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Vertebral Dimensions: Influence of X-Ray Technique and Patient Size on Measurements

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Abstract. In this study a new reference value, ''corrected vertebral dimension,'' is presented for vertebral height measurements. Of 68 females (age 18–88 years; mean 44.2 years) and 40 males (age 16–81 years; mean 55 years) the projected vertebral dimensions (T_4–L_5) were measured on lateral radiographs. In addition to this, the vertebra-to-film distances (VFD) were measured and a fixed focus-to-film distance (FFD) was used during the study. Corrected dimensions of the thoracic and lumbar vertebrae (T_4–L_5) were calculated using the FFD and VFD. These corrected dimensions were then used to recalculate projected vertebral dimensions at different focus-to-film distances. The applied geometric corrections were verified in a phantom study representing an *in vitro* situation. The results indicate that studies using different X-ray techniques for making lateral radiographs of the spine can become comparable when using corrected vertebral dimensions.

Key words: Vertebral dimension — Correction — Osteoporosis — Technique — Patient size

Changes in vertebral dimensions are a commonly used and well-accepted end-point criterium in clinical research on osteoporosis [1–3]. These changes can be detected either by using a semiquantitative or a quantitative method. The semiquantitative method is based on classification of deformities by visual interpretation [4]. The quantitative method is based on measuring vertebral dimensions (height, width, or area) [5–13]. Implementation of standardized, conventional, lateral spinal radiographs could enable comparison of dimensions in longitudinal studies or provide for reference values. Therefore, variables affecting the projection of the vertebrae on the film should be recorded. Divergence of the X-ray beam, the focus-to-film distance (FFD), and the vertebra-to-film distance (VFD) are major factors affecting the projected vertebral dimensions. The FFD can be standardized but the VFD depends on the width of the patient's body and the type of bucky table used.

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Gallagher et al. [6] reported a decrease of 5.5% in vertebral anterior height as a result of using a 111.8 cm FFD instead of a 101.6 cm FFD. Various authors have reported different FFDs: 101.6 cm [4–7, 10, 11], 111.8 cm [8], 120 cm [12], and 140 cm [13]. Others did not mention the FFD used in their studies [3, 9]. In this study we used a FFD of 150 cm and we measured the VFD in our patient population. Corrected dimensions of the thoracic and lumbar vertebrae (T_4–L_5) were calculated using the FFD and VFD. Measured dimensions were recalculated into dimensions at the standard FFD, as proposed by the European Communities Medical and Health Research Programme: 120 cm, and the often used 100 cm FFD [4–7, 10, 11, 14]. Furthermore, we investigated the influence of a change in VFD on the projected vertebral dimensions at different FFDs. Finally, the range of vertebral dimensions due to variation in FFD and VFD was compared with results found in the literature [7–12].

As serial radiographs were not within the scope of this study, we verified the applied geometric corrections in a phantom study, which represented an *in vitro* situation.

Materials and Methods

Phantom Study

We used a phantom designed for this study (Fig. 1). Consisting of seven perspex-cubes placed on a perspex rail. On all cubes, a lead wire 1.0 mm thick and 30.0 mm long was placed in the middle on the front of the cube (anterior height). The lead wire was used as the point from which object-to-table distance was measured. The X-ray beam was centered on the fourth cube with a fixed table-to-film distance of 8.5 cm. The object-to-film distance was calculated by adding the object-to-table distance to the table-to-film distance. Radiographs of the phantom were made at three fixed FFDs—100 cm, 120 cm, and 150 cm. OFDs were 20 cm, 27.5 cm, and 35 cm.

In-Vivo Study

Subjects. A total of 108 patients, 68 females (age 18–88 years; mean 44.2 years) and 40 males (age 16–81 years; mean 55 years), referred to our clinic for radiography of the thoracic and/or lumbar spine were included in this study.

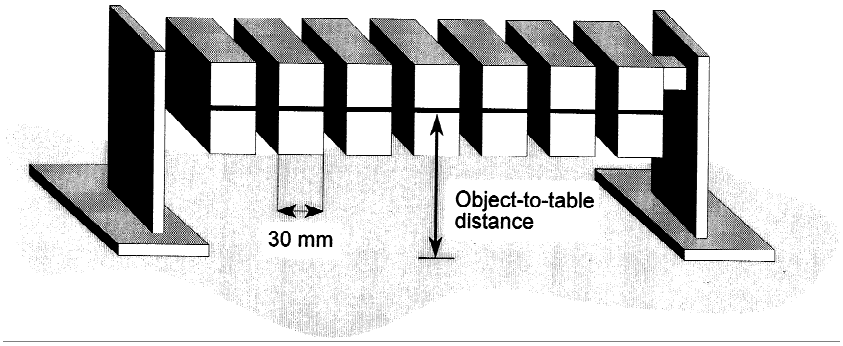

Fig. 1. Phantom with cubes and lead wires (representing the anterior height) used for the verification of the applied geometric corrections.

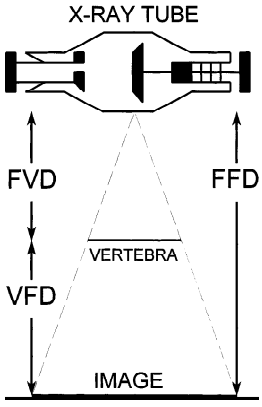

Fig. 2. Theory of linear magnification of projected dimensions caused by the X-ray beam's divergence. The magnification of the vertebral dimensions is directly related to the focus-to-film distance (FFD) and the vertebra-to-film distance (VFD). FVD is the focus-to-vertebra distance.

Radiographs. Lateral thoracic radiographs covering T_4–T_{12} were available from 65 female and 22 male patients. Lateral lumbar radiographs covering T_{12}–L_5 were available from 53 female and 40 male patients. The radiographs were made with a fixed FFD of 150 cm and a fixed table-to-film distance of 8.5 cm. All patients were positioned according to a standard protocol, i.e., lying on their side with knees bent, hips in anteflexion, and elbows bent in front of their face. The X-ray beam was centered on T_7 for lateral thoracic radiographs and on L_2 for lateral lumbar radiographs.

Vertebral coordinates resulting from placement of six points were obtained by a trained person using a translucent digitizing tablet (Model 2210 Numonics Corp., Montgomeryville, USA) and Sigmascan software (Jandel Scientific, Corte Madera, USA) [7]. Using software developed in-house, these coordinates were then used to calculate anterior, middle, and posterior vertebral heights as well as the anterior to posterior height ratio. To determine the intraobserver variation, all vertebrae (T_4–L_5) of one patient were measured 10 times. All vertebrae with an anterior to posterior height ratio more than 2 standard deviations (SDs) below the mean were excluded for final analysis.

Vertebra-to-Film Distance. The VFD distance was calculated by adding the vertebra-to-table distance and the table-to-film distance. The vertebra-to-table distance was measured using a special ruler mounted on the table surface; it projected a lighted cross-hair cursor at the back of the patient. By positioning the cursor on the midpoint of the spinous process of the vertebra on which the X-ray beam was centered (T_7 or L_2), the distance between the spinous process and the surface of the table could be read on the ruler's display. To determine the reproducibility of the vertebra-to-table distance measurements the vertebra-to-table distances of five volunteers were measured 10 times.

Theory and Equation. The divergence of the X-ray beam causes a magnified projection of a vertebra on a radiograph (Fig. 2). The magnification of the vertebra depends on the focus-to-film distance (FFD), the focus-to-vertebra distance (FVD), and the vertebra-to-film distance (VFD). If all distances are known, the magnification factor can be calculated using the following equation (CD = corrected dimension, MD = measured dimension, C = correction factor):

$$= \mathrm{MD} \times \left(\frac{\mathrm{FVD}}{\mathrm{FFD}} \right)$$

$$\mathrm{CD} = \mathrm{MD} \times \left(\frac{\mathrm{FFD} - \mathrm{VFD}}{\mathrm{FFD}} \right)$$

$$\mathrm{C} = \left(\frac{\mathrm{FFD} - \mathrm{VFD}}{\mathrm{FFD}} \right)$$

$$\mathrm{CD} = \mathrm{MD} \times \mathrm{C}$$

In order to calculate the projected image dimension for the same vertebra at a different FFDs, the corrected dimension is multiplied by the magnification factor, i.e., the inverse of the correction factor (1/C).

Results

Phantom Study

Measured length of the lead wires of all seven cubes at different object-to-film distances at three different focus-to-film distances are given in Table 1. After correction the mean measured length of the lead wires was 29.9 mm (0.14 mm SD), independent of FFD or object-to-film distance.

In-Vivo Study

Mean, SD, and coefficient of variation (CV) of measured and corrected height of male and female vertebrae T_4–L_5 are presented in Table 2. The mean CV of all vertebrae, as

Table 1. Measured length (mm) of lead wires on radiographs of the phantom at different focus-to-film (FFD) and object-to-film (OFD) distances

FFD (cm)	100	100	100	120	120	120	150	150	150
OFD (cm)	20	27.5	35	20	27.5	35	20	27.5	35
Cube									
1	37.6	41.5	45.8	36.1	39.2	42.4	34.8	36.9	39.1
2	37.5	41.3	45.7	36.0	39.0	42.4	34.7	36.7	39.1
3	37.5	41.2	45.6	36.0	38.9	41.9	34.5	36.6	38.9
4	37.5	40.9	45.6	35.9	38.8	42.0	34.5	36.6	39.0
5	37.4	41.0	45.7	36.0	38.9	41.9	34.5	36.7	39.0
6	37.5	41.2	45.9	36.0	39.0	42.0	34.6	36.7	39.0
7	37.6	41.3	46.1	36.1	39.1	42.1	34.7	36.8	39.1
Mean (mm)	37.5	41.2	45.8	36.0	39.0	42.1	34.6	36.7	39.0
Magnification	125.0%	137.3%	152.6%	120.0%	130.0%	140.3%	115.4%	122.4%	130.1%

measured 10 times in one patient, was 1.2%. The mean CV of the vertebrae to table distance measured 10 times in five volunteers was 1.5%. The corrected vertebral anterior heights and the mean vertebral anterior heights at different FFDs (100, 120, and 150 cm) for our male and female population are given in Figure 3.

The mean female VFD was 26.6 cm and the mean male 26.7 cm. For the females, the measured vertebra-to-table distance ranged from 15.9–24.5 cm, whereas for males it was 15.5–21.8 cm. As we use different types of bucky tables in our clinic the range of table-to-film distance can be from 5.9 to 8.5 cm. The range for VFD was calculated by combining the range of vertebra-to-table and range of table-to-film distances. This resulted in a VFD range for our clinic of 21.8–33.0 cm for females, and 21.4–30.3 cm for males.

Table 2. Mean, SD, and CV of measured and corrected female and male anterior vertebral heights (mm)

	Female			Male		
Measured	Mean	SD	CV	Mean	SD	CV
T4	23.49	1.26	0.054	25.65	1.51	0.059
T5	23.27	1.36	0.058	25.70	1.42	0.055
T6	23.29	1.53	0.066	25.70	1.40	0.054
T7	23.24	1.64	0.071	25.33	1.61	0.064
T8	24.12	1.66	0.069	26.06	2.12	0.081
T9	25.24	1.73	0.069	26.43	2.78	0.105
T10	27.07	1.64	0.061	28.23	2.47	0.087
T11	27.89	1.66	0.060	29.59	1.83	0.062
T12	30.63	2.37	0.077	30.66	2.17	0.071
L1	32.44	2.17	0.067	32.93	2.28	0.069
L2	34.66	2.34	0.068	34.46	3.18	0.092
L3	35.74	2.49	0.070	35.66	2.80	0.079
L4	36.31	2.33	0.064	35.31	2.58	0.073
L5	37.06	2.48	0.067	35.35	5.04	0.143
Corrected						
T4	19.22	1.06	0.055	20.81	1.29	0.062
T5	19.03	1.12	0.059	20.84	1.08	0.052
T6	19.01	1.23	0.065	20.84	1.14	0.055
T7	18.97	1.36	0.072	20.55	1.34	0.065
T8	19.67	1.37	0.070	21.14	1.74	0.082
T9	20.59	1.40	0.068	21.45	2.29	0.107
T10	22.08	1.33	0.060	22.92	2.05	0.089
T11	22.82	1.33	0.058	24.02	1.55	0.065
T12	24.98	1.88	0.075	25.28	1.75	0.069
L1	26.54	1.72	0.065	27.14	1.79	0.066
L2	28.35	1.90	0.067	28.43	2.48	0.087
L3	29.21	1.98	0.068	29.41	2.15	0.073
L4	29.68	1.82	0.061	29.14	2.07	0.071
L5	30.30	1.96	0.065	29.21	4.10	0.140

Discussion

The phantom study shows that the simple geometric correction proposed in this study yields the correct length of the lead wires within an error of 1%. These data also show a small systematic error if the object is further away from the center of the X-ray beam. This effect, on the order of 1%, can be explained by the penumbra which increases as the object is further away from the center of the X-ray beam. Due to the more complex geometry of vertebrae this effect will be larger *in vivo*.

The vertebral dimensions measured in our *in vivo* study are slightly larger than those reported in the literature [7–12]. We attribute this difference to a population effect, as we used the same method as other authors [7–9].

For our female population, the range for VFD is 21.8–33.0 cm. Using this range for VFD, a theoretical range of measured vertebral dimensions for each vertebra can be calculated. The difference between measured vertebral dimensions at minimal VFD and maximal VFD increases from 14% at FFD = 150 cm to 20% at FFD = 120 cm and 28% at FFD = 100 cm. Different female vertebral anterior heights reported in the literature are compared with the range of female vertebral anterior heights in the present study (Fig. 4) [7–12]. The data in Figure 4 show a remarkable fit between the results in the literature and our calculated range of vertebral dimensions.

An important advantage of measuring VFD and FFD is that the accuracy of the corrected vertebral dimension is greatly improved, as demonstrated in the phantom study. It can be concluded that measuring FFD and VFD is a simple, efficient, and quick way to diminish differences between populations. As such, corrected vertebral dimensions enables comparison between studies using different X-ray techniques.

In conclusion, for future research in which vertebral dimensions are used, we would like to recommend the use of corrected vertebral dimensions to improve comparability between studies.

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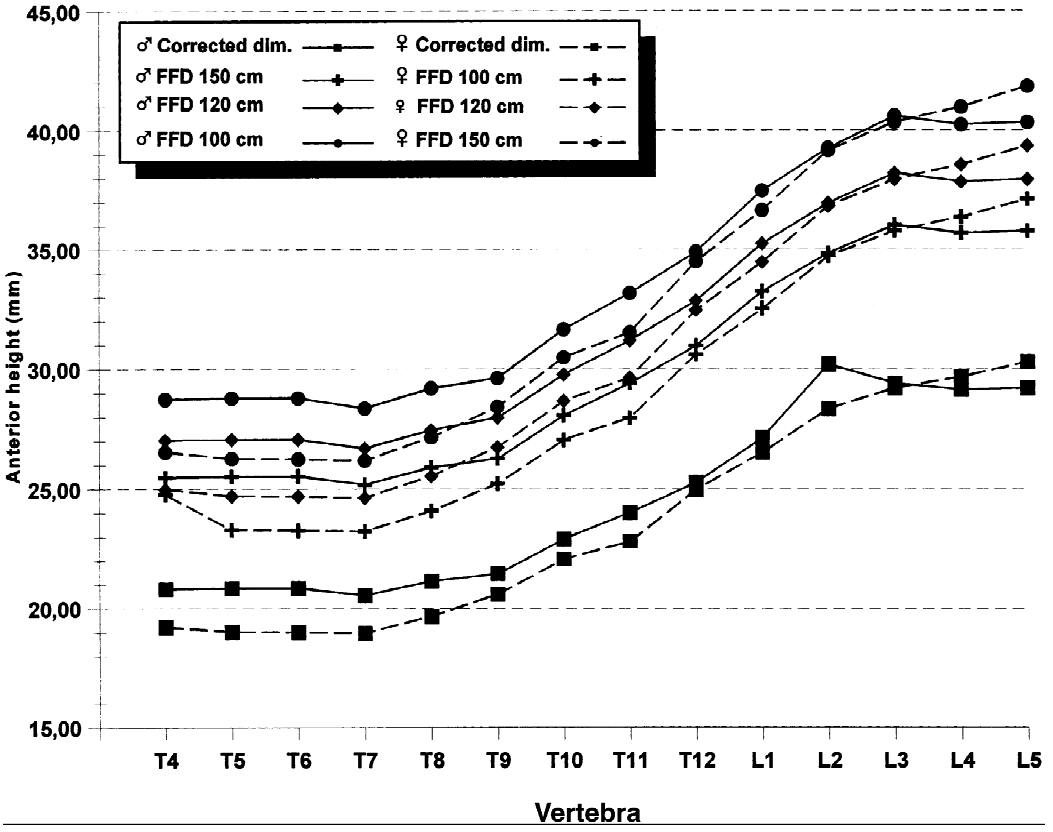

Fig. 3. Calculated mean vertebral anterior heights (mm) for females and males at different focus-to-film distances and the calculated corrected vertebral anterior heights.

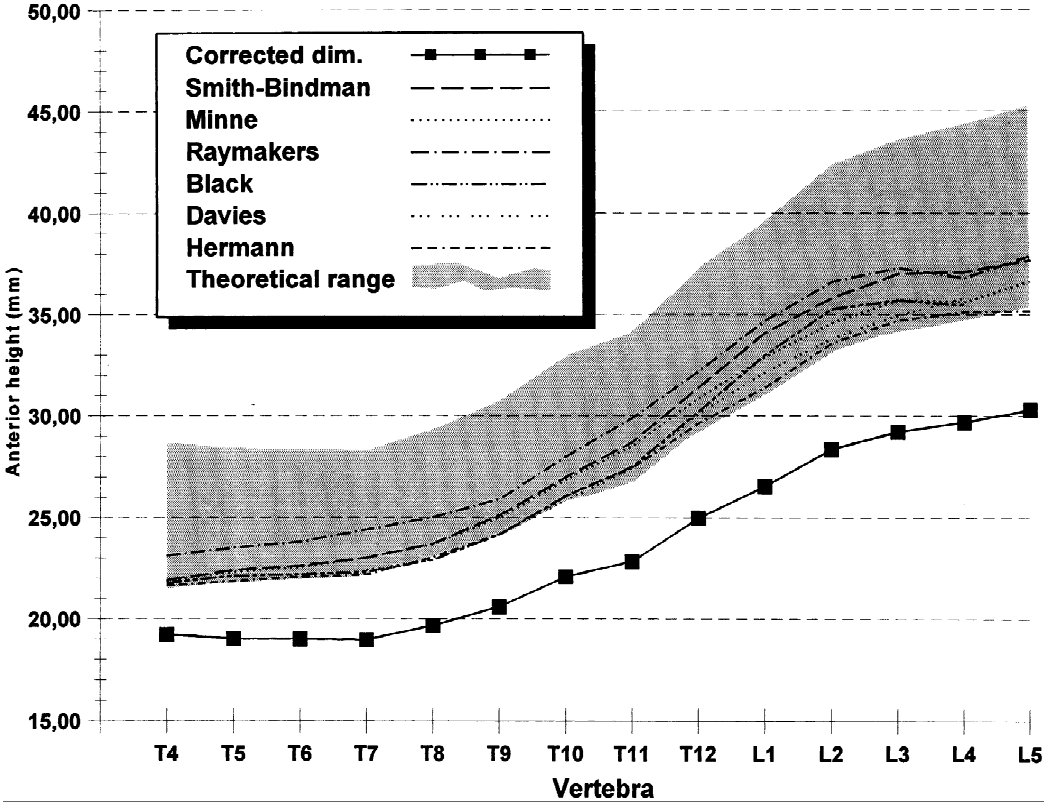

Fig. 4. Mean measured vertebral anterior heights for females of six studies [7–12], fitting within the calculated range of vertebral anterior heights, and the calculated corrected vertebral anterior heights for females in our study.

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