EVALUATION OF AXIAL ROTATION OF SPINE AND ITS IMPORTANCE IN SPINAL DEFORMITY

I. Pallová, S. Otáhal and P. Kubový

Charles University, Faculty of Physical Education and Sport,
Department of Anatomy and Biomechanics, Prague, Czech Republic

Iveta.Pallova@seznam.cz

Abstract: Presented paper deals with kinematics of the spine and especially focuses on axial rotaton of vertebrae. The aim of our work is to find out possibilities of axial vertebral rotation evaluation, to study vertebral rotation and its relation to other shape changes of vertebral column and trunk in 3D. The research group included individuals with idiopathic scoliosis. We have used anteroposterior X-ray and non-standard MRI examination. We have also used non-invasive topographical diagnostics methods, shadow and raster moire. We used stereometry as well, to monitor spinal deformities. Any of these methods do not enable exact quantitation of axial vertebral rotation.

Introduction

The movement of the spine is very complicated. Pairs of vertebrae undergo in general six-dimensional motion relative to one another. There is a coupling between lateral bending and axial rotation. Coupling refers to motion in which rotation or translation of a body around or along one axis is consistently assosciated with simultaneous rotation or translation around another axis (in the coordinated system, +z-axis bending is coupled with –y-axis axial rotation). In the lumbar spine the spinous processes point in the same direction as the lateral bending, in the thoracic spine lateral bending is coupled with axial rotation, so that the spinous processes move toward the convexity of the lateral curvature (13).

Based on previous studies dealing with associated motions of vertebra (bending and rotation) (5, 6, 9, 12 and others) it is possible to deduce, that direction of axial rotation in coupled lateral bending is influenced by the shape of spine in sagittal plane.

Spinal deformity represents the change of position of vertebrae and spinal segments in all the main three anatomic planes *x, y, z* (translation, rotation). In our study we focused on the axial rotation of vertebra in transversal plane, around the *y* axis – fig. 1.

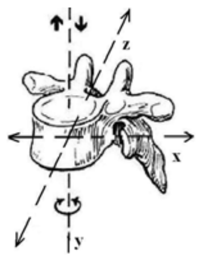

Figure 1: Rotation of vertebra around the *y* axis, the co-ordinated system is connected with vertebra, so it is not only the matter of anatomically defined planes.

The most common spinal deformity is idiopathic scoliosis. Scoliosis is a threedimensional deformation of spine and trunk. A large component of the deformity is a vertebral rotation causing one side of the trunk to become prominent, producing a rib or loin prominence. Vertebral rotation correlate most closely with lateral deviation of the spine (3). In the scoliotic spine, bending and rotation appear to be decoupled. The associated axial rotation is always into the convexity of the lateral curve. Simple segmental coupling of axial rotation and lateral bending could not be responsible for this axial rotation (10). In contrast to normal spines, in scoliotic spines exists a coupling between ventral flexion or extension and axial rotation (12).

Materials and Methods

Experimental group includes 16 females with adolescent idiopathic scoliosis. From 2003 to 2005 the patients were repeatedly examined and assessed. For detection of axial rotation of vertebrae and spine we have chosen various methods.

We have used non-invasive optical topographical methods, shadow and raster moire (method of stripes projection) and stereometry in biomechanical laboratories at Faculty of Physical Education and Sport, Charles University in Prague.

A shadow moire method works on principle of contour lines, which are formed on the back surface and give us three-dimensional information about shape – fig. 2a. Raster moire is based on projection of regular pattern – raster on surface of studied object. Spatial relation on the object are visualized in projected structure deformation and this image is recorded.

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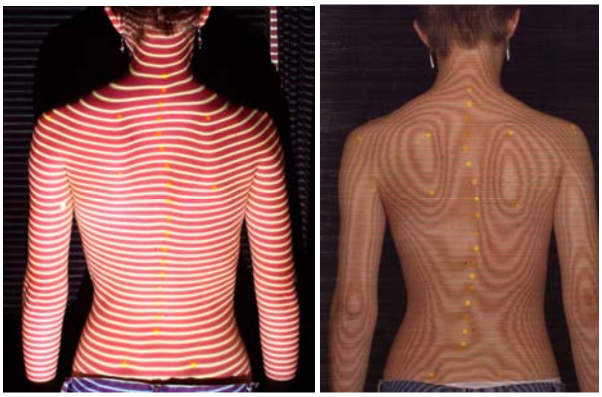
Shape reconstruction of the trunk can be carried out – fig. 2b. A stereometry uses a stereopair of images of the studied object acquired at least by two cameras to reconstruct its spatial properties (co-ordinates) – fig. 3.

In all used topographical methods subjects stood with their backs toward the camera in a relaxed upright position, undressed from the waist up. Sticky markers were attached to the processes of each vertebra from the seventh cervical vertebra (C7) to the fifth lumbar vertebra (L5), including the two posterior superior iliac spines and anguli scapulae.



a) b)

Figure 2: a) raster moire image b) moire shadow image illustrating the posterior trunk asymmetry, identical patient measured at the same time

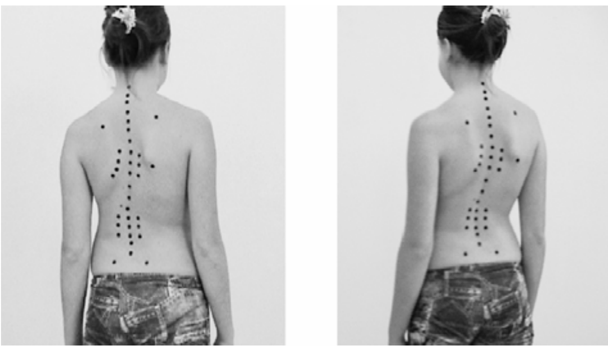


Figure 3: stereometry

We have evaluated 3D shape parameters in patients in upright stand during expiration. These methods show the behaviour of surface line adjacent to the spinal surface, but not the behaviour of the spine itself. By these methods we have evaluated axial rotation of the trunk and not the actual rotation of the vertebrae. Data we have stored and processed in computer. The data were calculated by computer - we used Excel, Obrazek, Maple and Matlab programs. In geometrical approach the scanned curvature was valued in a specific point of smooth spine curvature (polynom). Angle of trunk rotation (ATR) is expressed in degrees and the maximum asymmetry recorded – fig. 4.

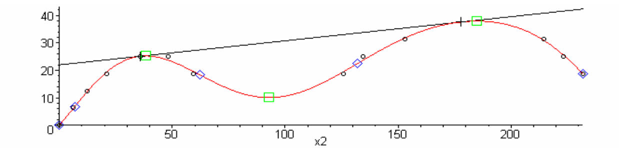


Figure 4: polynomial curve fitting of spine shape in horizontal plane – angle of trunk rotation, the angle between the tangent to the curve formed by paravertebral muscles and the horizontal line (x axis) in chosen cuts (maximum asymmetry)

Standard X-ray diagnostics evaluates the shape of spine in the frontal and sagittal plane by measurement according to Cobb (1). Transversal deformity (rotation) determination is more difficult to obtain.

The amount of vertebral rotation is usually measured on conventional anteroposterior (AP) radiographs according to Nash and Moe (7). The rotation is measured according to projection of the position of convex side pedicle, their projection is changing together with the change of rotation – fig. 5.

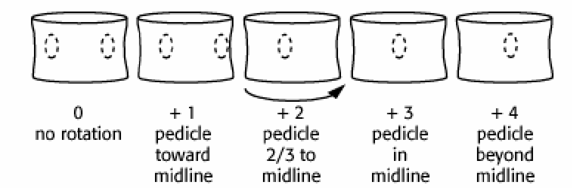
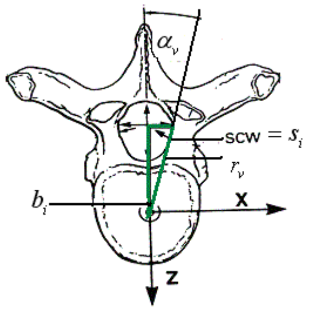
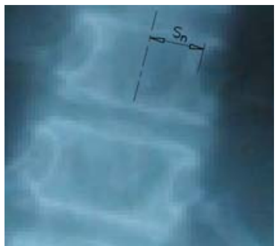


Figure 5: Nash and Moe methods – evaluating of axial vertebral rotation. This technique measures change of pedicle position with respect to the mid-sagitall plane of the vertebra to grade it on scale from 0+ to 4+ according to observation of the pedicle-shadow offset (16).

We have created model of calculation of vertebral rotation from anteroposterior X-ray image – fig. 6. This original method enables to count the change in vertebral position in the transversal plane from an anteroposterior projection X-ray radiographs. The method is based on average parameters of thoracic vertebra and uses as a reference point the origin of coordinated system (8).





$$\gamma_i = \alpha_v - \frac{180}{\pi}\sin\left(\frac{s_n}{r_x}\right)$$

Figure 6: evaluation of vertebral rotation around axial axis (γ_i) based on anteroposterior X-ray image, on the left the triangle for calculation of axial rotation, on the right the measured value on the X-ray image

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To verify the standard methods of the rotation evaluation based on AP X-ray we made an experiment. We verified projections of pedicles and spines of the rotated vertebra by means of X-raying the vertebra turn in the transversal plane (axial rotation) in every 3° within the range of 0° - 45° - fig. 7, 8.

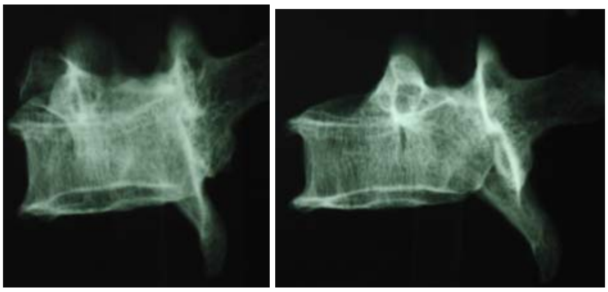


Figure 7 – projection of pedicle and processus spinosus in X-ray, on the left the thoracic vertebra with 21° of axial rotation, on the right the thoracic vertebra with 42°of axial rotation

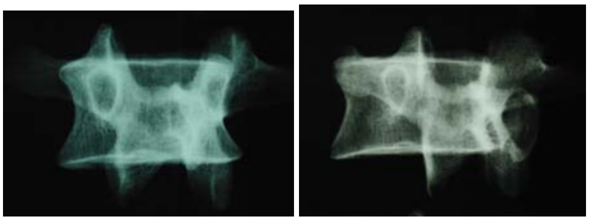


Figure 8 – projection of pedicle and processus spinosus in X-ray, on the left the lumbal vertebra with 24° of axial rotation, on the right the lumbal vertebra 36° of axial rotation

Axial rotation is more accurately determined by using CT (computer tomography) images (by means of Aaro and Dahlborn method) (4). But CT represents even higher radiation than X-ray, e.g. chest CT is equal to 400 of chest X-rays, yielding equivalent doze of 8 mSv. This doze is equal to 3.6 years long exposition to natural radiation background (B. Wall, National Radiological Protection Board, NRPB, UK).

To not threaten the patient´s health we assessed vertebral rotation of spinal deformity according to magnetic resonance imaging (MRI). We used 2 mm cuts of thoracic vertebrae. The axial vertebral rotation angle was measured in transversal plane in non-standard MRI application by 5 methods. One method is shown at the fig. 9.

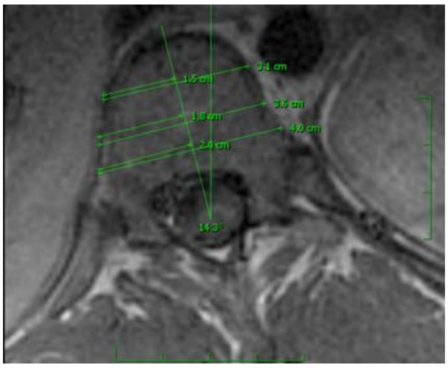
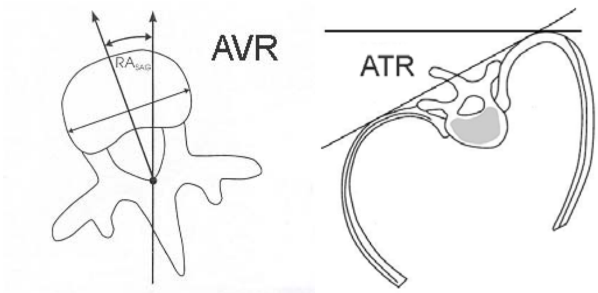


Figure 9: one method of evaluating of the axial vertebral rotation, MRI image of transversal cut of thoracic vertebra, axial vertebral rotation = the angle between assessed symmetrical axis and vertical axis

We also monitored relation and range of the vertebral rotation (AVR, fig. 10a) to the rib deformity (ATR, fig. 10b). We observed MRI transversal cuts of deformed scoliotic spine, range of vertebra and rib turns.



a) b)

Figure 10: angle of vertebral rotation (AVR) versus angle of trunk rotation (ATR)

a) AVR, the range of vertebral rotation around the longitudinal axis (around the *y* axis) related to the sagittal plane (vertikal axis) was measured by the Aaro and Dahlborn technique (4).

b) ATR, angle is formed between a horizontal line drawn paralel to the table, and the line drawn tangential to the rib deformity. This angle shows the magnitude of the rib deformity (2).

Results

Non-invasive topographical diagnostics methods are applicable for quantification of various spinal disorders. They provide complete information about the shape of a trunk, but not directly about the axial vertebral rotation. Advantage of these methods is the possibility of frequent repeating without ionising radiation. We have found that a significant rotational prominence may exist with only small degrees of lateral curvature, and therefore a small Cobb angle.

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We were finding out reliability of the original method of the axial rotation of thoracic vertebrae evaluation according to AP X-ray projection (8). Values, initial for calculation of the axial rotation, were measured with the same gauge in the X-ray image of thoracic vertebrae of the same patient with spinal deformity (scoliosis). Intraindividual error (using maximum and minimum measured values) of measurement is up to 5°, interindividual error of average values is up to 3°, the difference of minima and maxima of rotation is up to 7°.

We verified projection of pedicles and spinous processes according to the defined positions of axial rotation of vertebra in every 3° in AP X-ray. Based on results there is a question of reliability of the rotation evaluation according to the Nash and Moe method. In fact, only degrees 0 and +1 seem to occur, which we consider to be a very wide (insufficient) evaluation of the vertebra rotation.

MRI images were obtained with the recruits lying supine on the table. We assessed vertebral rotation of spinal deformity based on magnetic resonance imaging (MRI) by various methods. Confidence interval ranged between ± 3°.

We found out, that there had not been direct relation of the range of vertebral rotation (AVR) to the rib deformity (ATR) – tab. 1. The vertebral rotation is always bigger than the rib asymmetry (deformity) without any recognizable relation between the vertebral rotation and ribs. The ATR has no significant relation to the AVR, therefor it is impossible to assess the vertebral rotation from the trunk rotation.

Table 1: Transversal MRI cut of deformed spine – thoracic vertebra, vertebral rotation (AVR) according to Aaro and Dahlborn, rib deformity (ATR)

proband	AVR	ATR
1	17°	4°
2	19°	2°
3	17°	6°

Discussion

Scoliosis is usually first observed as a change in back shape and thus back surface evaluation is important in clinical assessement. There is no direct determination between surface shape and skeletal anatomy, but changes of the spinal curvature are manifested by back shape changes - asymmetry (11). Optical methods offer three-dimensional information about the axial system and has no frequency limitations. Accuracy of results is influenced by the quality of image, experience of examiner, manual identification of the skin markers. There are no unambiguously defined significant points for evaluation of shape parameters of spinal deformity and their standardization.

While true AP radiographs are taken with patient standing, MRI is taken with patient supine. Difficulty of positioning patients also causes an important problem. Patient is influenced by the wide range of aspects including gravitation and deformity of the chest parts etc., which do not cause the error of given methods, but they can affect the final shape of the spine and trunk deformity.

According to the findings in literature ATR (angle of trunk rotation) has not significant relation to AVR (angle of vertebral rotation). There is no association between the Cobb angle, vertebral rotation and rib deformity (2). Partial outcome of our experiments confirm also that rib deformity is not closely related to the extent of vertebral rotation. The question is the rib deformity and its use in screening and its change according to the position of the patient.

We must also consider, that there is deformity of spine and trunk not only as "a whole", but there is also deformity of the vertebra itself, i.e. own deformation of each vertebra. It might be important, for example, when we were looking for the axis of vertebra symmetry in the transversal plane in MRI. However, in a man (live organism) we can not expect absolute symmetry. The shape stability of the axial system is quality characteristic for stability of bilateral trunk symmetry which is during the life strongly attacked by various biological and mechanical influences (14).

Conclusions

Scoliosis is a three-dimensional deformity, affecting the shape of the back. This deformity has shape changes in the frontal plane (traditional Cobb methods), sagittal plane (typical loss of kyphosis in scolisosis or kyphotic curves) and the transversal plane (rib or loin hump). Despite the triplanar nature of scoliosis, conventional methods to quantify the deformity are based on measurements made on radiographs taken in only one plane (3). The full geometric description of scoliosis includes the three-dimensional description of the vertebral column, as well as the rib cage.

It is extremely difficult to identify the vertebral rotation in the transversal plane in particular person, there is the role of natural variability of the "state" of the system (man) as a whole as well as his/her parts (vertebra). When using the stated methods of measurement, individual postural characteristics of the proband can influence the axial rotation during the measurement.

In our work we presented possibilities of evaluation of vertebral rotation and quantification of spine and back surface shape in 3D. Any of these methods do not enable exact quantitation of axial vertebral rotation, the error reaches up to a few degrees. Range of vertebral rotation is not observed in scoliosis (spine deformities), but based on our findings, the axial vertebral rotation ranges from 0° to 30°. Considering common rotation 20° then, when the absolute error is 5°, the relative error will be 25%.

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Quantitative criteria of the axial rotation measurement have not been established yet. There is no optimum system of the vertebral rotation evaluation in accord with 3D examination of the spine curvature. We suppose that the axial rotation is an important factor in diagnostics and therapy of scoliosis. Further research will be focused on monitoring the trends of curves in 3D (deviation related to turn).

There is a lack of clear biomechanical analyses to explain the interaction of kyphosis and lordosis, the lateral and axial deformity of the spine in idiopathic scoliosis.

Acknowledgements

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