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Horizontal plane morphometry of normal and scoliotic vertebrae

A methodological study

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Summary. Computed tomography (CT) scans are widely used for quantification of the morphology of the vertebral body and of the changes of the thoracic cage in the horizontal plane in scoliosis. So far, however, no method exists for precise quantification of the parameters of the posterior elements. We present a method for quantification on the basis of CT scans of different parameters of the morphology of both the vertebral body and posterior elements in the horizontal plane. The precision and accuracy of the method were estimated in a model study by CT scanning of a normal and a scoliotic vertebra in different, controlled, tilted positions. Moreover, in a clinical study CT scans of 19 thoracic vertebrae from non-scoliotic subjects and the apex vertebra from 40 scoliotic subjects were selected to test the applicability of the method to clinical studies. The intra- and interobserver variation of the measurements was analysed. The angle between the longitudinal axis of the vertebral body and that of the whole vertebra was used to evaluate the asymmetry of the vertebral body. The right to left pedicle width index, the right to left hemi-canal width index and the index of transverse process angles related to the axis of the vertebra were used to quantify the asymmetry of the posterior elements. The results indicate that, except for the pedicle width index, the variables under study were not significantly influenced by a 5° or 10° tilt ventrally, dorsally, or laterally of either the normal or the scoliotic vertebra. Hence, the method can be satisfactorily applied to longitudinal group comparisons. However, its use in longitudinal studies of individual patients is questionable.

Key words: Scoliotic vertebra – Computed tomography – Morphometric method

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The morphological vertebral changes occurring in the horizontal plane in scoliosis were recognized as early as at the beginning of the 19th century [7]. Although the asymmetry of the vertebral body and posterior elements has been described in experimental [5] and human [6] scoliosis, it has been difficult to quantify the morphological changes of a vertebra in the horizontal plane on plain radiographs.

The introduction of a new method in 1978 (computed tomography, CT) provided the possibility for quantification in vivo of the vertebral morphology and thoracic deformity in the horizontal plane [1, 2]. This method has so far been used almost exclusively for estimation of the rotation along the longitudinal axis [4, 9], but no method has been reported for studies of the structural changes of the posterior elements.

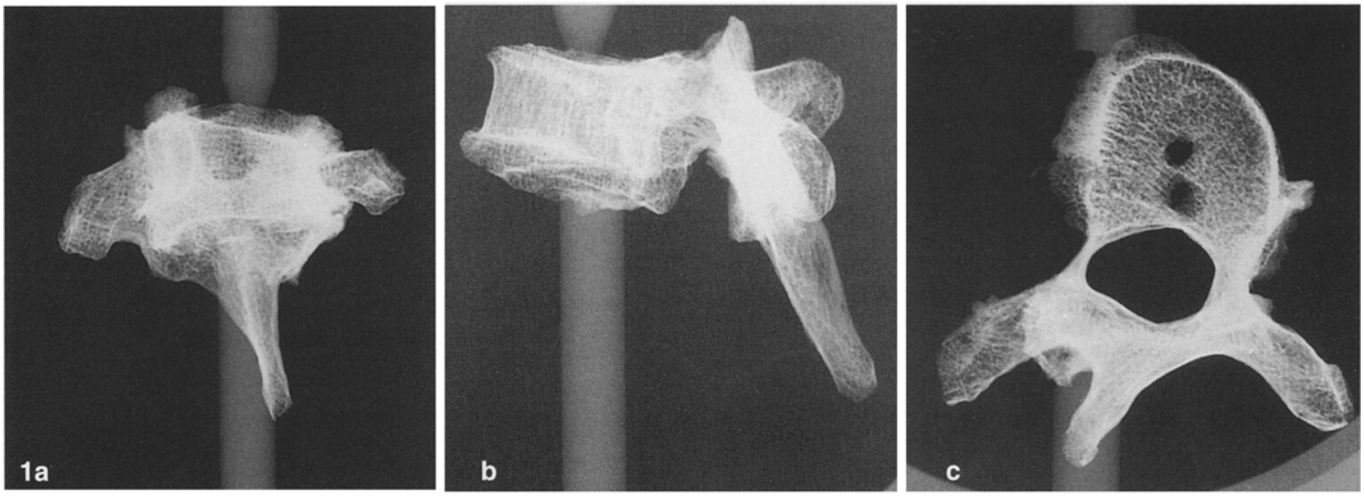
In this study, a method has been derived for quantification of the morphology not only of the anterior but also of the posterior parts of the vertebra on CT scans. It was tested in a model study of one normal and one scoliotic vertebra at different standardized tilting positions and in clinical material, and the intra- and interobserver precision of the measurements was estimated.

Materials and methods

Model study

One isolated normal vertebra and the apex vertebra of a right convex thoracic scoliotic spine were used in this study. Both vertebrae were skeletally mature (Fig. 1). The age of the individuals was unknown. The scoliotic vertebra probably belonged to a subject with severe scoliosis.

Each vertebra was fixed in a device used in an earlier study (the accuracy of the goniometer was 1°) which allowed gradual rotation in the frontal and horizontal planes [1]. Rotation in the sagittal plane was obtained by tilting the gantry of the CT (Fig. 2). The anteroposterior axis of each vertebra was set at 0°, and the CT scan section was parallel to the lower endplate of each vertebra. This position was considered the neutral position.



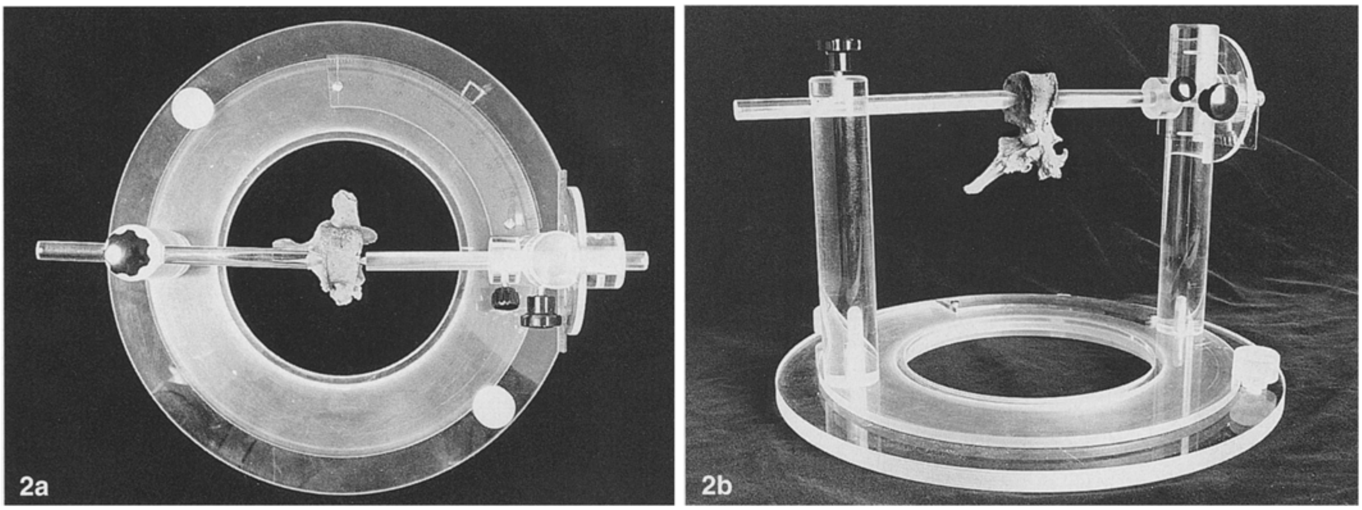


Fig. 1. Radiographs in the frontal (**a**), sagittal (**b**) and horizontal (**c**) planes of the scoliotic vertebra in the model study

Fig. 2. The device used for CT scanning of the scoliotic vertebra in the model study

Nine CT scans were taken of the normal verebra in the craniocaudal direction. For the scoliotic vertebra, the sections were limited to the upper 2/3 of the vertebra parallel to the lower endplate in order to obtain images of the section through the pedicles and the transverse processes. Measurements obtained with the vertebra in the neutral position were used as reference values. Each specimen was tilted by 5° and 10° ventrally or dorsally, respectively, and again by 5°, 10°, and 15° laterally to one side.

Due to the irregular morphological characteristics and the tilting of the observed normal and scoliotic vertebrae, usually one or at most two CT sections inlcuded the vertebral body, both pedicles, the canal, both transverse processes, and both laminae. When the vertebra was tilted laterally by 15° or more, neither of the transverse processes was imaged in any CT sections, in the normal or in the scoliotic vertebra. Therefore, the values at 15° lateral tilting were excluded.

The following points were marked on each of the CT sections studied. *a* the anterior midpoint of the vertebral body, which is the point farthest away from point *b*; *b*, the anterior midpoint of the medullary canal; *c* the posterior midpoint of the medullary canal. A line was drawn between points *a* and *b* and one through *b* and *c*, representing the longitudinal axis of the vertebral body and the longitudinal axis of the whole vertebra, respectively.

The mid-axis of the transverse process was defined as the midline of the transverse process through the midpoint of the tip (*t,t'*). The right and the left transverse process axes meet line *bc* at point *o* and *o"*, respectively (Fig. 3).

The following measurements were made:

1. The angle between the vertebral body longitudinal axis (*ab*) and the extension of the line *bc* representing the longitudinal axis of the whole vertebra (VBVA). This anlge reflects the magnitude of the modelling drift of the scoliotic vertebral body towards the concavity [7].
2. The narrowest width of the right and the left pedicle for the normal vertebra (PWr or PWl) or the convex and the concave for the scoliotic vertebra (PWcx or PWcv), respectively.
3. The axis of the vertebra, i.e. the extension of line *bc*, divides the medullary canal into two parts. The greatest width of the right and left hemidiameter for the normal vertebra (CWr or CWl) or the convex and the concave for the scoliotic vertebra (CWcx or CWcv).
4. The angle between the right (convex) and the left (concave) transverse process axis (*to* or *t'o'*) and the axis of the vertebra (*bc*), expressed as TPAr or TPAcx and TPAl or TPAcv, respectively (Fig. 3).

From these measurements the following indices were computed:

1. PWi, the pedicle width index: PWr/PWl for the normal or PWcx/PWcv for the scoliotic vertebra.

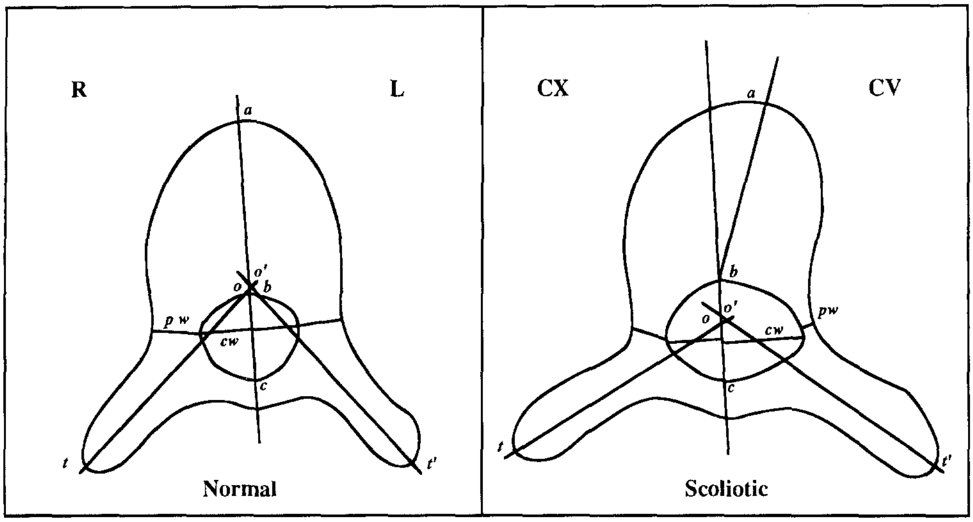


Fig. 3. Drawing showing the points and lines used to measure the parameters examined in normal and scoliotic vertebrae: *a*, the anterior midpoint of the vertebral body which is the farthest from point *b*; *b*, the anterior midpoint of the medullary canal; *c* the posterior midpoint of the medullary canal; *ab*, the longitudinal axis of the vertebral body; *bc*, the longitudinal axis of the whole vertebra; *to,t'o'*, the mid-axis of the transverse processes; *pw*, the narrowest width of the pedicles; *cw*, the greatest width of the hemi-diameter of the medullary canal

2. CWi, the canal width index: CWr/CWl or CWcx/CWcv.
3. TPAi, the transverse process angle index: TPAr/TPAl and TPAcx/TPAcv, respectively.

Distances were measured using a micrometer (accuracy 0.1 mm) and angles with a goniometer (accuracy 1°).

The means of ten measurements carried out by observer A were calculated for each tilting position of both vertebral specimens. Morever, three observers (A, B and C) independently measured all parameters twice at each tilted position of both vertebrae. The interval between measurements by each observer was at least 1 day.

Clinical study

In order to estimate the applicability of the method, the same parameters were measured on the CT scans of 19 vertebrae from non-scoliotic subjects at the T8–10 level and 40 apex vertebrae from subjects with thoracic scoliosis. Measurements of the CT scans of the vertebrae from the non-scoliotic and scoliotic subjects were carried out twice by one observer (A) and once by another (B).

Statistics

Student's *t*-test was used to evaluate the influence of vertebral tilt on the measured parameters as compared with the corresponding values in the non-tilted position. The intra- and interobserver precision is expressed as SD.

Results

Model study

Normal vertebra. The VBVA, the CWi and the TPAi were not significantly different between the various tilted positions compared with the neutral position. However, the pedicle width index (PWi) was significantly smaller than the reference value when the vertebra was tilted laterally by 10° or more (Table 1).

The average intraobserver precision, expressed as the SD for the respective measurements, was 0.2° for VBVA, 0.022 for PWi, 0.03 for CWi and 0.045 for TPAi (Table 2).

Scoliotic vertebra. The PWi was significantly smaller at the 10° laterally tilted position compared with the neutral position. No significant changes of the other parameters were found for the various tilted positions of the vertebra (Table 3).

The *intraobserver precision* (SD) was 1.6° for VBVA, 0.243 for PWi, 0.035 for CWi and 0.05 for TPAi (Table 4).

The *interobserver precision* (SD) of the measurements of the normal vertebra was 0.4° for VBVA, 0.037 for PWi, 0.056 for CWi and 0.085 for TPAi, and for the scoliotic vertebra 2.2°, 0.356, 0.07 and 0.082, respectively.

Table 1. The influence of the tilt of the normal vertebra in different positions on various indices (mean ± SD of ten measurements by one observer)

Position	*n*	VBVA	PWi	CWi	TPAi
Neutral	10°	0° ± 0°	1.002 ± 0.016	1.008 ± 0.04	1.221 ± 0.063
5°ventrally	10°	0° ± 0°	0.994 ± 0.021	1.013 ± 0.049	1.151 ± 0.072
10°ventrally	10°	0° ± 0°	0.997 ± 0.02	1.010 ± 0.013	1.204 ± 0.054
5°dorsally	10°	0° ± 0°	0.997 ± 0.019	1.013 ± 0.049	1.206 ± 0.04
10°dorsally	10°	0° ± 0°	1.019 ± 0.027	1.009 ± 0.042	1.179 ± 0.05
5°laterally	10°	0° ± 0°	0.988 ± 0.025	1.017 ± 0.043	1.245 ± 0.047
10°laterally	10°	0° ± 0°	0.930 ± 0.005**	1.022 ± 0.033	1.201 ± 0.047

** $P<0.01$ compared with the corresponding value in neutral position for abbreviations, see text

Table 2. Intraobserver precision (SD) of the first and second measurements of the normal vertebra performed by three observers

Observer	VBVA	PWi	CWi	TPAi
A	0°	0.016	0.021	0.049
B	0.5°	0.029	0.032	0.032
C	0°	0.021	0.036	0.055
Average	0.2°	0.022	0.030	0.045

Clinical study

The intraobserver difference for 59 CT scans of the thoracic vertebrae at theT8–10 level (19 normal and 40 scoliotic apex vertebrae) was not significant for the parameters measured. The interobserver difference, except for TPAi, was not significant. The intraobserver precision (SD) was 2.4° for VBVA, 0.108 for PWi, 0.059 for CWi and 0.050 for TPAi. The interobserver precision (SD) was 2.9°, 0.119, 0.096 and 0.094, respectively.

Discussion

The precision of measurements of skeletal structures may be influenced by three sources of variability: the patient, the procedure and the clinician [8]. Consequently, the sources of error in this study could depend on the level of the vertebrae examined, the procedure itself and the variability of the measurements by the individual observers.

The aim of the model study was to quantify separately the variations of the parameters examined and to test the variability of the measurements between the individual observers. Since the study was carried out with well-defined and controlled tilting of the vertebra and under standardized CT conditions, the sources of error arising from the material used and the procedure itself were eliminated. Moreover, the use of angles and relative values, such as indices, rather than absolute values were considered to improve further the accuracy of the measurements for comparative studies.

With regard to the variability of the measurements depending on the individual observer, there are two main sources of error, i.e. ascertaining standardized topographic points on the image and the experience and skill of the individual observer to perform those measurements. Both are unavoidable common sources of error in all such studies. The original CT method for the estimation of vertebral rotation [1, 2] has been found unsatisfactory by other authors [9]. The accuracy of the measurements is,however, usually estimated by analysis of the intra- and interobserver variations. In this study, the intraobserver difference (SD) was less for the more experienced observers A and B than for observer C, indicating that skill influences the evaluation of the measurements. However, as a whole both the intra- and interobserver degrees of precision were satisfactory for group comparisons.

The inter- and intraobserver precision of the parameters examined in the model study was higher in the normal than in the scoliotic vertebra. This can be explained by the deformity of the scoliotic vertebra caused by modelling.

VBVA reflects the magnitude of the vertebral body modelling towards the concavity of the scoliosis. Neither in the normal nor in the scoliotic vertebral specimen was VBVA influenced by a 10° tilting. The variation of VBVA measurements in the scoliotic vertebra used resulted from the difficulty in identifying the point *a* furthest from point *b*, because of the blurred ridge of the vertebral body on the CT scans.

PWi, CWi and TPAi were used to evaluate the asymmetry of the posterior elements of the vertebra in scoliosis. PWi was significantly influenced by a vertebral lateral tilt of 10°, indicating that asymmetry of pedicle width should not be based on PWi alone. The CWi of both, the normal and the scoliotic vertebrae were not significantly changed by a 10° tilt. The variations of PWi and CWi were mainly caused by the irregular shape of the pedicles. TPAi showed no significant variation with a tilt of up to 10°. If the vertebra tilts more than 10° laterally, the two transverse processes will not be imaged on the same CT section. The irregular contour of the tip and the non-straight form of the transvers process may make determination of its middle axis difficult, which may explain the variation in the measurements.

The CT scans of the thoracic vertebrae from 59 non-scoliotic and scoliotic subjects including the vertebral body and both transverse processes were considered not to be tilted by more than 10°. The fact that the intra- and interobserver differences are similar to those of the model study implies that the method can also be put to practical use.

In this study, a new method is presented for morphometric studies not only of the body but also of the poste-

Table 3. The influence of the tilt of the scoliotic vertebra in different positions on various indices (mean ± SD of ten measurements by one observer)

Position	*n*	VBVA	PWi	CWi	TPAi
Neutral	10°	17.5° ± 1.4°	2.980 ± 0.048	0.690 ± 0.025	1.183 ± 0.063
5°ventrally	10°	18.4° ± 1.5°	2.984 ± 0.059	0.701 ± 0.029	1.190 ± 0.039
10°ventrally	10°	18.8° ± 1.2°	2.946 ± 0.082	0.689 ± 0.029	1.177 ± 0.028
5°dorsally	10°	17.2° ± 1.3°	2.980 ± 0.048	0.689 ± 0.037	1.205 ± 0.074
10°dorsally	10°	18.0° ± 0.8°	2.980 ± 0.103	0.691 ± 0.031	1.179 ± 0.056
5°laterally	10°	17.9° ± 1.0°	2.936 ± 0.09	0.699 ± 0.026	1.234 ± 0.107
10°laterally	10°	18.8° ± 1.3°	2.864 ± 0.105*	0.693 ± 0.031	1.235 ± 0.046

* $P < 0.05$ compared with the corresponding value in neutral position

Table 4. Intraobserver precision (SD) of the first and second measurements of the scoliotic vertebra performed by three obersvers

Observer	VBVA	PWi	CWi	TPAi
A	0.5°	0.076	0.022	0.040
B	1.3°	0.145	0.031	0.035
C	3.0°	0.509	0.051	0.076
Average	1.6°	0.243	0.035	0.050

rior elements of normal and scoliotic vertebrae in the horizontal plane. VBVA, CWi and TPAi are not influenced by vertebral tilting up to 10° and can therefore be quantified on CT scans, whereas PWi can be used only for approximative estimation of the pedicle width asymmetry. The results indicate that the precision of the method is sufficient for group comparisons. However, because of the high SD of the interobserver measurements, used of the method for longitudinal studies of individual patients is questionable, but not for longitudinal group comparisons, provided that the number of observations in each group is sufficiently large.

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