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THE DEVELOPMENT OF CERTAIN METHODS FOR ASSESSING THE EFFICIENCY OF KINETIC SPECIFIC EXERCISES IN SCOLIOSIS REHABILITATION

PhD Thesis – Abstract

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In recent years, more people are paying increase attention to body position and they address to orthopedic specialists or physical therapists for elaborate postural evaluations. Body posture influences us not only aesthetically but also psychologically through the image we present to those around us and that we observe in ourselves. When it comes to children, more and more parents are concerned about how children are developing, especially as new technologies make them spend more time in front of screens, and lack of exercise can easily be seen in obesity and posture problems. Studies conducted in recent years show an increasing percentage of children who develop spine deviations, in the sagittal plane (hyperkyphosis, hyperlordosis), frontal plane (scoliosis) or both. The earlier these problems are detected, the greater the possibility of correction. Children with posture problems are examined by an orthopedic doctor, but the diagnosis is confirmed by X-ray of the entire spine (frontal and profile), which allows measurements such as the Cobb angle, degree of bone maturation, degree of vertebral rotation. Unfortunately, the radiological examination remains the standard method of diagnosis, but also of evaluating over time the evolution of spinal deviations (even if this investigation involves exposing the body to X-rays that are harmful. Therefore, when we discuss scoliosis, this deviation in the frontal plane requires repeated evaluations and the development of equipment, as a non-invasive method that allows numerous examinations, is a necessity. Starting from this observation but also from the lack of consensus between orthopedists and physiotherapists regarding the effectiveness of specific exercises for scoliosis recovery, I started my doctoral research.

The present thesis is structured in 7 chapters. Chapter 1 gives a brief presentation of the entire thesis. Chapter 2 contains the current state of knowledge related to the anatomy and biomechanics of the spine, the diagnosis of scoliosis and its evaluation methods. In chapter 3, the methods currently used as therapeutic exercises are presented. The results of the original theoretical research can be found in chapter 4, and in chapter 5 the description of the equipments used in the research are carried out. Chapter 6 presents in detail the experimental research carried out with the proposed tools. Conclusions, personal contributions, respectively further research directions are expressed in chapter 7.

Chapter 1. Introduction

In this chapter, the organization of the doctoral thesis is briefly presented, making a chapter-by-chapter summary of the entire thesis. The main objectives of the thesis are also formulated here:

- The design and construction of an experimental stand, which allows the acquisition of characteristic numerical data for the vertebral column, followed by the modeling of its shape and the mathematical calculation of the Cobb angles. The applied investigation method must be non-invasive, painless. The equipment is desirable to be mobile, so that the determinations can be made in any space, either in the orthopedist's office or in the physical therapist's office.
- Identifying the calculation algorithms that allow the creation of mathematical models of the spine in the frontal plane and the validation of the mathematical models by comparison with reference values on the radiograph.
- Evaluating the effectiveness of the exercise programs used in the recovery of scoliosis, (which belong to different treatment methods) by using the new equipment proposed in the research.
- The use of thermography in the study of the effectiveness of activating the back muscles in the case of exercises specific to scoliosis recovery programs.

Chapter 2. The current state of the art of investigating spinal deformities

The vertebral column represents the median bony axis of the human body, being made up of 33-34 overlapping vertebrae from the pelvis to the base of the skull. In the sagittal plane, according to Kapandji, the following curves are described: the lordotic curves in the cervical and lumbar areas, with the anteriorly oriented convexity, and the kyphotic curves in the thoracic and sacrococcygeal areas with the posteriorly oriented convexity [1]. In the frontal view, the spine shows much less pronounced curves (it can be a curvature with convexity to the right in the thoracic area, due to the position of the heart), so most authors consider it to be straight [2].

The deviation from the physiological position of the spine causes deviations that appear, either in the sagittal plane (hyperkyphosis or hyperlordosis), or in the frontal plane (scoliosis), or in all planes (kyphoscoliosis or scoliosis with profile straightness). Changes in body posture are, initially, functional due to the lack of postural control, but adopting wrong positions, repeatedly, over a longer period of time, can cause permanent structural changes, without the possibility of voluntary correction. According to SOSORT (Society of Scoliosis Orthopedic and Rehabilitation Treatment), the term "scoliosis" is used to describe a heterogeneous group of conditions that cause changes in the shape and position of the spine, chest and trunk[3]. Scoliosis is a complex deviation of the spine that initially appears as a frontal tilt of the rachis and which, following progressive evolution, causes changes both in the sagittal plane (exaggeration or reduction of the physiological kyphotic and lordotic curves) and in the transversal plane (rotation vertebral bodies), resulting multiple morpho-functional disorders. Despite the numerous studies carried out, the cause that determines the appearance and evolution of a scoliosis is not fully elucidated, but there are a number of intrinsic and extrinsic factors that can influence the appearance of this deviation (genetic determination, abnormalities of the vertebral disc or vertebral bodies, anomalies of the endocrine system, imbalance of the paravertebral muscles, changes in bone density, disorders of the nervous system, etc.) [2, 4]. The diagnosis of scoliosis is made by the pediatric orthopedic doctor following a clinical and radiological evaluation. The scoliosis evaluation protocol specifies further clinical and radiological controls every 6 months until the age of bone maturation is reached [2, 5]. The radiological examination is the one that confirms the diagnosis of scoliosis, the radiography bringing precise information on the magnitude of the curvature (the Cobb angle can be measured), the degree of rotation of the vertebral bodies, the age of bone maturation, the location of the upper and lower limit vertebrae and the apex vertebra. The treatment of scoliosis has been standardized according to the magnitude of the curvature measured on the radiograph [3, 6-8]Thus:

- for values of the Cobb angle between 10º and 25º, it is indicated to perform specific physical exercises for scoliosis.
- for values of the Cobb angle between 25º and 50º, orthopedic treatment (brace) and physical exercises specific to scoliosis are indicated.
- for values of the Cobb angle above 50º, surgical intervention through spinal osteosynthesis is indicated.

As we stated above, the scoliosis follow-up protocol provides for the periodic evaluation, every 6 months of children or adolescents with scoliosis. Paraclinical examination methods of scoliosis belong to medical imaging and consist of taking global or sequential, planar or dotted images of the spine, in the frontal and/or sagittal plane [8]. The following scoliosis investigation methods are currently used:

- ✓ images through classic radiology
- ✓ computed tomography
- ✓ imaging based on nuclear magnetic resonance
- ✓ Moiré topography
- ✓ optical scanning through systems like ISIS (Integrated Shape Imaging System)
- ✓ computerized raster stereography
- ✓ digital ultrasonic mapping
- ✓ three-dimensional mapping through digital image acquisition
- ✓ thermography
- ✓ the Kinect sensor
- ✓ the accelerometric sensors
- ✓ smartphone applications.

Classic radiology imaging and computed tomography use X-rays in the examination. There are studies that highlight the harmfulness of the repeated action of X-rays on the human body, especially children. The risk of cancer is 4.3% higher in people exposed to successive radiographs during the evaluation of scoliosis[9-11]. In recent years, new systems have been developed that use low doses of radiation, micro-dose X-rays.

Magnetic resonance imaging (MRI) is an imaging technique that reproduces images of the body using a strong magnetic field. The spine can be investigated very well by MRI, thus providing very precise information on all the soft tissues (vertebral discs, ligaments, spinal cord, muscles) but also on the bone tissue (vertebral bodies, ribs). But this investigation is not used to measure Cobb angles.

Moiré topography, optical scanning through ISIS (Integrated Shape Imaging System), computerized raster stereography, three-dimensional mapping through digital image processing, are optical methods for assessing the posture of body segments. They are non-invasive and non-contact methods that perform a scan of the back surface but do not allow the quantification of Cobb angles except for In Speck technology. This is based on three-dimensional mapping through digital image processing and with this system mathematical algorithms have been developed to allow the calculation of the angles of inclination in the frontal plane [12].

Digital ultrasound mapping is a method of three-dimensional analysis of the spine using ultrasound. The equipment renders schematic images in the three spatial planes and their analysis allows the identification of spinal deviations. With the Zebris system, the mobility of the spine can be analyzed and there are studies that present mathematical approaches to calculate the Cobb angles in the case of scoliosis [13].

In recent years, thermographic cameras, accelerometric sensors or the Kinect sensor have been used to detect deviations in posture analysis. Numerous smartphone applications have also been developed to help assessors detect asymmetric positions of different body segments. The advantages of these methods consist in the fact that they are non-invasive for the body of the investigated persons.

Each method, with its advantages and disadvantages, is presented in detail in the thesis.

Chapter 3. Current study on physical therapy methods used in scoliosis rehabilitation

Physiotherapy treatment goals are:

- slowing down the rate of evolution of scoliosis or, if possible, stopping the evolution of scoliosis or even reducing the Cobb angle.
- erasing wrong postural reflexes and forming new engrams on the correct position of the body in space, both statically and dynamically.
- increase in respiratory capacity[3].

Over time, numerous treatment methods that have been developed are based on static or dynamic exercises, exercises with assistive objects or even entire devices. The exercises act on the 3 planes in which the changes specific to scoliosis appear.

Classic physical therapy uses physical exercises that come from basic gymnastics. The exercises are analytical, performed simply, with or without objects, emphasizing breathing and giving particular importance to the back muscles as a whole and the abdominal muscles. Exercises are performed from all gymnastic positions: sanding, sitting, lying, kneeling or hanging.

Schroth therapy is the first therapy that addressed scoliosis three-dimensionally. Katharina Schroth, the founder of the method, introduced the principle of angular breathing as well as that of changing the perception of posture in the recovery of scoliosis. In this therapy there are used different positions in which the patient can perform self-elongation, deflection, derotation and stabilization (isometric contraction). All corrections are made simultaneously, during an angular breath directed towards concavities in deep inspiration and convexities during forced expiration[14].

The SEAS concept (Scientific Exercises Approach to Scoliosis) is based on cognitive-behavioral principles and not typical exercises as in other methods. Thus, subjects with scoliosis learn to perform a self-correction and then different exercises are introduced, performed symmetrically but in which the correction is consciously preserved [3, 7]. The ultimate goal is to stabilize the spine in the correct position.

Side shift exercise and hitch exercise were first introduced by Mehta in 1985. Depending on the location of the scoliosis, translation movements (for the thoracic area) or lifting (for the lumbar area and pelvis) can be performed [8, 15].

DoboMed is a method that mainly addresses mild, progressive idiopathic scoliosis. The exercises are carried out in a closed kinematic chain, from symmetrical positions, but the self-corrections follow alignment in the frontal plane and derotation in the transverse plane guided by breathing [3, 15]**.**

The Méziéres method aims to balance the tone within the body's muscle chains because it believes that postural deviations occur in the context of shortening of the body's posterior musculature. It consists in maintaining specific postures, in which the muscle chains are stretched and within these positions, correct, diaphragmatic breathing is performed**.**

Chapter 4. The spine and postural deformations in the frontal plane - mathematical modelling.

Mathematical modeling of the spine is possible by knowing the coordinates of some points on the column spine. An equipment consisting of accelerometric sensors can transmit the necessary coordinates. The "C" or "S" shape of the scoliotic column can be rendered using a high degree polynomial. In the study, the shape of the graphic representation was followed according to the degree of the polynomial. However, to analytically calculate the Cobb angle(s), the coordinates of two or three inflection points are needed, which requires the use of interpolation polynomials of at least the fourth or fifth degree.

To model the shape of the spine, two types of scoliosis were studied: a scoliosis with one curvature and a scoliosis with two curves. The 8th degree polynomial approximation was initially accepted, due to the use of eight experimentally determined precision points (with the designed equipment, consisting of 8 accelerometric sensors) and an imposed reference point, located on the spine, considered the origin of the system. A dedicated software application, written in MATHCAD14, was created to determine the coefficients of the polynomial and the subsequent processing of the data. Thus, the coordinates of the inflection points I1, I2, I3 and I4 and the Cobb angles between these points were obtained. Due to the fact that working with an approximation function of 8^{th} degree is difficult, the results were checked using approximation functions of 4^{th} degree polynomial approximation, which results in 2 real inflection points for the case of simple scoliosis with one curvature, and 5^{th} degree polynomial approximation, case which results in 3 real inflection points for the case of complex scoliosis with two curves.

For the cases taken into analysis, the values determined by the two mathematical functions are very close to the value calculated on the radiograph. The graphs obtained by mathematical calculation are shown below (Figure 1 and Figure 2) compared to the shape of the spine on the radiograph.

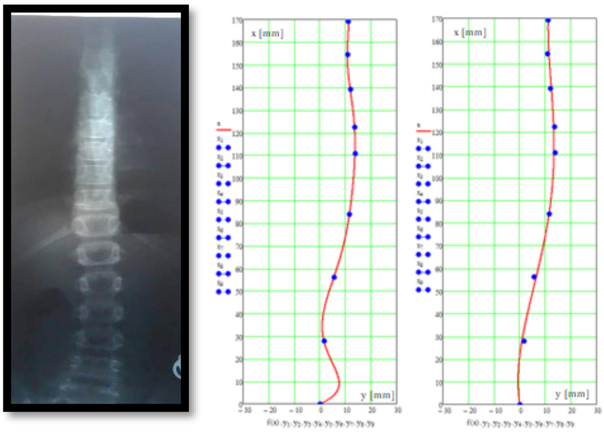


Figure 1. a) The shape of the column on RX, b) Mathematical model of the column calculated with approximation polynomial of 8^{th} degree, c) Mathematical model of column calculated with approximation polynomial of 4^{th} degree

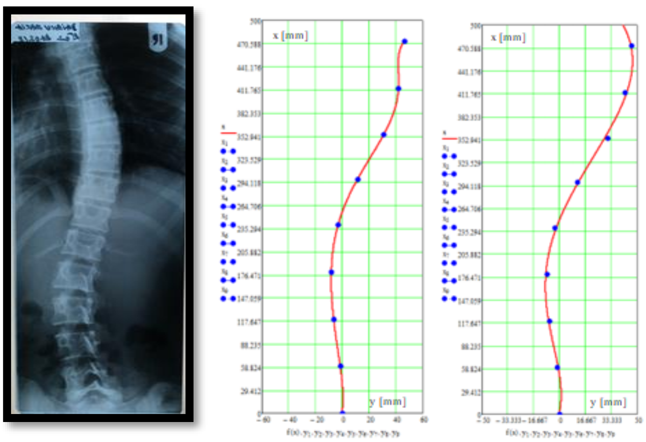


Figure 2. a) The shape of the column on RX; b) Mathematical model of the

calculated column with approximation polynomial of 8th degree, c) Mathematical model of the column calculated with polynomial of5th degree 5 approximation

The tests carried out highlighted the possibility of using high degree approximation polynomials in order to obtain the mathematical form of the spine and the calculation of the Cobb angle/angles. For the calculation of Cobb angles, it is necessary to use at least degree 4 of the polynomial for scoliosis with one curvature, and degree 5 of the polynomial can be used in modeling the shape of a scoliosis with more than one curvature. This way of modeling the spine can be extremely useful in following the evolution of a scoliosis by the orthopedic doctor who must observe the evolution over time of the spinal deviation, but also by the physiotherapist who must carry out effective recovery programs.

Since the literature does not provide theoretical or practical elements related to such a mathematical approach, the content of this chapter is largely original.

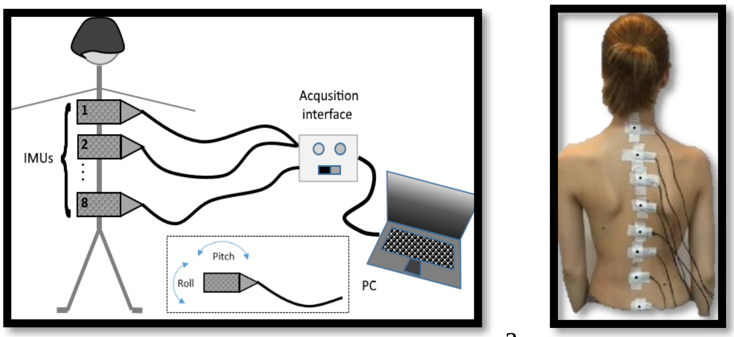
Chapter 5. Equipment used in experimental research

In the framework of the doctoral research, the goal was to create a device that would allow the calculation of the angle of inclination without harming the investigated body.

An equipment consisting of accelerometric sensors was designed and built because the use of these sensors has several advantages:

- it is possible to take measurements regardless of the age of the patient diagnosed with scoliosis and regardless of gender.
- the data retrieval time is relatively short.
- represents a non-invasive and painless method.
- provides numerical data, easy to store and necessary for generating a mathematical model of the column.

The number of data sampling points was set at 8, sufficient to be used in higher degree approximation polynomial modeling and rational from a practical point of view, considering the physical dimensions of the components.



a. b.

Figure 3. a) Equipment diagram of data from accelerometers. b) Positioning of the sensors on the spinous apophyses of the column spine

An acquisition system consisting of an assembly of 8 MEMS IMUs [16] (inertial measurement units) connected via their I2C bus to an I2C multiplexer [17] and a microcontroller board [18] was designed and built. (Figure 3.a). Since the IMU boards are PCB supports, they have been protected against the ingress of foreign materials (glue, liquid drops, finger touch) by encapsulating them in heat shrink tubing. Encapsulation also allows the sensor to be applied to the patient's skin using a medical adhesive.

Each sensor must be glued to the skin, above the vertebral spinous apophyses (as can be seen in Figure 3.b). Accelerometric sensors generate data consisting of the three angles (φ_x, φ_y,

φ_z) around the axes of a reference system. Considering the accepted mathematical model as a plane curve in the frontal plane, only the Pitch angle provided by the sensors was used. The projection of the measurement points on the frontal plane consists of nine points, for which the angles φ_{xi} (i = 1...8) are known from the sensors, and the distances between the points li, i + 1 (i = 1...8) were measured directly during the investigation. In Figure 4, points M1 ... M9 are represented, in an orthogonal reference system. The 8 measurement points were joined by a point that coincides with the origin of the reference system [19].

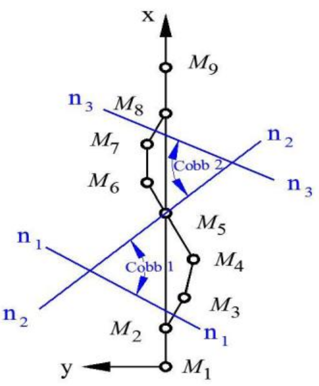
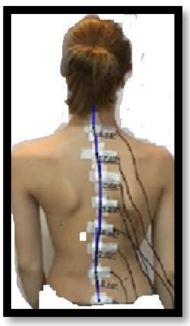
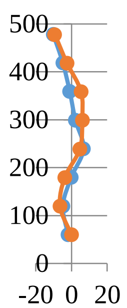


Figure 4. The 9 acquisition points and Cobb angles

The microcontroller reads all 8 accelerometer values in a continuous loop, calculates the angles and transmits the values to the connected PC with the frequency of 5 Hz. This method of acquisition can be used both to evaluate the position of the spine in orthostatism but also during the static exercises encountered in the recovery methods specific to scoliosis and in which the spine is kept in the same position for a few seconds.

In order to validate the data obtained experimentally, a dedicated test was subsequently carried out, in which the coordinates of some points noted on the column and the obtained mathematical form were compared with data resulting from the acquisition of a reference image, considered as a reference. The results of the above procedure are illustrated in Figure 5, for the standing position. For this position, the reference image (Figure 5. a), the processed reference image (Figure 5. b), the graphic representation of the column obtained with the accelerometric sensors (blue) and from the image (red) are placed side by side (Figure 5 .c) and the Pitch angles resulting from the two approaches (Figure 5. d).





φ [deg]	
Senzori	Imagine
-2.77	-6.1
4.46	2.52
6.54	8.19
-4.32	1.23
-3.00	-0.64
-3.70	-7.61
-5.11	-6.54

a) b) c) d)

Figure 5. a) Reference image, b) Processed reference image, c) Column shape obtained by image processing, respectively data acquisition, d) Pitch angles resulting from image processing, respectively data acquisition

The second system used in the experimental research was the FLIR B200 thermal imaging camera. Studies in the literature have demonstrated that children with scoliosis present areas of thermal asymmetry on the back of the trunk and this observation was significantly correlated with the angle of rotation of the trunk [20]. The authors concluded that thermography can be used as a complementary tool in the screening of children with scoliosis [21].

Taking thermal images presents substantial advantages over traditional methods of spine investigation:

- it is non-invasive and painless for the patient.
- images can be taken in any workspace, because the device is small, mobile and light.
- the thermal chamber is easy to handle by the therapist and offers instant results.
- the thermal image is unique due to its intuitive character. No other imaging procedure provides such an easy-to-read result.
- the therapist can take images at the beginning of the session, but also during the exercise program, thus obtaining valuable information regarding the effectiveness of the proposed exercise.

During the experiments, the images were taken by the physiotherapist in the office working with the patients. As a procedure, it was found useful to take several image sequences, in order to be able to make comparisons.

Chapter 6. Experimental research

Experimental determinations with the equipment based on accelerometric sensors

To validate the designed equipment and calculation methods, experimental measurements were made on a group of 9 subjects diagnosed with scoliosis (subjects with one curvature and two curvatures). The values of the Cobb angles obtained following the application of the mathematical algorithms had a good correlation with the values calculated by the radiologist on the X-ray. The difference between the mathematically calculated values and the values calculated by radiologists did not exceed 2-3º. The obtained experimental results confirmed the hypothesis of using approximation polynomials of 4^{th} degree for scoliosis with a single curvature and those of 5^{th} degree for scoliosis with two curvatures at the expense of polynomials of higher degrees.

Having validated the work protocol, the analysis of the exercises used in the physical therapy programs was carried out.

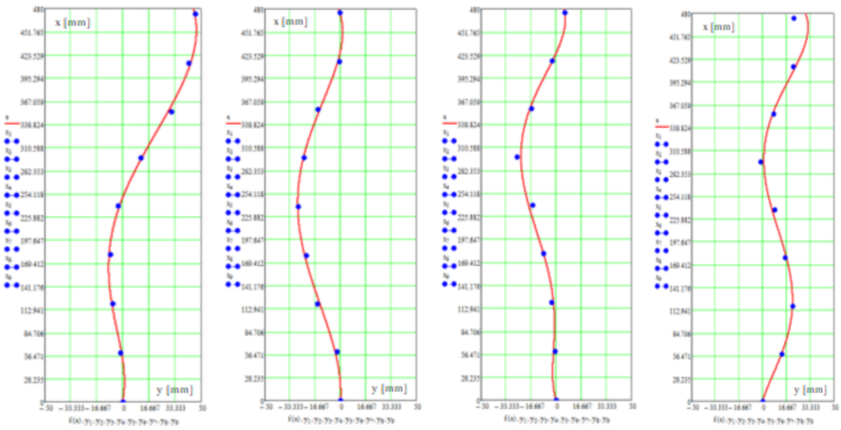
The lateral tilt movement that is used in classical physical therapy programs was initially taken up for analysis. The study participant performed both right and left side tilts on a 10º to 10º progressive scale. The subject's movement was guided on a graduated scale in front of him. For each lateral tilt position, both a data acquisition from the accelerometric sensors and a photographic acquisition were made [22]. The analysis of the results confirmed that the movement that determines the alignment of the vertebral bodies is that of tilting on the side of the convexity. Therefore, in the case of single-curvature scoliosis the side-bending movement, in which the concavity opens, is a safe movement that can be used both during physical therapy exercises and in everyday life. In the case of double-curved scoliosis, lateral tilts accentuate one of the curves, so these movements must be avoided both in the case of exercises in physical therapy programs and in the activities that subjects with scoliosis carry out on a daily basis.

In the following experiment, three types of exercises that belong to different methods of scoliosis treatment were analyzed: Schroth, Mézières, classical physical therapy. Cobb angles were calculated in the standing position (as performed by X-ray) but also during exercises. The Cobb angle values calculated in different exercise sequences were compared with the Cobb angle value obtained on X-ray. Table 1 shows the values recorded in the first case taken for analysis.

Table 1. Cobb angle values during the exercises taken in the study, for the 2 curves

Cobb angle values	RX	Standing position	Schroth Exercise	Exercise from Mézières method	Exercise from hanging
Cobb 1	22°	21.84°	14.79°	11.44°	22.25°
Cobb 2	28°	28.37°	21.39°	23.24°	24.21°

The graphic representation of the values obtained after the mathematical calculation is presented in Figure 6.



a) b) c) d)

Figure 6. Spine model calculated using the 5th degree approximation polynomial in different exercises a) Standing, b) Schroth exercise, c) Mézières exercise, d) Hanging exercise

The table and graphs above highlight a decrease in Cobb angles in the positions adopted during the 3 exercises specific to the different treatment methods. The position where both Cobb angles decrease the most is part of the Schroth method. Also, a significant decrease in angular values can be observed in the Mézières position, but following the curve described by modeling, an increase in compensatory curves can be observed. In the suspension position, only an improvement in the Cobb angle value in the dorsal area was highlighted.

The experiment was repeated on the entire group studied (9 subjects) and the results showed the superior efficiency of the exercise in the Schroth method because the greatest decrease in Cobb angles is achieved during the execution of this type of exercise.

Experimental determinations using the thermal imaging camera

Starting from the observations in the specialized literature, we used the FLIR B200 thermal imaging camera in research experiments to analyze the effectiveness of physical therapy exercises specific to different treatment methods. The thermographic camera was used to record the temperature of the body surface before the start of the exercises (to know the initial state of the subjects) and at the end of the exercise (to observe the final effect). All experiments took into account the requirements of the European Association of Thermography: room temperature $23\pm1^{o}C$, image acquisition was made from 1.5m away from the subject, perpendicular to the evaluated area.

Three different experiments were performed. The first experiment aimed to evaluate the three exercises that were also tracked with the accelerometer equipment, a second study evaluated exercises performed from lying positions (ventral and lateral) specific to the Schroth technique and classical physical therapy and the last experiment aimed to evaluate exercises that are performed symmetrically for muscle toning and are indicated very often by instructors or therapists.

Initially, the testing was carried out in parallel with the equipment made up of accelerometric sensors and the thermal imaging camera. It was found that the repetition of movements in which muscle contraction causes a repositioning of the vertebral bodies and implicitly a decrease in the Cobb angle, causes an increase in temperature in the targeted area. The exercises that decreased the Cobb angle the most in the frontal plane were those that also showed an obvious increase in temperature from baseline. The results obtained as a result of this experiment confirmed the hypothesis from which we started at the beginning: the more efficiently the muscles are activated, an increase in the temperature occurs on the surface of the skin, and at the level of the spine, a repositioning of the vertebral bodies is achieved, by decreasing the angle Cobb.

Next, the experiment with the thermal imaging camera targeted a group of 30 subjects. All subjects experienced increases in back skin temperature after each type of exercise, but comparisons of the (ΔT) differences in increases observed after each type of exercise revealed that it was the Schroth therapy-specific exercise that determined the greater increase in temperature in the back. Also, of the other two exercises, the one belonging to the Méziéres method recorded a higher temperature increase in the back than the hanging one.

The second study aimed at the evaluation of exercises specific to Schroth therapy and classical physical therapy from the ventral and lateral lying positions. This experiment was performed on a group of 14 subjects. The changes occurring in the thoracic and lumbar areas were separately analyzed. Following this experiment, the following observations were made:

- ✓ the use of the thermal imaging camera makes possible the differentiated analysis of the efficiency of recovery methods specific to scoliosis
- ✓ the images captured with the thermographic camera revealed that exercises from the Schroth method (which use isometric contractions) increase the temperature at the back level more than classic exercises (which use concentric and eccentric contractions);
- ✓ it was observed that during the exercises from the Schroth method, the muscles are activated more specifically on the area of convexity, at the level of the vertebra at the top of the curvature, which implies a greater efficiency of them in correcting the lateral inclination.
- ✓ the exercises evaluated in lying lateral position from both treatment methods proved to be the ones to correct better the deviation in the frontal plane;
- ✓ the Schroth exercises in the prone position are less effective for correcting the deviation in the frontal plane.
- ✓ exercises in the prone position belonging to the Cotrel method are effective especially in the case of long thoracic scoliosis.
- ✓ in the case of lumbar scoliosis, the use of exercises from the Cotrel method initially revealed an increase in local temperature in the concave area, which implies that a greater number of repetitions is needed to observe increased activity around the convexity muscles.

The last experiment carried out in the framework of the PhD research aimed to analyze the activation of the back muscles during the movements performed symmetrically by subjects with scoliosis and also by subjects without postural deviations, to observe if there are differences in the activation of the back muscles between the two categories of subjects. Thirty subjects were divided into 2 groups: a control group and a study group, each group consisting of 15 participants. Healthy subjects without postural deviations were included in the control group.

The study group included subjects diagnosed with mild scoliosis without an indication for a brace and without other associated diseases. A first acquisition was made after adjusting the body to the ambient temperature of the room where the experiment took place and another one after each exercise performed. Three exercises that are generally recommended by instructors or therapists to tone the back muscles were chosen for evaluation. These exercises are shown in Figure 7.

Figure 7. The exercises chosen for analysis within the experiment.

During the experiment, a symmetrical muscle activation was observed in the subjects of the control group during the 3 analyzed exercises. The back muscles on the right and left side worked in balance, activating symmetrically during the movements as can be seen in Figure 8.

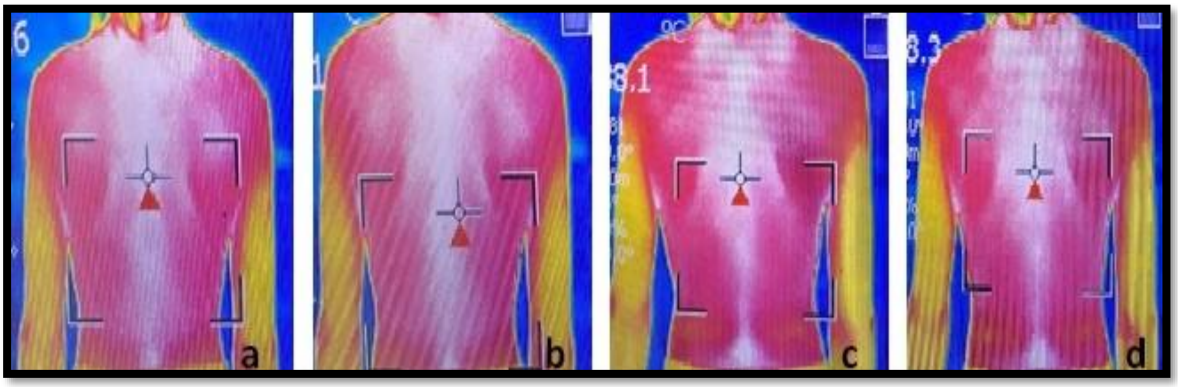


Figure 8. Subject without scoliosis a) initially acquired image, b) acquired image at the end of exercise 1, c) image acquired at the end of exercise 2, d) image acquired at the end of exercise 3

In the case of the subjects in the study group, the first image taken showed a chromatic asymmetry between the right and left sides of the back due to the different temperatures in the muscles [23]. Later, during the execution of the exercises even if they were carried out symmetrically, an asymmetric activation of the back muscles was found, as can be seen in the example in Figure 9.

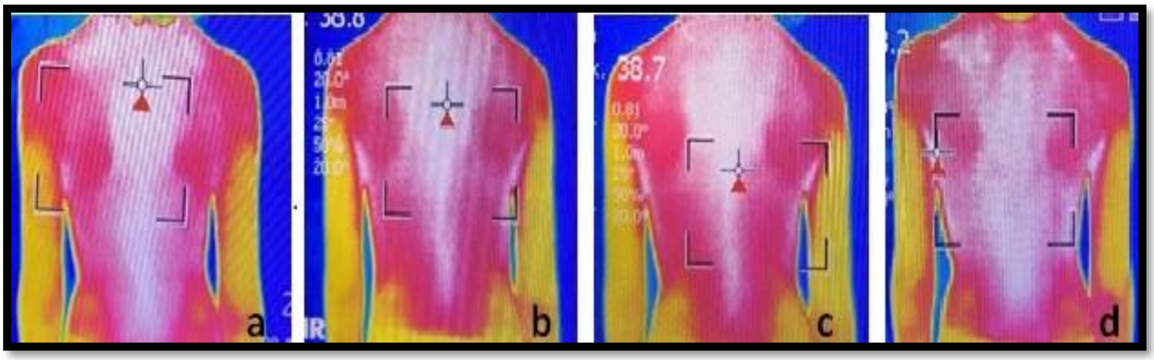


Figure 9. Subject with scoliosis a) initially acquired image, b) image acquired at the end of exercise 1, c) image acquired at the end of exercise 2, d) image acquired at the end of exercise 3

As the acquired images of the subjects with scoliosis revealed asymmetric muscle activation, they were also asked to participate in a further assessment where the exercises were corrected in real-time by the physiotherapist through verbal cues on areas of interest or back position, upper and lower limbs. In Figure 10 you can see how the corrections made by the physiotherapist influence the muscle activity during the execution of the exercises: the initial image, the final image after the first experiment and the final image after the second experiment.

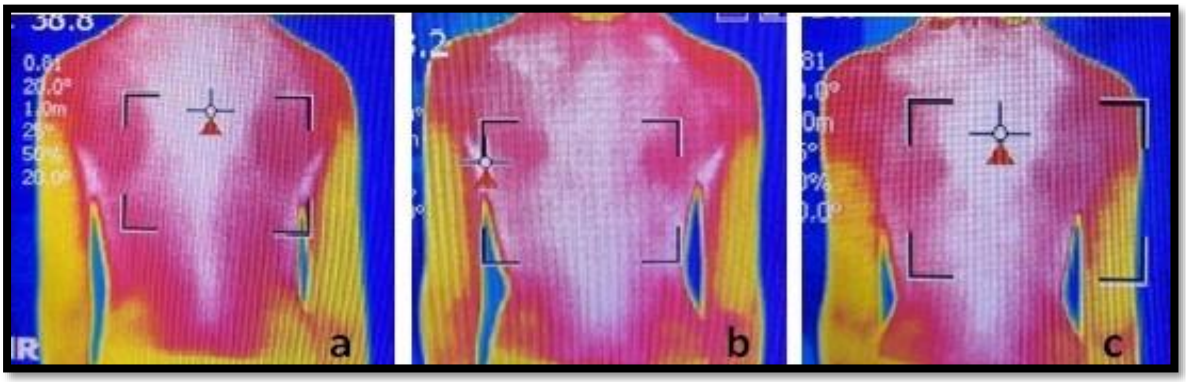


Figure 11. Subject with scoliosis: a) image taken at the beginning of experiment 1 b) image taken at the end of experiment 1 c) image taken at the end of experiment 2

The second experiment carried out with the subjects of the study group highlighted the fact that in the case of subjects with mild scoliosis, a balanced activation of the back muscles can be achieved if they are supervised and corrected by a therapist. The minimal imbalance observed at the initial assessment is maintained during the execution of symmetrical exercises if no external intervention is made to make them aware of the positions used or the asymmetrical movements executed.

Chapter 7. Conclusions and personal contributions

The present paper **”The development of certain methods for assessing the efficiency of kinetic specific exercises in scoliosis rehabilitation** is based on the theoretical and practical knowledge of the author accumulated in an experience of over 20 years in the field of medical recovery. The research thesis was carried out with the aim of to demonstrate the beneficial effect that physical exercises have on improving posture in the case of scoliosis, through the changes in Cobb angles during treatment, but also the activation of the back muscles during specific physical exercises.

The analysis of the results obtained from theoretical research and experiments led to the following conclusions:

- Mathematical modeling of the shape of the vertebral column is possible by using polynomial approximation functions of degree 4, 5 and 8 using dedicated software applications (generated in MATHCAD14);
- The approximation curves obtained are close in shape to those of the spine present on the X-ray and the numerical value of the Cobb angles calculated with the help of the normals at the inflection points of the polynomial curves are very close to the values calculated by the radiologists on the X-ray in the case of the entire batch taken in study.
- The 4th degree approximation polynomial can be used in the case of scoliosis with a single curvature because it leads to finding 2 inflection points between which the sought Cobb angle can be calculated.
- The approximation polynomial of the 5th degree leads to obtaining three inflection points which are necessary for the calculation of 2 Cobb angles present in the case of scoliosis with 2 curves.
- This way of modeling the spine can be extremely useful in following the evolution of a scoliosis and, therefore, the developed accelerometer equipment facilitates and streamlines the observation of scoliosis over time by both the doctor and the physiotherapist.
- The equipment made up of accelerometric sensors can be used to analyze changes in Cobb angles during exercise sessions in which it is desired to assess their efficiency.
- Following the evolution of the Cobb angles in certain exercise sequences, the therapist can correct and make the exercise program more efficient.
- The designed equipment allows the therapist to choose the most effective exercises for each individual patient.
- The thermal imaging camera can be a very useful tool in physical therapy rooms, during postural rebalancing programs.
- • The use of the thermal imaging camera makes the work of the therapist easier because he can better observe the muscles involved in performing the exercises, which makes possible an effective correction.
- The exercises that belong to the Schroth method bring the greatest changes in the Cobb angles compared to the reference values and the analysis with the thermograph showed a greater increase in the temperature on the convexity zone in the case of their execution.
- The specific exercise of the Mézières method in most cases changes the Cobb angle in the main curvature, but compensation elements may appear above and below it.
- Analyzing the lateral tilting movements indicated in the case of classic recovery programs, an alignment of the vertebral bodies in the area of convexity was found, but the upper and lower compensation areas can register an aggravation by increasing the curves.
- The position from which the exercise is performed is important because it can help make the movement more efficient. Exercises in the lateral decubitus activate the back muscles more effectively than exercises in the ventral decubitus.
- The exercises in the prone position specific to the Cotrel method are effective, especially in the case of long thoracic scoliosis, because the muscle activation is carried out on the middle thoracic and lumbar area.
- The use of the thermographic camera as an investigation method revealed that symmetrical exercises performed by children with mild scoliosis can asymmetrically activate the back muscles if not corrected by a therapist.

- Symmetrical exercises could be recommended in home programs, only after the subjects know how to perform them correctly and only under the supervision of adults who have been trained in advance.

Personal contributions

- Synthesis of interdisciplinary bibliographic material, which includes information from anatomy, biomechanics, mathematics, informatics, investigative medicine and kinesiotherapy.
- Mathematical modeling of the shape of the vertebral column by determining polynomial approximation functions of 4^{th}, 5^{th} and 8^{th} degree, using dedicated software applications (generated in MATHCAD14);
- The proposal to use polynomials of 4^{th} degree in the case of scoliosis with one curvature and polynomials of 4^{th} degree in the case of double scoliosis, for the calculations necessary for the mathematical modeling of the scoliotic spine.
- Designing an equipment consisting of accelerometric sensors that can be attached to the skin of the investigated subject to detect the deviation in the frontal plane.
- Validation of the values obtained by mathematical calculation with the values measured on X-ray in the case of a group of subjects diagnosed with scoliosis.
- Using the equipment made up of accelerometric sensors, to study the change of Cobb angles, in different sequences of rehabilitation exercises.
- Carrying out a comparison between exercises that belong to different treatment methods, considering the changes in Cobb angles in different sequences of movement execution.
- Interpretation of the results obtained from the experiments, by creating graphs and tables relevant to the study.
- The proposal to use the thermographic camera to analyze the activation mode of the back muscles during scoliosis-specific exercises.
- Analysis of temperature variations at the back depending on the exercise performed by the subject with scoliosis.
- Comparative thermographic investigations between exercises belonging to different methods of specific scoliosis treatment (Schroth method, Méziéres method, classical physical therapy);
- Testing a group of 30 subjects and subsequent analysis of the acquired images, in order to assess the effectiveness of the exercises performed to correct scoliosis.
- Investigating some exercises performed symmetrically (often used in physical therapy offices and also indicated on the Internet) by subjects with mild scoliosis and also by subjects without deviations in the frontal plane, to follow the mode of action of the back muscles.
- Demonstrating the necessity of carrying out rehabilitation treatments under the supervision of therapists, even in cases of mild scoliosis, due to the fact that the muscles of subjects with postural deviations act differently compared to people without posture problems.
- The results obtained proved the importance of evaluating physical exercises individually, for each individual case, in order to increase the efficiency of the exercises used.

Looking at all the results obtained in the doctoral research as a whole, it can be stated that performing physical exercises can act in order to reduce scoliotic curves. The corrective movements determine both a repositioning of the vertebral bodies by reducing the Cobb angles and a selective activation of the muscles in the areas of major inclination. However, it is important that the exercises are adapted to the type of scoliosis and the ability of the subject to correctly execute the exercises according to the indications given by the therapist. The use of equipment that provides real-time information on the position of the spine or the degree of muscle involvement can be essential in making physical therapy programs more efficient.

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