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CROSS-SECTIONAL AND LONGITUDINAL STUDY OF SPINAL CURVATURE AND ROTATION

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Abstract

Three-dimensional shape of the spines of 171 patients with idiopathic scoliosis was studied longitudinally by means of 388 stereo-radiographs (average 2.3 observations of each patient). The vertebral body line was defined as the line passing through the centers of the vertebral bodies. The curvature of this line was measured, along with its curvature projected onto the frontal and sagittal planes. The local plane of the vertebral body line was rotated on average 7.3 times as much as the rotations of the vertebrae at curve apices. At the curve apices, the frontal plane curvature usually exceeded the sagittal plane curvature, but without evidence that these apices occurred in regions of reduced sagittal plane curvature. In progressive scoliosis there was no evidence of reduced sagittal plane curvature, or of the sagittal plane curvature changing with progression of the frontal plane curve.

1. INTRODUCTION

This paper is concerned with the 3-dimensional morphology of idiopathic scoliosis. Adams, in 1865 described the 3-dimensional nature of scoliosis deformity, without the benefit of radiology. Several methods have been developed to try to visualize the 3-dimensional shape of the spine better. In order to describe interactions between curvatures in different planes, du Peloux et al. (1965) introduced the concept of the 'plan d'élection' which is a plane of maximum curvature of a region of the spine. Raso et al. (1980) reported a method for calculating the amount of rotation of the plane of maximum curvature. In a spine with scoliosis the plane of maximum curvature of the spine and the planes of symmetry of the vertebrae were found to diverge (Stokes et al., 1987). Deane and Duthie (1973) used tomographic methods to demonstrate rotational components of scoliosis, and also to demonstrate the sagittal plane wedging of vertebrae which appeared to result in abnormal sagittal plane curvature. Arkin (1950) studied the axial rotation of vertebrae in a scoliosis curve in relation to normal lateral bending movements.

Apart from the need to understand the nature of these deformities better, the 3-dimensional shape of the spine has been implicated in the etiology of these deformities. The etiology of idiopathic scoliosis is probably multifactorial, with many factors, including abnormal spinal shape and growth playing a part (Nachemson and Sahlstrand, 1977). Perdriolle and Vidal (1987) felt that mechanical torsion of the spine is an important etiologic factor. Somerville (1952) reported an animal model in which an interaction between a posterior tethering of the rabbit spine and continuing growth produced a scoliosis deformity, and this theory was investigated further by Dickson al. (1984) who developed a theory of the etiology of idiopathic scoliosis based on the idea that it results from the rotation of a lordotic region of the spine. Jarvis et al. (1988) investigated the tether theory by applying a tether to animal and human spinal specimens. One problem has been defining what is normal curvature of the spine (Beck and Killus, 1973; Stagnara et al., 1982; Bernhardt and Bridwell, 1989).

Willner and Johnson (1983) reported the evolution of sagittal curvature of the spine with adolescent growth, with maximum curvature occurring at the onset of the growth spurt. Pelker and Gage (1982) found some evidence of abnormal sagittal curvature in the thoracic region of spines with scoliosis but Desmet et al. (1984) found no relationship between the degree of sagittal plane curvature and the degree of frontal plane curvature in thoracic scoliosis.

In this study, the spine is considered as a line in space with vertebrae rotated about the line. The three-dimensional line passing through the midpoints of vertebral bodies is called the "vertebral body line". The complete geometry of the spine can then be described by the shape of the vertebral body line, the position and orientation of the vertebrae about this line, and the shape of the individual vertebrae. The purpose of the study was to determine the relationship between the local plane of maximum curvature of the spine and the vertebral axial rotation, and the relationship between the magnitudes of spinal curvatures in the frontal and sagittal planes. These relationships were studied longitudinally as well as in a cross section of patients.

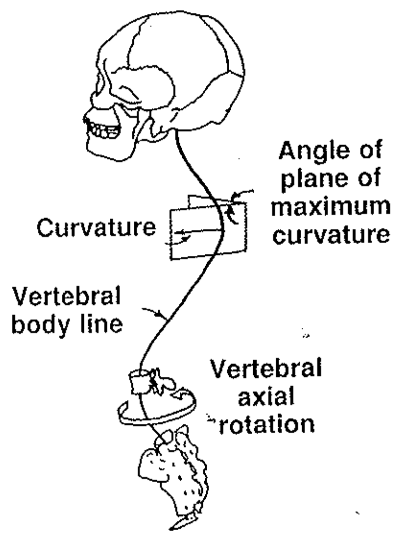

Figure 1 Representation of spinal geometry used in this study.

2. METHODS

Stereo radiographs (388 clinic visits of 171 patients with idiopathic scoliosis) were digitized to give a three-dimensional mathematical description of the spinal shape. The average age at the first film was 13.6 years (range 8.6 - 20), and the mean period of follow-up was 1.9 years (max. 5.5 years).

The center of each vertebral body was determined as the midpoint between endplate centers measured in three-dimensions from stereo x-rays of the 12 thoracic and 5 lumbar vertebrae. A fifth order polynomial curve was then fitted to the AP and lateral projections of these points with the vertical dimension as the independent parameter. This mathematical representation of the vertebral body line was then used to calculate the 3-D curvature and the curvature in each of the two principal anatomic planes. At any point on the spine the axial rotation of a local plane of maximum curvature of the spine is defined by the arctangent of these two curvatures. This plane can be considered as containing the vector comprising the local radius of curvature of the vertebral body line (Figure 1). Thus in a spine with no scoliosis, but with finite lordosis or kyphosis, the local plane of maximum curvature is always coincidental with the sagittal plane. In principle, this plane and its associated vector can point in any of the four quadrants (0°-360°) since lordosis and kyphosis have positive and negative polarity, and right and left scoliosis have positive and negative polarity. However, for simplicity, we ignored polarity of sagittal plane curvature and defined this angle as having values from minus 90° (left scoliosis only) through 0° (lordosis or kyphosis only) to 90° (right scoliosis only). The transverse angulation (axial rotation) of each vertebra was calculated by the method of Stokes et al. (1986).

The following were calculated for the greatest scoliosis curve in each film: Analytic Cobb angle (COBB), maximum lateral deviation from the spinal axis (MAXLD), vertebra axial rotation (VAXROT), magnitude of 3-D curvature at the apex (3DC) and in the frontal (FPC) and sagittal plane (SPC) projections, and rotation from the sagittal plane of the local best fit plane at the curve apex (PMC).

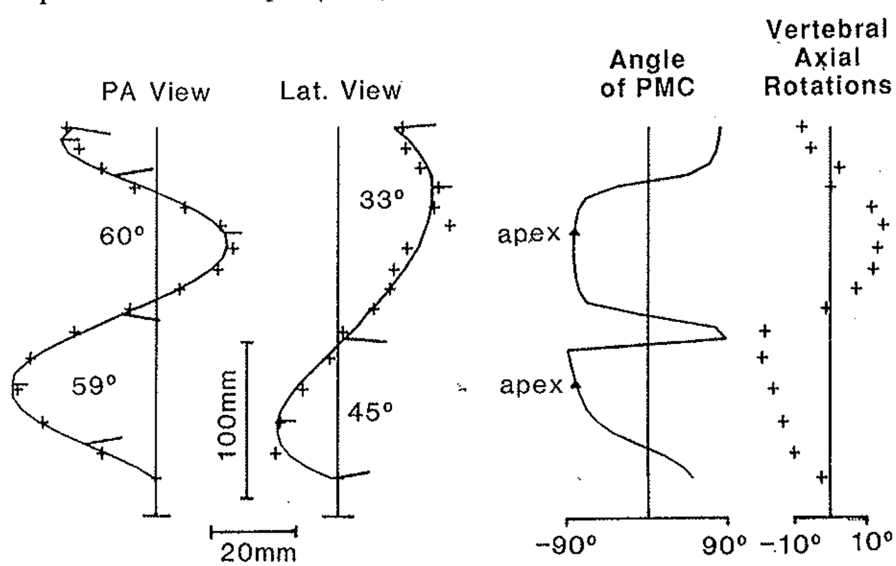

Figure 2 Example of measurements of a patient with 59° and 60° Cobb angle scoliosis curves.

3. RESULTS

The average Cobb angle of initial study films was 26° (6°- 70°). The relationship between PMC rotation and VAXROT was complex. The mean magnitude of PMC rotation (61°) exceeded that of VAXROT (8.3°) by a factor of 7.3, but there was a weak correlation between them (r=0.3). For 163 curves with the apex in a lordotic region of the spine these rotations were in the same sense, but in 225 curves with local kyphosis at the curve apex the sense was opposite. Since PMC rotation was derived from the ratio of FPC and SPC, PMC rotation was large either because the FPC was large or because SPC was small. There was a strong correlation between VAXROT and frontal plane curve magnitude (COBB, FPC and MAXLD), as has been reported previously. It appears that the frontal plane measures are strongly related to each other whereas SPC varies both between patients and by level of the spine, with little relationship to the frontal plane deformity. However, the relatively large values of PMC rotation occurred because the local frontal plane curvature (FPC) was often large compared to the sagittal curvature (SPC). In the sagittal plane, the magnitude of the apex curvature SPC was compared with the average measurement of this curvature at all vertebra levels in the same patient. The apices of scoliosis curves on average did not occur in regions of reduced sagittal plane curvature (more 'straight' region).

For 92 patients studied longitudinally, the study of progression was complicated by treatment. However, in 8 patients with clear evidence of frontal plane progression, the sagittal plane curvature tended to remain constant. Progression occurred as an increase in frontal plane curvature with a corresponding increase in PMC, along with much smaller increase in the magnitude of VAXROT.

4. DISCUSSION

The divergence of the local plane of maximum curvature from the sagittal plane which occurs in idiopathic scoliosis was found to be much greater in magnitude than the vertebral axial rotation, and often in the opposite direction. One can speculate that this loss of sagittal plane symmetry predisposes the scoliosis to progress. In a spine without scoliosis, the plane of maximum curvature rotation is always 0°, as is also the rotation of the vertebral plane of symmetry.

At the curve apices, the frontal plane curvature usually exceeded the sagittal plane curvature, but without evidence that these apices occurred in regions of reduced sagittal plane curvature. In progressive scoliosis there was no evidence of reduced sagittal plane curvature, or of the sagittal plane curvature changing with progression of the frontal plane curve.

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REFERENCES

ADAMS W: "Lectures on the pathology and treatment of lateral and other forms of curvature of the spine." London, John Churchill & Sons, 1865

ARKIN AM: "The mechanism of rotation in combination with lateral deviation in the normal spine." *J. Bone Joint Surg.,* 32A:180-188, 1950.

BECK A, KILLUS J: "Normal posture of spine determined by mathematical and statistical methods." *Aerospace Med.,* 44:1277-1281, 1973.

BERNHARDT M, BRIDWELL KH: "Segmental analysis of the sagittal plane alignment of the normal thoracic and lumbar spines and thoracolumbar junction." *Spine*, 14:717-721, 1989

DEANE G, DUTHIE RB.: "A new projectional look at articulated scoliotic spines." *Acta Orthop. Scand.,* 44:351-365, 1973.

DESMET AA, ASHER MA, COOK LT, GOIN JE, SCHEUCH H, ORRICK JM.: "Three dimensional analysis of right thoracic idiopathic scoliosis." *Spine,* 9:377-381, 1984.
DICKSON RA, LAWTON JO, ARCHER IA, BUTT WP: "The pathogenesis of idiopathic scoliosis. Biplanar spinal asymmetry." *J. Bone Joint Surg.,* (Br) 66(1)B:8-15, 1984.
JARVIS JG, ASHMAN RB, JOHNSTON CE, HERRING JA: "The posterior tether in scoliosis." *Clin. Orthop.,* 227:126-134, 1988.
NACHEMSON A, SAHLSTRAND T: "Etiologic factors in adolescent idiopathic scoliosis." *Spine,* 2:176-184, 1977.
PELKER R, GAGE JR: "The correlation of idiopathic lumbar scoliosis and lumbar lordosis." *Clin. Orthop.,* 163:199-201, 1982.
PELOUX J DU, FAUCHET R, FAUCON B, STAGNARA P.: "Le plan d'election pour l'examen radiologique des cyphoscolioses." *Rev. Chir. Orthop.,* 51:517-524, 1965.
PERDRIOLLE R, VIDAL J: "Morphology of scoliosis: Three-dimensional evolution." *Orthopaedics,* 10:909-915, 1987.
RASO VJ, GILLESPIE R, MCNEICE GM: "Determination of the Maximum Plane of Deformity in Idiopathic Scoliosis." Scoliosis Research Society 1979, *Orthop. Trans.,* 4:23,1980.
SOMERVILLE EW: "Rotational lordosis: The development of the single curve." *J. Bone Joint Surg.,* 34B:421-427, 1952.
STAGNARA P, DEMAUROY JC, DRAN G, GONON GP, COSTANZO G, DIMNET J,: "Reciprocal angulation of vertebral bodies in a sagittal plane: Approach to references for the evaluation of kyphosis and lordosis." *Spine,* 7:335-342, 1982.
STOKES IAF, BIGALOW LC, MORELAND MS: "Measurement of Axial Rotation of Vertebrae in Scoliosis." *Spine,* 11:213-218, 1986.
STOKES IAF, BIGALOW LC, MORELAND MS:: " Three-dimensional spinal curvature in idiopathic scoliosis." *J. Orthop. Res.,* 5:102-113, 1987.
WILLNER S, JOHNSON B: "Thoracic Kyphosis and Lumbar Lordosis During the Growth Period in Children." *Acta Paediatr. Scand.,* 72:873-878, 1983.