IOP Conf. Series: Materials Science and Engineering **444** (2018) 052020 doi:10.1088/1757-899X/444/5/052020

Discussion on Cobb Angle variation during progressive lateral flexion of the trunk

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Abstract. Scoliosis as a spinal disorder is very frequent in children population. The objective parameter to define the gravity of scoliosis and to assess its evolution is the Cobb angle. The variation of the Cobb angle in different tilted positions is studied within an experimental program. Data is acquired from a set of sensors attached to the patient's back and is processed to provide the Cobb angle. The mathematical approach is based on a fifth degree polynomial, which approximates the shape of the column. The results show that lumbar and thoracic Cobb angle vary in opposite directions, so that the flexion to the right and to the left aggravates the scoliosis, no matter on which side it is.

1. Introduction

Statistics produced in recent years have shown an increase in number of children diagnosed with scoliosis. This is a deviation of the spine characterized by the presence of one or more curves in the frontal plane, accompanied by the rotation of the vertebral bodies [1, 2]. This deviation of the column occurs especially in girls (75-80% of cases) at the age of puberty or a few years before it. Studies show that 91-92% of all scoliosis diagnosed are idiopathic scoliosis, the scoliosis with unknown cause [3].

Diagnosis of scoliosis is made after a clinical examination and a radiological examination, in which the value of the inclination angle of scoliosis is determined (the Cobb angle). This is defined as the angle formed by the intersection of the tangent line to the upper plateau of the superior vertebra of the curvature and the tangent line to the inferior plateau of the lower vertebra of the curvature. Following the radiological examination, the therapeutic protocol to be followed, is depending on the magnitude of the Cobb angle [1, 4]:

-if the angle is up to 25 ° - only therapeutic exercises are indicated,

-if the angle is between 25° and 45 °, there are indicated therapeutic exercises and the wearing of the brace,

- if the angle is greater than 45 ° -50 ° there is a recommendation for surgery.

The Cobb angle is conventionally determined using an X-Ray image taken for a straight, orthostatic posture.

In current practice, there are many cases where wearing a brace is needed and children refuse this device. In these cases scoliosis evolves dramatically without proper treatment. The role of the brace in the middle stage of the scoliosis is to correct and sustain the column. During the wearing of the brace, the amplitude of the lateral flexion movements is diminished, allowing only the anterior flexion of the trunk, done in the coxofemoral joint.

The purpose of the current study is to calculate the Cobb angle at different degrees of lateral flexion of the trunk in order to observe what happens with the spine of a child with medium scoliosis, who does not wear the brace and performs normal daily activities. The variations of the Cobb angle during different movements of the trunk are of interest as in everyday life children perform multiple lateral flexion or sit in tilted positions during classes or at home when they do their homework. Studies on the variation of Cobb angle in variable postures are not very frequent in the literature. The studies focus rather on reproducibility of measurements [5, 6] or variation depending on the experience of the operator or on a parameter such as gravity, which influences the posture during a day-time [7].

2. Equipment and processing of data

The method proposed to acquire data is based on the use of eight accelerometers attached to the column of the patient. Details regarding the components and the functioning of the system are given in previous papers of the authors [8]. The accelerometers provide the angles relative to the vertical axis, within the frontal plan.

The angles φ_i (i= 1... 8) and the distance l_i between the sensors allow the computation of their coordinates (x_i, y_i) as shown in Figure 1. Point M_1 (0, 0) is considered the origin of the reference system.

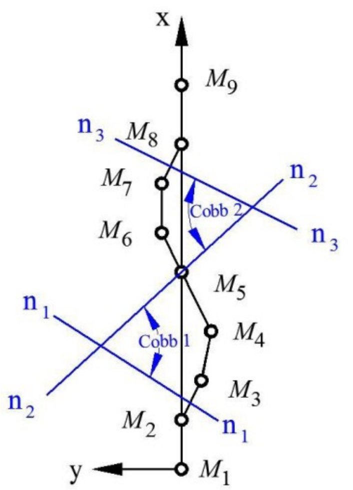

Figure1. Scheme of the sensors applied on the column and Cobb angles. [8]

Figure 1 illustrates the Cobb angles of an "S"-shaped column. Data provided by the acquiring system are processed guided by the following workflow:

- computation of the coordinates:

$$\begin{cases} x_{M1} = 0 \\ y_{M1} = 0 \\ x_{Mi+1} = x_{Mi} + l_i \cos\varphi_i & i = \overline{1,8} \\ y_{Mi+1} = y_{Mi} + l_i \sin\varphi_i & i = \overline{1,8} \end{cases} . \quad (1)$$

- graphical representation of the experimentally resulted shape of the column and comparison with the photo taken during the measurement
- approximation of the column shape with a five degree polynomial, $y(x)$ and calculus of the inflexion points (x_1, x_2, x_3), which are the roots of a third degree polynomial, $y''(x)$:

$$y = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5, \quad (2)$$

$$y'' = b_0 + b_1x + b_2x^2 + b_3x^3 . \quad (3)$$

- calculus of the normal line angles to the curve $y(x)$ and then of the Cobb angles:

$$m_1 = -\frac{1}{y'(x_1)}, \qquad m_2 = -\frac{1}{y'(x_2)}, \qquad m_3 = -\frac{1}{y'(x_3)}, \tag{4}$$

$$Cobb1 = \arctan\left|\frac{m_1 - m_2}{1 - m_1 m_2}\right|, \qquad Cobb2 = \arctan\left|\frac{m_2 - m_3}{1 - m_2 m_3}\right|. \tag{5}$$

- study on the Cobb angles course during the lateral flexion of the trunk to the right and to the left, at different progressive angles.

3. Experimental results

The experimental program is based on measurements, which were performed with the consent of patients and their parents.

The patient with a medium "S"-shaped idiopathic scoliosis was asked to tilt starting from the orthostatic posture, to the left and then to the right in progressive tilted positions with the step of 10 degrees between positions. In each position, a photo was taken as a reference needed to validate the further mathematically generated shape.

A sample of calculus developed in MS Excel for the orthostatic posture (0 deg) is presented in table 1.

Table 1. Determination of Cobb angles for the tilt angle 0deg.

	Sensor number	φ [deg]	l [mm]	y [mm]	x [mm]
Coordinates of the sensors	1	-1.84	60	-1.9265	59.9690
	2	-2.77	60	-4.8261	119.8990
	3	4.46	60	-0.1603	179.7173
	4	6.54	60	6.6734	239.3268
	5	-4.32	60	2.1538	299.1564
	6	-10.65	60	-8.9346	358.1228
	7	-3.7	60	-12.8066	417.9978
	8	-5.11	60	-18.1507	477.7593
Fifth degree approximation polynomial	$y = -6.185E-11x^5 + 9.779E-08x^4 - 5.696E-05x^3 + 1.459E-02x^2 - 1.553E+00x + 5.005E+01$				
Second derivative of the polynomial	$y'' = -1.237E-09x^3 + 1.17E-06x^2 - 0.00034x + 0.02918$				
Roots of the second derivative (inflexion points)	$I_1(152.005; -1.77)$; $I_2(339.382; -4.247)$; $I_3(457.26; -16.554)$				
Cobb Angles	Cobb1 = 15.70 deg; Cobb2 = 4.80 deg.				

Similar calculus was performed using data acquired for angles in the interval [-50; +50] deg, step 10 deg, considering the angles negative for the tilting to the left and positive for the tilting to the right.

Figures 2 ... 12 present the images and the graphs of the fifth degree polynomial determinate with the coordinates resulted from processing data from the accelerometers. One can notice the high degree of similarity of the shapes mathematically generated and the images, which is considered a validation of the mathematical model and the accuracy of calculation.

The lumbar (Cobb1) and thoracic (Cobb2) Cobb angles were represented in respect with the angle of tilting (figure 13).On the same graph is added a polynomial approximation of the courses (Cobb1 - third degree, Cobb2 - fifth degree).

The most important observation is that the trends of Cobb1 and Cobb2 are opposite. The graphs are approximately antisymmetric. This means that no matter on what side the scoliosis is noticeable in orthostatic position, tilting aggravates one of the curvatures.

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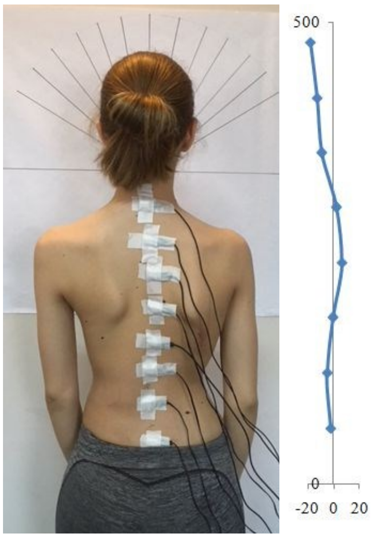

Figure 2. Photo and experimental shape (0 deg).

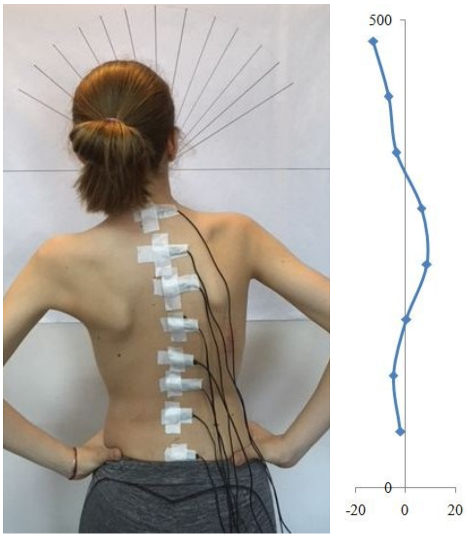

Figure 3. Photo and experimental shape (- 10 deg).

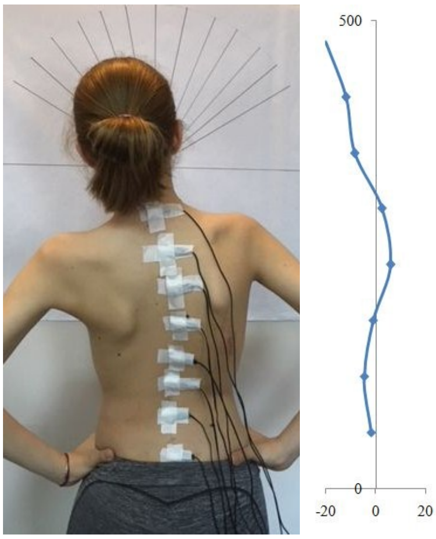

Figure 4. Photo and experimental shape (-20 deg).

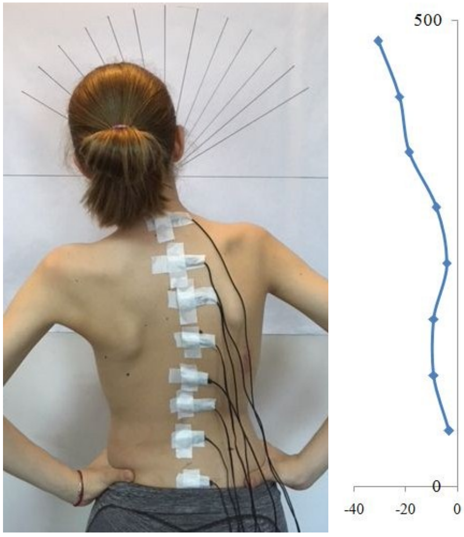

Figure 5. Photo and experimental shape (-30 deg).

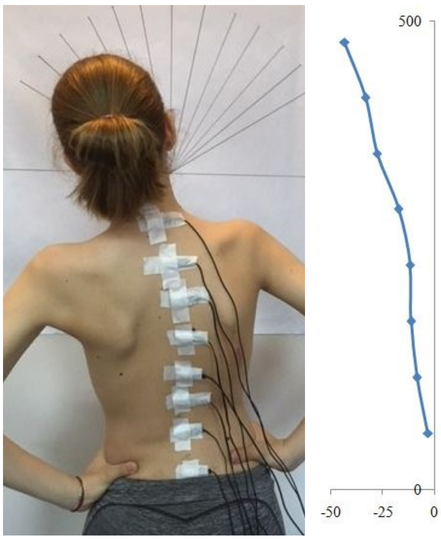

Figure 6. Photo and experimental shape (-40 deg).

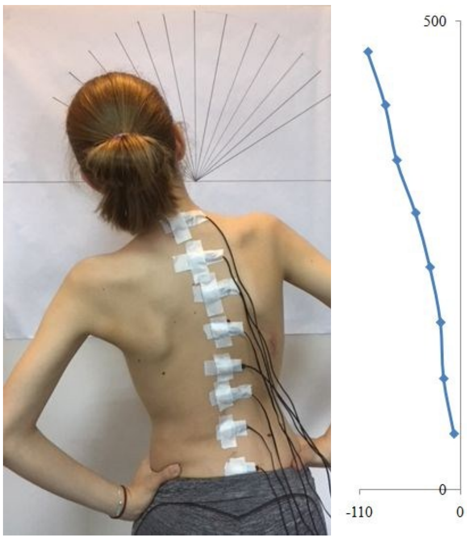

Figure 7. Photo and experimental shape (-50 deg).

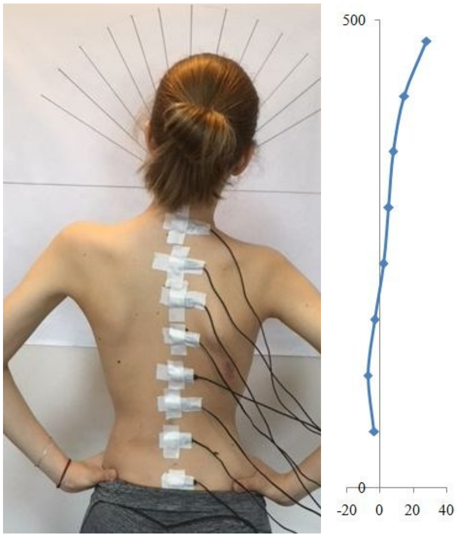

Figure 8. Photo and experimental shape (10 deg).

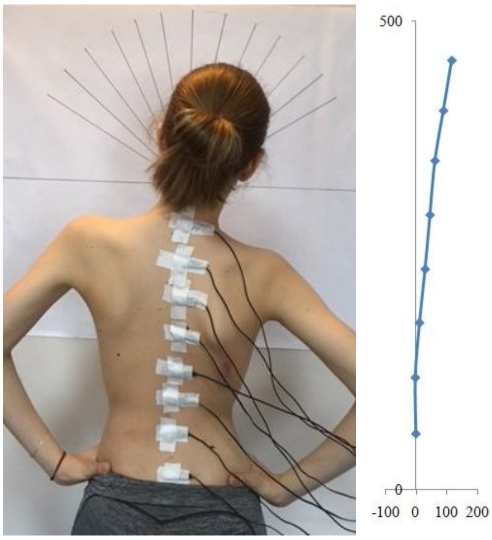

Figure 9. Photo and experimental shape (20 deg).

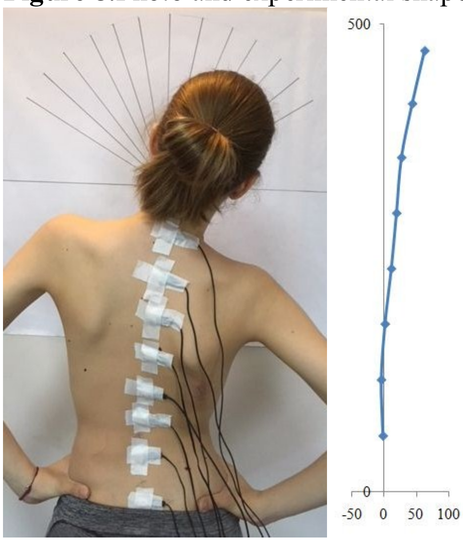

Figure 10. Photo and experimental shape (30 deg).

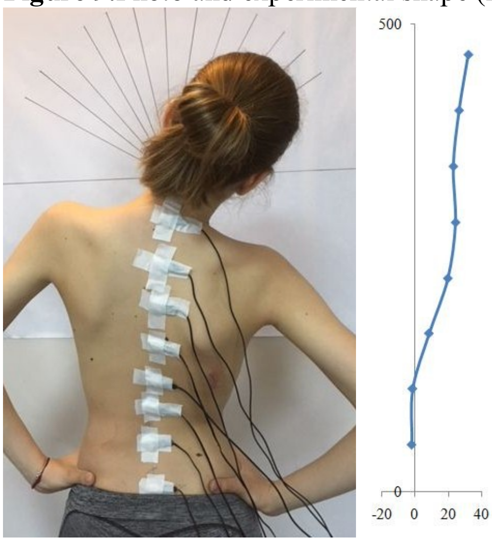

Figure 11. Photo and experimental shape (40 deg).

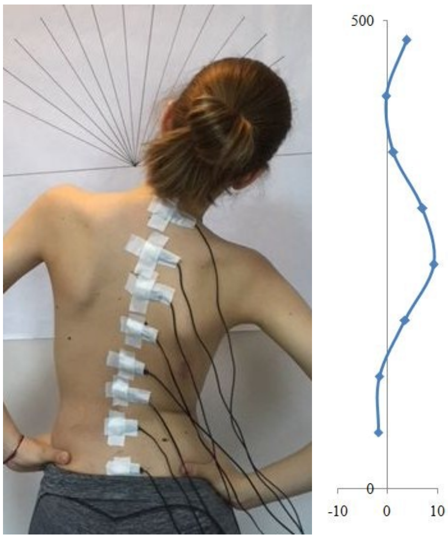

Figure 12. Photo and experimental shape (50 deg).

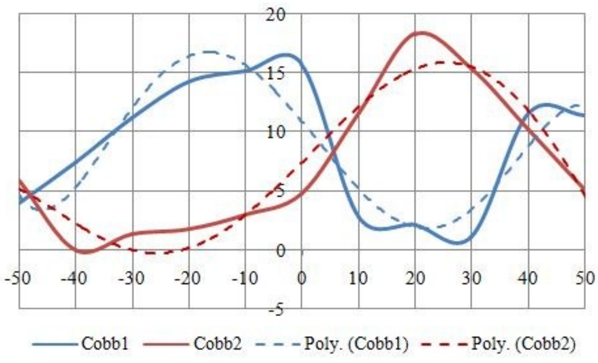

Figure 13. Variation of the Cobb angles.

However, in the case of the scoliosis taken into study, it can be notice a decrease of both Cobb angle for the inclination on the left of the trunk (the concave side of the thoracic deviation of the spine), which is similar to the position used in Schroth method for scoliosis rehabilitation. This contravenes the principles that have been used for the recovery of scoliosis until recently, namely: to do a tilting movement on the convex side in order to open the concavity and to succeed in elongating the shortened muscles in this area. Unfortunately, in the case of a double scoliosis, as the one discussed, the repeated and uncontrolled lateral inclination movements as well as the long lateral postures lead to the worsening of one of the curves at least. It is therefore necessary to wear the brace during daily activities in the case of medium scoliosis, which prevents lateral inclination of the column.

4. Conclusions

The study of Cobb angle variation in respect with the tilt angle of the trunk is a sequence of an extended research program regarding the treatment of idiopathic scoliosis. Experimental data processed analytically and graphically provided the shape of the column and the values of the Cobb angles. The mathematical approach was validated by comparison of the simulated shape of the column with the photos taken during the measurements. Judging the results, the conclusion is that tilting aggravates the Cobb angles in an anti-symmetric manner. Thus, control of the posture becomes very important and wearing directions of brace should be respected in order to stop scoliosis from evolving.

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