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Sedat Göçen
Hasan Havitçioğlu
Emin Alici

A new method to measure vertebral rotation from CT scans

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S. Göçen · H. Havitçioğlu · E. Alici
Department of Orthopedics
and Traumatology,
Dokuz Eylül University
School of Medicine,
İzmir, Turkey

S. Göçen (✉)
186/1 Sok. No:1 Doktorlar Sitesi B Blok.
K:7 D:13, TR-35040 Bornova,
İzmir, Turkey
Tel.: +90-232-3394567,
Fax: +90-232-4337958

Abstract CT measurement methods have good reliability for idiopathic scoliosis transverse plane deformity evaluation. However, because of application difficulties and variations in how these methods are applied, more sensitive methods are needed. This paper presents a new method for measurement of vertebral rotation from tomographic scans. First, the method was subject to clinical, intra-observer and inter-observer analysis. Twenty-three patients with adolescent idiopathic scoliosis were studied to test the clinical reliability of this method. There were no statistical differences between the results of the new method and Ho's method (P = 0.3380) in the clinical study. Intra-observer and inter-observer analysis showed that this method was reliable. An experimental study was then conducted to show the confidence limits of our new method, which were found to be ± 1.6°, and there was no significant difference between the mean rotation value obtained from CT scans using our new method and that obtained using the mechanical method. These results suggest that our new method is a simple, practical and reliable method for measurement of vertebral rotation from CT scans.

Key words Vertebral rotation · Idiopathic scoliosis · CT · Method

Introduction

The importance of vertebral rotation in the etiology and management of scoliosis is well recognized. Evaluation of transverse plane deformity in idiopathic scoliosis is still controversial.

Displacement of the spinous process from the midline was used to measure rotation by Cobb [16]. Later, Nash and Moe introduced their own method, in which the displacement of the convex-side pedicle toward the midline was considered to be in direct proportion to the degree of rotation [13]. Perdriolle quantitatively measured pedicle shift using a specific template [14]. Some authors have also described analytic methods based on trigonometric and geometric measurements on plain radiographs [4, 5, 16, 18].

Because of the high rate of error, application difficulties and performer variation of these conventional radiography measurement methods, authors have looked for more sensitive methods [3]. The use of CT to measure vertebral rotation was introduced by Aaro and Dahlborn in 1981, in a study of five patients [1]. Subsequently, they used the method to assess rotational deformity of spine and rib cage and the derotation effect of the Boston brace, and to study the relation between lateral curvature and rotation of the apical vertebra [2]. Recently, Ecker et al. used the CT method to evaluate the effect of Cotrel-Dubousset instrumentation in idiopathic scoliosis [6]. In this method, the sagittal angle (RA sag) was taken to be the angle between the sagittal plane and the line between the correct posterior mid-point of the vertebral canal and the center point of the corpus vertebrae.

A second method was described by Ho et al. in 1993 [9]. The vertebral rotation angle was taken to be the angle between the sagittal plane and mid-angle line of connecting lines of three points. These three reference points were the inner connecting points of two laminae and bilaterally, the inner connecting points of the laminae and pedicles.

Krismer et al. described a new method to measure axial rotation on CT scans. They suggested that the error level of previously used rotation parameters were too high for clinical use [10].

Recently, we reported our clinical experience with three methods (Aaro-Dahlborn, Ho and Krismer) in 25 cases. We found Krismer's method was the least reliable and Ho's method was the most practical and the most reliable method for measuring axial rotation in idiopathic scoliosis [7].

Here we report a new method for measurement of vertebral rotation from CT scans. The reliability of the method is tested in an intra-observer and inter-observer error study by comparison with Ho's method.

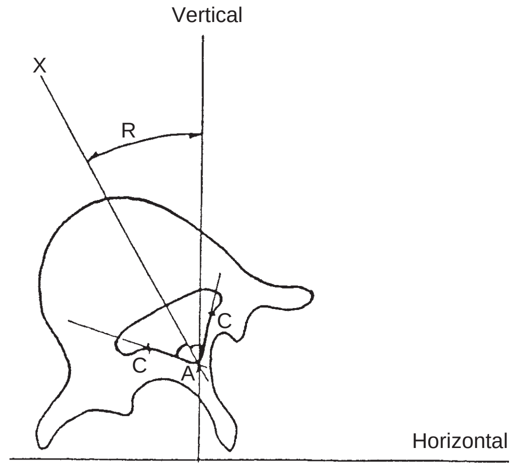

Fig. 1 Ho's method. This diagram shows the data points needed to measure vertebral rotation: *A* is the junction of inner surface of laminae, *C* is the junction of the inner surfaces of laminae and pedicles, *XA* is the line bisecting the *CAC* angle, R is the angle of vertebral rotation

Materials and methods

Twenty-three patients with idiopathic scoliosis were analyzed and studied. There were 15 girls and 8 boys with a mean age of 12.8 years (range 11–18 years).

Before CT imaging, anteroposterior (AP) and lateral plain roentgenographs were taken in standing position. On AP radiographs, apical and neutral vertebrae were defined. Frontal plane deformity was measured using the Cobb method. Mean AP Cobb angle was 35.4° (range 14°–58°).

Patients lay down on the CT table, on which a plain apparatus had been prepared especially for this purpose. The patients were positioned so that the pelvis and shoulders were symmetric. The costal hump, which occurred on the curvature side, was balanced with an elevator placed on the other side. Cross-sections of the apical and neutral vertebrae were then taken on the same plane. The purpose of taking the neutral vertebra cross-section was to prevent any possible positional changes. The subjects were scanned lying supine using a low mAS (milliamperes/second) technique (120 kV, 40 mA, 2 s). The whole length of the spinal curvature was scanned including the upper and lower end vertebrae. The first cut was made at the middle of the pedicle shadows, parallel to the lower vertebral end plate. Subsequent CT sections were similarly positioned 1 mm above and below, at the midpoint of the pedicle shadows.

The apical and neutral vertebra measurements of each person were made from these cross-sections. For the determination of the real vertebral rotation value, the neutral vertebra value was subtracted from apical vertebra value.

Calculation of vertebral rotation angle

The CT scan was viewed on a video monitor and a cursor was used to locate data points. Two sets of data points were evaluated.

Method 1: Ho's method

In this method (Fig. 1) three data points were selected: one at the junction of the inner surfaces of two laminae (*A*); and the other two at the respective junctions of the inner surfaces of the laminae and the pedicles (*C,C*). A line bisecting the *CAC* angle formed by the two laminae was drawn by the computer program, and the angle of vertebral rotation was taken as the angle between this line and the vertical plane drawn by the computer.

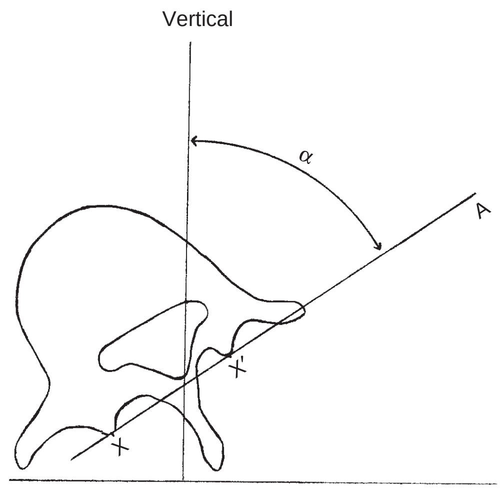

Fig. 2 Our new method. *X* and *X'* are the most posterior points of two pedicles; *A* is the line joining these two points; (α) is the angle between this line and the vertical plane at the opposite side of the rotation

Method 2: new method

The most posterior points of two pedicles were marked. A line (*A*) was drawn joining these two points. The angle (α) between this line and the vertical plane was calculated at the opposite side of the rotation (Fig. 2). The angle of vertebral rotation was calculated by subtracting this angle (α) from 90° (RA = 90°–α).

On CT images, both the above CT measurement methods were applied on apical and neutral vertebrae to find real vertebral rotation and apical vertebra value. All values were recorded.

Intra-observer analysis

To test the reliability of the new method of measuring vertebral rotation, one observer (S.G.) measured 20 different CT scans, which were selected randomly at three different points in time, using the

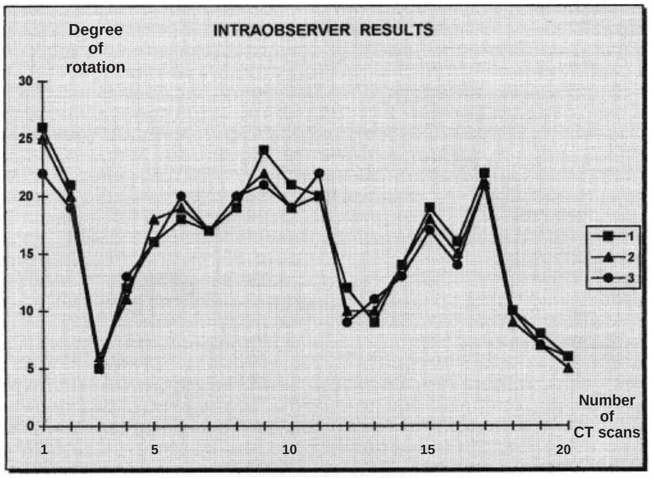

Fig. 3 Intra-observer measurement results of the new CT measurement method

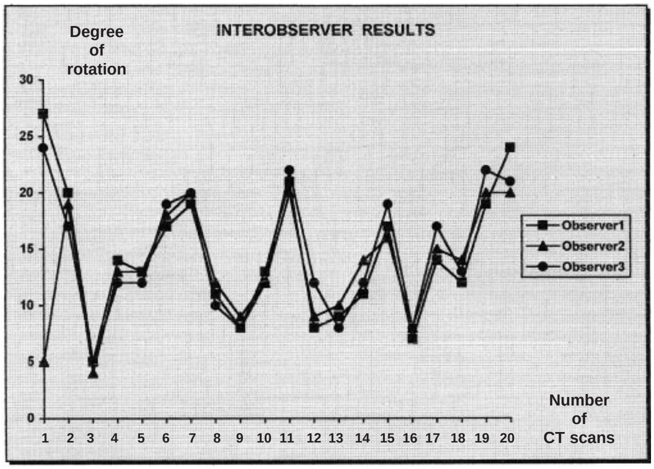

Fig. 4 Inter-observer measurement results of the new CT measurement method

new method to select data points for drawing reference lines to measure rotation angle (Fig. 3).

Inter-observer analysis

Three different observers measured the same 20 CT scans with the new method (Fig. 4). The correlation between their measurements is presented in Table 1.

Experimental study

In an experimental study, a dry vertebra was mounted on a specially designed jig. CT scans were obtained with 0° tilt and at 0°, 5°, 10°, 15°, 20°, 30° and 40° rotated position, rotating first to the right and then to the left. Three horizontal CT cuts of the vertebra were obtained at each known tilt and rotation position. The first cut was taken at the level of middle of the pedicle, and the others were taken at 1 mm proximal and 1 mm distal to the first cut. Each CT scan was measured twice by two observers on separate occasions. In this experimental study, only method 2 was evaluated.

Table 1 Statistical correlation between results obtained with the mechanical method and those of our new CT method (method 2) in the experimental study. For all correlations, the probability value (P) = 0.00

Degree of rotation	Observer 1 (L)	Observer 1 (R)	Observer 2 (L)	Observer 2 (R)
Degree of rotation	0.9994	0.9970	0.9989	0.9988
Observer 1 (L)	0.9994	0.9985	0.9998	0.9974
Observer 1 (R)	0.9970	0.9985	0.9981	0.9963
Observer 2 (L)	0.9989	0.9998	0.9981	0.9960
Observer 2 (R)	0.9988	0.9974	0.9963	0.9960

Statistical analysis

Real vertebral rotation degree was used in statistical analysis. The Wilcoxon matched-pairs signed-ranks test was used to evaluate the apical vertebral rotation of 23 patients.

Friedman's two-way ANOVA tests were used to evaluate the intra-observer and inter-observer analysis.

The Spearman correlation test was used to evaluate the results of the experimental study. The mechanical measurements were separately compared with left and right rotation measurements of both observers.

Results

Patients' CT values measured by method 1 had a mean of 12.24° (3°–26°) and the ones measured by method 2 had an 11.92° (3.5°–28°) mean (Fig. 5).

The Wilcoxon matched-pairs signed-ranks test was used to evaluate the statistical correlation between these two CT methods. There were no statistical differences between method 1 and method 2 (z = –0.9581 and P = 0.3380).

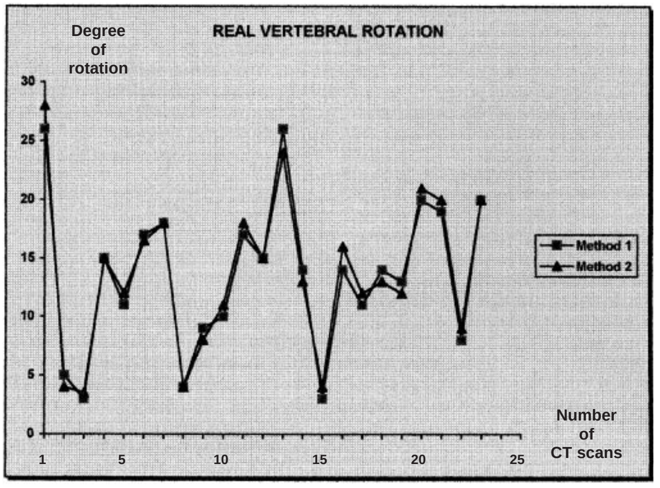

Fig. 5 Real vertebral rotation: a comparison of the values obtained by the two CT measurement methods

Intra-observer analysis for method 2

Method 2 showed a standard deviation of ± 1.18° to ± 2.97° (95% confidence intervals). Intra-observer analysis with the Friedman two-way ANOVA test revealed no statistical differences between the three measurements (P = 0.3206).

Inter-observer reliability for methods 1 and 2

Method 2 showed a standard deviation of ± 2.79°to ± 4.21° (95% confidence intervals). Inter-observer analysis with the Friedman two-way ANOVA test revealed no statistical differences between the three observers' results (P = 0.3405).

Experimental study

Relations between mechanical and CT measurements

The measurements obtained from all three CT cuts correlated highly with those obtained from the mechanical jig for tilt 0°–40° (Table 1). There were no significant differences between the mean rotations obtained from CT scans using method 2 and those obtained using the mechanical method. We found the confidence limit of method 2 to be ± 1.6°.

Discussion

The evaluation of transverse plane deformity in idiopathic scoliosis is fraught with difficulties. CT measurement methods are known to be more precise and more reliable than the conventional methods [7, 8, 10]. There are contradictory reports on the results and reliability of the defined conventional graphic assessments [3, 5, 12, 16].

Today, many authors accept that methods like the Cobb method, which are based on the spinous process, are not reliable, as the end of the spinous process is deformed extensively [8, 12, 18].

A study by Ho et al. reports that, not only does the Nash and Moe method give unreliable results, but there are also great inter-observer differences. For example, in the vertebrae evaluated as grade 0 in the Nash and Moe method, a rotation of between –4° and 11° was determined by CT measurement [9].

Russel and Raso evaluated four methods using measurements with analytic techniques, and reported that radiographs taken in oblique and special positions are required for the application of these methods. Their clinical use is therefore difficult and there are many positional errors [16].

Richards declared that the Perdriolle method does not have inter-observer reliability, having a tolerance of more than 10° in one-third of the observers [15].

However, CT measurement methods were used restrictively, not routinely, as they are two-dimensional, could be applied only in supine position and are more invasive [7, 9, 10].

Recently, three-dimensional stereoradiographic reconstruction methods have been defined. Skalli et al. [17] showed that independent of the errors due to measurement techniques or the deformation of the scoliotic vertebrae, differences between mathematical procedures mean that similar results will be obtained only if combined rotations are less than 10°, and using CT scans for measuring vertebral axial rotations is valid only if the other rotations of the vertebra are small. Although it is clear that three-dimensional measurements are more reliable and suitable for segmental rotation measurements, these methods are more invasive, time consuming and expensive.

The first method described for measuring vertebral rotation, and used as gold standard for years, was the Aaro and Dahlborn method, but its lack of inter-observer reliability restricts its clinical application [7, 8]. In this method, the junction of the inner surfaces of the lamina is constant and easily identifiable, but the other datum point, i.e. the midpoint of the anterior surface of the spinal canal, is not so easily identifiable and we believe that this is the main reason of error between observers [7].

As mentioned before, the method described by Ho et al. is the most reliable and practical one among the methods described previously [7]. They reported a tolerance of ± 1.2° [8]. The method we describe gives similar results to Ho's, which shows its reliability in clinical use. The most serious disadvantage of the method described by Ho et al. is the difficulty inexperienced clinicians have finding the reference points and measuring the bisector, especially on the video monitor. In the method we define, the simplicity of finding the reference points and measuring the rotation rate is an advantage. Furthermore, the results of the intra-observer and inter-observer analysis show that this new method is reliable.

The most serious disadvantage of the new method we describe is that it requires imaging cross-sections passing from the middle of both pedicles, to monitor their back sides. To do this, we recommend taking cross-sections from the mid-points, and 1 mm above and below, the pedicle shadows of the apical and neutral vertebrae. In this way, three pedicle cross-sections can be taken from each of the vertebrae measured, and the most symmetrical section can be estimated. It must be considered that the standard of the CT sections determines how reliable the results are. This is valid for all of the CT measurement methods defined.

In the experimental study, the tolerance of our new method was found to be ± 1.6°. This is a fairly low tolerance for vertebral rotation measurements. To our knowledge, the accuracy of the Aaro and Dahlborn method has been evaluated exclusively by Aaro and Dahlborn [1], based on one scoliotic L2 vertebra. The mean difference between the true and measured values amounted to 3.0°, and in the case of combined frontal and sagittal rotation, up to 7° [1]. Therefore, without quality control of the scans being measured, the results of CT measurement of rotational angle may be similar to methods based on plain radiographs with digitization of landmarks and computation of rotation angles: Matteri et al. [11] ± 4° SD (95% CI approximately 8°); Bunnel F 3° SD [4] and Drerup F 4° SD [5], Stokes et al. [18] slightly worse. Even the Perdriolle method has a range of less than 10°.

The vertebra used in this study was taken from a normal person. In cases where important morphological changes may occur in the vertebrae, like congenital scoliosis (especially pedicle asymmetry), the reliability of this method decreases as with other methods.

The search for more precise and easier methods of CT measurement of vertebral rotation continues. We think that our new method is simple, practical and reliable. Nevertheless, further studies will be useful to find out more reliable and practical methods.

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