

RELATIVE ROTATION ANGLE BETWEEN SPINAL VERTEBRAE USING COMPLEX SHAPE MARKERS

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Keywords: vertebral column, rotation angle, marker, VB application

Abstract: The paper presents a method to determine the relative rotation angle between two successive vertebrae or between the first and the last vertebra of a segment of the spine. A set of "T" shape markers are applied on the vertebrae of interest and 3D coordinates of four points are picked up using a non – invasive method of investigation. Mathematical processing of coordinates allows computation of angles. A numerical example illustrates the principle of the method. An appropriate software was designed to access a database, to accomplish the calculus and to display the results.

1. INTRODUCTION

The most persons of now-days society suffer of mild or severe spinal column deformations, such as scoliosis, lordosis and kiphosis. These deformations cause diminution of personal comfort and physical and intellectual effort capacity. When severe, deformations bring on accentuated distortions of thorax shape and alteration of respiratory process. Such spinal diseases occur frequently to school age population, due to incorrect posture and/or to the improper desks design and only infrequently to adult population, due to sedentary activities (teachers, librarians, IT specialists etc.). It is necessary to identify at early stages the spine deformations [3].

There are several methods to investigate the vertebral column. Traditionally, the X-rays image is regularly used by doctors. World-wide, the present trend is to replace classical invasive methods with non – conventional, non – invasive ones, using CCD cameras, ultrasounds or laser sources [1], [2], [4-6]. All these methods are computer assisted, in order to pick, stock and process the measurement data. As a general rule, the computer – assisted methods gather numerical data for each vertebra, process data and provide different information, such as distances and angles between the elements of the column.

Assuming a certain method of investigation able to supply numerical data is chosen, the present paper presents an algorithm to compute the relative rotation angle between vertebrae.

2. PRINCIPLE OF THE METHOD

Ultrasound or imaging methods use markers temporary fixed on the vertebrae. Complex shape markers allow gain of 3D coordinates of more points. Such information can be processed in multiple ways and can provide a picture of relative position both for neighbour vertebrae and for the entire structure of the vertebral column.

The paper proposes a method to measure the relative rotation angle between two successive vertebrae. The method can be extended to a zone of the column (cervical, thoracic and lumbar), to interzonal segments or to the entire structure of the spine.

The complex shape marker was conceived on the basis of several criteria to be satisfied:

- ❑ possibility to collect coordinates for more points
- ❑ position of measuring points so that mathematical process to be as simple as possible
- ❑ plastic behaviour of the marker so that it totally adheres to the surface of the skin around the vertebra
- ❑ a reference point on the marker, which must superpose the spinous process
- ❑ a specific geometrical element to ensure marker's positioning along the direction of two successive vertebrae.

Taking a close account to the above mentioned requirements, a set of "T" shape markers was designed and manufactured (fig. 1). The markers contain four specific points, where coordinates are going to be recorded.

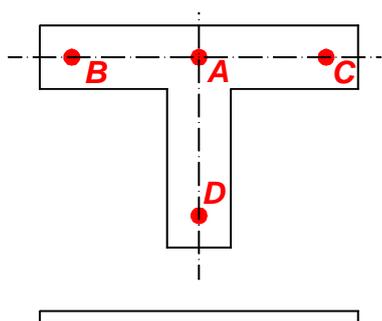


Fig. 1. "T" shape marker allowing measurement of coordinates in four points

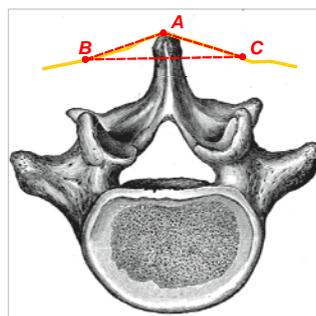


Fig. 2. Deformation of the marker applied on the skin and generation of the triangle ABC

The marker is made of a silicon material, which allows geometrical adhesion on the skin with non – toxically, weak adhesives, for short temporary fixing. For instance, medical electrode adhesive substances are appropriate.

Four holes are drilled in the body of the marker, corresponding to points A, B, C and D. The marker is fixed so that point A superposes the spinous process of the investigated vertebra and point D lies on the line containing the successive spinous processes. In the beginning, the marker is plane and the points B, C and D are equidistant to the central point A. Sticking the marker on the vertebra of a patient deforms the marker, which gets a spatial shape. The points A, B and C, first aligned, displace and determine the vertexes of a triangle. Figure 2 shows an upper view of a lumbar vertebra and the displaced position of the points A, B and C. The point A superposes the spinous process no matter the shape the marker gets.

Ideally, points A and D belong to a vertical line, triangle ABC is horizontal and its sides AB and AC have equal lengths. This situation is very less probable, even for patients considered to be biologically normal. Generally, the triangle ABC belongs to a spatially random plane. Its projection both on a horizontal and vertical plane is a scalene triangle.

To determine the relative rotation angle between two successive vertebrae, indexed 1 and 2, one needs to develop the following sequences:

- ❑ gathering coordinates of points A, B and C for the vertebra 1
- ❑ drawing of altitude AE to the base BC
- ❑ projection of the triangle ABC on a horizontal plane; it results a triangle A'B'C' and a corresponding altitude A'E' (red coloured in figure 3.a). The altitude A'E' passes, at an acceptable approximation through the centre of vertebra's body. Hence, this altitude can be considered a symmetry axis of the vertebra and taken for a reference element to characterize the its spatial position
- ❑ gathering coordinates of points A, B and C for the vertebra 2
- ❑ drawing of altitude AE to the base BC
- ❑ projection of the triangle ABC on a horizontal plane; it results a triangle A'B'C' and a

corresponding altitude $A'E'$ (blue coloured in figure 3.a)

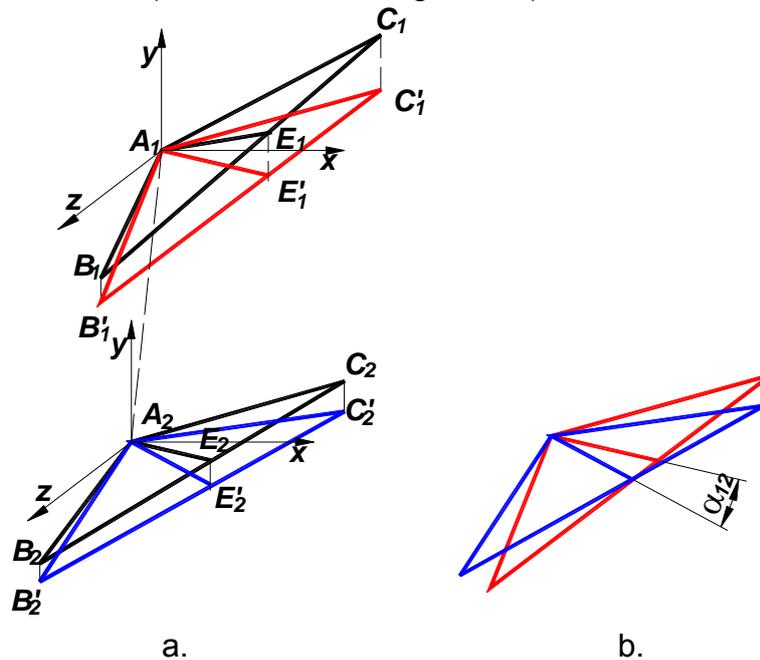


Fig. 3. Principle of computing the relative rotation between two vertebrae

- translation of projections $A'B'C'$ into a common horizontal plane and computation of the angle α_{12} , between the projections of the altitudes. This angle indicates the relative rotation of the two vertebrae (Fig. 3.b)
- measuring the coordinates of the point D is not necessary rotation calculation. Its existence is important for the correct positioning of the marker.

Mathematically, the algorithm to compute the angle α_{12} needs to accomplish the following steps:

- measuring of coordinates for vertebra 1 [$A_1(x_{1A}, y_{1A}, z_{1A})$, $B_1(x_{1B}, y_{1B}, z_{1B})$, $C_1(x_{1C}, y_{1C}, z_{1C})$]
- writing the equation of the line $B'_1C'_1$ in a horizontal plane containing the point A_1 :

$$\frac{x - x_{1B}}{x_{1C} - x_{1B}} = \frac{z - z_{1B}}{z_{1C} - z_{1B}} \Rightarrow z = m_1x + n_1 \quad (1)$$

- computation of the slope of a perpendicular line to $B'_1C'_1$ (equal to the slope of the altitude from the vertex A_1):

$$m_{E1} = -\frac{1}{m_1}, \quad (2)$$

- measuring of coordinates for vertebra 2 [$A_2(x_{2A}, y_{2A}, z_{2A})$, $B_2(x_{2B}, y_{2B}, z_{2B})$, $C_2(x_{2C}, y_{2C}, z_{2C})$]
- writing the equation of the line $B'_2C'_2$ in a horizontal plane containing the point A_2 :

$$\frac{x - x_{2B}}{x_{2C} - x_{2B}} = \frac{z - z_{2B}}{z_{2C} - z_{2B}} \Rightarrow z = m_2x + n_2, \quad (3)$$

- computation of the slope of a perpendicular line to $B'_2C'_2$ (equal to the slope of the altitude from the vertex A_2):

$$m_{E2} = -\frac{1}{m_2}, \quad (4)$$

- calculus of the tangent of the angle between $A_1E'_1$ and $A_2E'_2$:

$$\operatorname{tg}\alpha = \frac{m_{E_2} - m_{E_1}}{1 + m_{E_1}m_{E_2}}. \quad (5)$$

3. NUMERICAL EXAMPLE

To illustrate the algorithm described above, here is numerical application.

It is assumed that the coordinates of the points on the marker with $AB=AC=AD=15\text{mm}$ are known. Table 1 presents the stages of the calculus.

Table 1. Steps to calculate the relative rotation of vertebrae

Step	Description of the elements implied in calculus	Expression or value
1	Coordinates of points A, B, C for the vertebra 1	$A_1(0, 0, 0), B_1(5, -8, 11), C_1(8, 7, -9)$
2	Equation of the line $B'_1C'_1$	$z = -\frac{20}{3}x + \frac{133}{3}, y = 0$
3	Slope of the altitude A_1E_1	$m_{E_1} = \frac{3}{20}$
4	Coordinates of points A, B, C for the vertebra 2	$A_2(-5, -25, 5), B_2(-1, -29, 15), C_2(2, -21, -16)$
5	Equation of the line $B'_2C'_2$	$z = -\frac{31}{3}x + \frac{14}{3}$
6	Slope of the altitude A_2E_2	$m_{E_2} = \frac{3}{31}$
7	Angle of relative rotation between vertebrae α_{12}	$\operatorname{tg}\alpha = -0.05246 \rightarrow \alpha = -3^\circ$

Figure 4 shows a scaled plot of the case analyzed above.

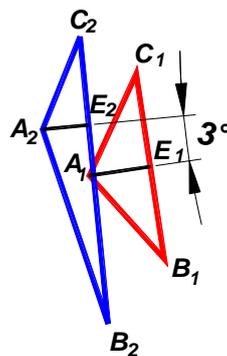


Fig. 4. Scaled geometrical elements for the numerical example

4. SOFTWARE FOR AUTOMATED COMPUTATION

For automated processing of data, a Microsoft Visual Basic application was conceived. The software can read numerical values from databases saved in a *.mdb, *.xls or other ASCII file, set to up-date automatically.

The module *Form* of the program is given in figure 5. Two *Data* controls extract the coordinates of the points A, B and C from the database, corresponding to vertebrae 1 and 2, selected by the operator.

If two successive vertebrae are selected, the command button *Rotation pair of vertebrae* starts running the sequence of code containing the operations described by

relations (1)...(5). The result, expressed in degrees is displayed inside the *Textbox* near the selected pair of vertebrae label. The command button *New pair of vertebrae* deletes the coordinates previously written inside the *Textboxes* $x(A)$, $y(A)$, $z(A)$, $x(B)$, $y(B)$, $z(B)$, $x(C)$, $y(C)$, $z(C)$ and resets the database to index 0. Repeating this procedure it is possible to determine the relative rotation angles for all pairs of successive vertebrae, which the spine consists of.

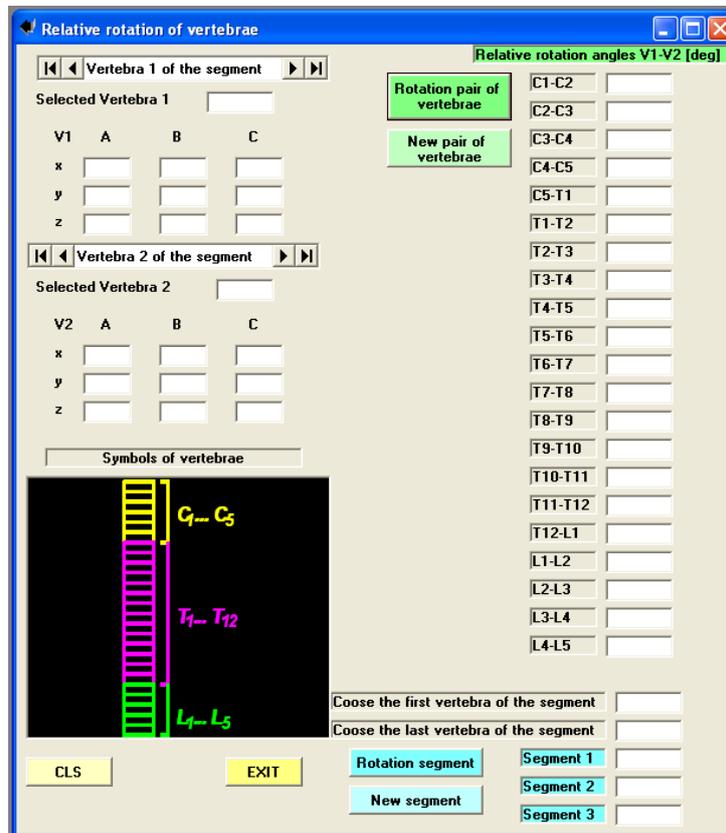


Fig. 5. Graphical interface of the VBA

The program is designed so that it can provide the angle between two vertebrae which define a segment of the vertebral column. The label *Choose the first vertebra of the segment* asks the operator to introduce the symbol of the starting vertebra into the *Textbox* next to the label. The label *Choose the last vertebra of the segment* asks for indicating the symbol of the last vertebra in the segment. The command button *Rotation segment* initiates the development of appropriate code and use of suited coordinates. The result is displayed in the *Textbox* next to the label *Segment 1*. It is foreseen in the application to calculate the rotation for three segments by means of repeated commands *Rotation segment* and *New segment*.

Figure 6 presents a typical plot for the king of information the program supplies. Five successive vertebrae forming a spinal segment are symbolically drawn. The body of each vertebra is a circle and the direction of the spinous process is indicated by an oriented line. For a clear illustration each vertebra is differently coloured. The figure shows the angles between successive vertebrae $V1-V2$, $V2-V3$, $V3-V4$, $V4-V5$ and between the first and the last one $V1-V5$.

The graphical interface of the program includes on the lower side a suggestive scheme for symbols of vertebrae belonging to cervical, thoracic and lumbar zones (Fig. 7), [7]. The pelvic segment was omitted because it is not involved in the deformations of column in study.

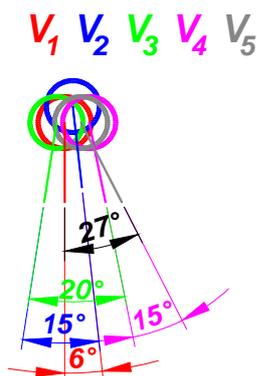


Fig. 6. Values of rotation angles between successive and extreme vertebra of a segment made of five vertebrae



Fig. 7. Spinal segments

The command button *CLS* empties all variables in the memory, so that the program is ready for a new analysis. The command button *EXIT* ends the application.

Correct reading of fields of the database needs a structure similar to the one in table 2.

Table 2. Fields of the database

ID	Symbol of vertebra	X _A	y _A	Z _A	X _B	y _B	Z _B	X _C	y _C	Z _C
1	C1									
2	C2									
3	C3									
⋮	⋮									

For practical application of the method a set of at least 24 identical markers is needed to be stuck on the column of the patient. The method is simple, cheap and precise. The errors can only originate in incorrect positioning of markers.

5. CONCLUSIONS

The method to determine relative rotation of successive or random vertebrae provides supplemental numerical information, which completes the usual data about the spine. Most softwares attached to anthropomorphic measurement apparatuses supply few numerical data.

The method is simple from mathematical point of view, easy to transfer to a software and provides accurate results. The program presented in the paper is a VB application, which can be run on any computer where MS Office package is installed.

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