthy, with correct construction of thoracic cage and spine, free from pain.

The method of the study. Angle measurements were carried out using Saunders inclinometer: angle α – the positioning of the sternum body and β - the positioning of the sacrum. The measurements of values of thoracic kyphosis angle ω_1 and lumbar lordosis angle ω_2 were carried out with DIERS Formetric 4D system. The measurements based on Mork and Westgard protocol were taken in three positions: (1) passive, free, without supporting the back or active involvement of muscles, with posterior pelvic tilt; (2) constrained, active, without supporting the back, adopted on the command “sit up straight – draw your shoulder blades together” and (3) corrected, active, without supporting the back, adopted under the supervision of the examiner, assessed as full, active, physiological extension of the spine achieved by raising the sternum, increasing anterior pelvic tilt, pulling the head back with a jaw positioned parallel to the floor and by slightly leaning the body forward.

Statistical methods. Statistical analysis of the measurement results was carried out in the following calculations: plausibility of measurement, basic descriptive statistics, calculating percentage error, skewness of distribution, studying the significance of differences between average results of measurement, examining the correlation between variables and studying confidence interval for mean results. The calculations were conducted with Statistica 13.1 StatSoft. The level of statistical significance was set for $p < 0.05$.

Results. In line with the basis of the Euclidean geometry and the relation of the unifying sense, it was assumed that the lines of the sternum body and the sacrum might be “inscribed” in the shape of a triangle. The unifying sense for the angle of the sternum body (α) and the angle of the sacrum (β) is the γ angle - as a difference between the positioning of β and α angles ($\gamma = \beta - \alpha$). The interdependence between the movements of the sternum body and the sacrum results in its influence on the changes in the curvatures of thoracic and lumbar spine. The unifying sense for the angle of kyphosis (ω_1) and the sternum (α) is the angle: $\gamma_1 = 180^\circ - (\alpha + \omega_1)$, whereas the unifying sense for the angle of the sacrum (β) and lumbar lordosis (ω_2) is the angle: $\gamma_2 = 180^\circ - (\beta + \omega_2)$.

For all the examined body positions adopted while sitting: passive, constrained and corrected, a regularity as regards the unifying sense γ_1 and $(\alpha + \omega_1)$ as well as γ_2 and $(\beta + \omega_2)$ was observed: the correlation coefficient is very high and it amounts to (-1). On the basis of the above, it was concluded that if the corresponding sum of angles is increasing, the corresponding unifying sense γ_1 or γ_2 is decreasing, and vice-versa.

Statistical analysis of the results showed that only the kyphosis angle ω_1 can be subject to correction both in the corrected and constrained position. This fact is confirmed by studying the significance of average results for thoracic kyphosis angle ω_1 , which shows that the test value u is lower than the critical value u_{α} , for both women and men. The values obtained for men: $u = 0.08 < 1.974 = u_{\alpha,0,05;164}$ and for women: $u = 0.27 < 1.976 = u_{\alpha,0,05;150}$. On the basis of the above, H_0 hypothesis was accepted. In the constrained position, there is a statistically significant difference in the evaluation of the remaining angles in comparison to the corrected position. For those results, the H_0 hypothesis was rejected.

Adopting a passive sitting position was identified as inappropriate. This can be confirmed, among others, by the calculated values of the coefficient of correlation between γ and α , which amount to: for men -0.806 and for women -0.842 ; and between γ and β , which amount to: for men 0.873 and for women 0.877 . It is interpreted as high correlation that means there is no difference in the value of the angle of the sternum body positioning α and the unifying sense γ as well as the angle of the sacrum positioning β and the unifying sense γ . For the results given, the H_0 hypothesis was rejected.

The constrained position, as well as the passive position, were assessed as incorrect. It is justified, for example, by the coefficient of correlation calculated between γ_1 and α , amounting to -0.980 for men and -0.902 for women as well as γ_1 and ω_1 amounting to -0.927 for men and -0.933 for women. It is interpreted as a very high correlation, which means there is no difference in the unifying sense γ_1 and α nor in γ_1 and ω_1 . For the results given, the H_0 hypothesis was rejected. In the constrained position, there is a statistically significant $p=0,006555$, bigger difference in the range of the sacrum positioning among women than among men.

The detected incorrectness of both passive and constrained positions are confirmed by higher error values of empirical median calculations in comparison to theoretical median. The results show that for men, for example, in the evaluation of the unifying sense γ_1 , the error in the passive position amounts to 57.55% ; and in the constrained position – to 32.30% , whereas in the corrected position it amounts to 0.34% .

As opposed to the passive and constrained positions, the corrected position was assessed as a proper one. It is demonstrated by the fact that there is a slight correlation diversity between γ_1 and α , amounting to -0.412 for men, and to -0.457 for women as well as between γ_2 and β amounting to -0.458 for men and -0.433 for women, in relation to a very high correlation γ_1 and ω_1 , amounting to -0.936 for man and -0.979 for women as well as for γ_2 and ω_2 amounting to -0.950 for men and -0.941 for women. For the results given, the H_0 hypothesis was rejected. The fact that the corrected position has all the proper qualities is confirmed by the lowest error value of empirical median calculations in comparison to theoretical median, which, for example, for the unifying sense γ_1 , for a woman in the corrected position, amounts to 0.08% , whereas in the passive position, it amounts to 9.85% and in the constrained position, to $1,63\%$. The average results of the parameters measured in the corrected position as regards the relation of men-women are included in the following limits, respectively: the angle of the sternum body oscillates between $64.03^\circ - 63.31^\circ$, the angle of thoracic kyphosis ranges from 43.48° to 43.35° . In this position, the sacrum is positioned within the range of $113.21^\circ - 113.35^\circ$, whereas lumbar lordosis reaches the value of $39.33^\circ - 37.30^\circ$, respectively. To assess the corrected position, it is important to control both the positioning of the sacrum, and, particularly, the sternum body whose setting angle amounting to around 65° may be treated as the indicator of a proper correction of body posture.

Conclusions

1. In line with the basis of the Euclidean geometry and the relation of the “unifying sense”, the lines of the sternum body and the sacrum might be “inscribed” in the shape of a triangle, documenting their correlation.
2. The interrelated movements and positioning of the sternum body and the sacrum trigger changes in the values of angles of thoracic kyphosis and lumbar lordosis.
3. The constructed pattern of „unifying sense” relation of γ (the sternum body in relation to the sacrum), γ_1 (the sternum body and thoracic kyphosis) and γ_2 (the sacrum and lumbar lordosis) enables evaluating body posture while sitting.
4. Out of the three positions examined, the corrected position showed the system of interdependence of the parameters measured; the system was the basis for interpreting the accuracy of body posture while sitting.
5. In clinical practice, implementing the positioning of the sternum at the angle of 65° , as one of the aims of postural education, may be the final solution to the problem of correcting posture while sitting.