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Original Article

Radiograph-Based Study of Gender-Specific Vertebral Area Gain in Healthy Children and Adolescents as a Function of Age, Height, and Weight

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Abstract

This study reports gender-specific vertebral area gain data from children and adolescents. Vertebral area was measured on lateral and anteroposterior thoracic and lumbar spine radiographs from 100 female and 100 male subjects aged 7–28 yr. T9, T11, T12, L1, and L2 X-ray area calculation was based on calculation of the area of the geometric figure of a trapezoid whose 2 nonparallel sides were equal in length, taking account of the waisted shape of the vertebrae. Both the boys and girls of our study population showed statistically significant dependence ($p < 0.001$) of vertebral area gain on chronologic age, height, and weight right through the end of puberty, and especially so up to age 15 yr. However, height and weight were clearly better predictors of lateral and anteroposterior vertebral area gain than was chronologic age. Once vertebral growth is complete by age 18 yr or so, the lateral vertebral areas of the male subjects—regardless of body weight and height—are, on average, 25% larger, and the anteroposterior areas up to 30% larger than those of their female counterparts. After adjusting for chronologic age, height, and weight however we did not find significant differences, between gender, in vertebral area of male and female subjects, neither among children younger than 11 yr nor adolescents ages of 12–14 yr and young adults older than 18 yr.

Key Words: Conventional radiography; growth; normative data; sex differences; vertebral morphometry.

Introduction

Studies to date suggest that bone mass, characterized by bone volume and bone density, is a suitable measure of bone strength and biomechanical competence, particularly of the vertebral bodies *(1,2)*. Peak bone mass attained in puberty is thought to have a clearly greater role in determining osteoporotic fracture risk later in life. Peak bone mass maximization by the end of skeletal growth is therefore considered a central approach to osteoporosis prevention today. A major prerequisite for estimating optimal peak bone mass is the determination of normal reference database of bone size and bone mass in boys and girls of different age in a healthy population.

While being an important part of the central weight-bearing skeleton and a major site of osteoporosis manifestations later in life, the growing spine is essentially uncharted territory when it comes to gender-specific, clinically useful reference data regarding such vertebral body dimensions as width, depth, height, or area *(3–7)*. The impact of such

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anthropometric variables as height and weight on vertebral growth and hence on bone mass continues to be a matter of debate *(7,8)* and a relation to hormonally controlled growth phases in puberty is quite likely *(9–12)*.

A host of diverse noninvasive methods of determining bone density and bone mass have been used in children and adolescents. Also, it seems that studies finding no gender differences comprise prepubertal populations. Most studies of puberty or early adulthood do report gender differences. Results are inconsistent, at least in part, and clearly suggest no definite gender differences during growth *(6,7,12–18)*. Vertebral area calculations based on lateral or anteroposterior X-rays—increasingly used for the diagnosis of osteoporotic spine deformities in adults are not yet available for children and adolescents *(19)*.

The objective of the present study, therefore, was to establish spine X-ray-based gender-specific vertebral area gain data in healthy children and adolescents, and to identify growth dependence on chronologic age, sex, height, and/or weight. The vertebral area data generated in this study can be used with some limitations as reference baseline values for evaluation of spine deformities experienced later in life.

Materials and Methods

Vertebral area was measured on lateral and anteroposterior thoracic and lumbar spine radiographs from 100 male subjects aged 8–28 yr (median: 14; standard deviation [SD]: 4.6) and 100 female subjects aged 7–25 yr (median: 14; SD: 3.8). The study population was made up exclusively of healthy, competitive sports-oriented children and adolescents from the East German region of Mecklenburg-Vorpommern who had for years been in regular intense training in various sports. In the former East Germany, periodic X-rays were mandatory for competitive athletes, and there was little geographical mobility and no immigration from other countries.

Inclusion criteria for subject (radiograph) evaluation in this study are the availability of a longitudinal series of thoracic and lumbar spine X-rays in 2 planes, and of height and weight records for each X-ray day. The criteria for exclusion of subjects were those defined in the German Democratic Republic Athletes' Association Training Center Medical Care and Monitoring Guidelines *(20)*.

(*Richtlinien zur sportmedizinischen Betreuung der Sportler der Trainingszentren und Trainingsstützpunkte des Deutschen Turn- und Sportbundes der DDR*)

Thus, the diseases listed below (among others) were considered contraindications to taking up any competitive sport and, therefore, were automatically exclusion criteria for our study population.

1. Orthopedic contraindications: Spondylolisthesis, Scheuermann's disease, bilateral spondylolysis, established scoliosis ($>10°$ deviation) or established kyphosis; muscle, tendon, and/or joint disease; or injury resulting in functional restriction incompatible with athletic activity.
2. Medical contraindications: Structural heart disease, established hypertension, bronchial asthma, glomerulonephritis, recurrent gastrointestinal disease, diabetes mellitus, endocrine disorders.
3. A number of neuropsychiatric, gynecologic, and dermatologic contraindications.

The radiographs were made available to us by the *Rostock Olympiastützpunkt* (former name: *Sportmedizinischer Dienst des Bezirkes Rostock*) X-Ray Film Archives and cover the period from 1967 to 1990.

The examination of the reproducibility of the measuring methods with radiographs took place by means of Student's *t*-test for the correlating samples (significance $p < 0.05$). Eighteen single dimensions of radiographs from the T9, T11, T12, L1, and L2 in the anterior-posterior and lateral path of rays were made of the first 47 subjects. A replication of these measurements proceeded after 4 wk by the same investigator. The deviation of means of the single body of vertebra, in reference to the first measurement, was between 0.03% and 0.77%. Particularly in the upper thorax and lower lumbar spine areas, imprecision accumulates because of an unequal area projection of the body of vertebra related to the upper and lower borders. Beyond that, an imprecision occurs with further increases of soft tissue in the upper thorax and lower lumbar areas. So we evaluated the T9, T11, T12,. L1, and L2 as useful.

The few spine X-rays from the time before 1976 had been performed with the patients in the horizontal position, whereas all others were taken in the vertical-standing position. The focus film distance was 120 cm, centering on T7 on thoracic spine X-rays and on L2 on lumbar spine X-rays.

The processed dimensions were those measured on the radiographs, no enlargement factor being used. We did not use a correction factor because absolute individual values were of secondary importance to our study objective because we compared cohorts and a correction factor would have had the same effect on all groups. All X-rays were measured by the same examiner under identical conditions using a caliper rule (Aristo; accurate to 0.1 mm) and magnifying glass on the viewing box.

Morphometric points for the measurement of all vertebral dimensions were defined in accordance with pertinent accounts in the literature, making any modifications that may have been necessary to meet our study objective—vertebral area calculation. A number of techniques for the diagnosis of osteoporotic vertebral deformities *(21–23)* and investigations aimed at defining normal ranges for vertebral body dimensions were based on similar morphometric point coordinates *(5,24,25)*.

Based on the study by Nelson et al *(19)* dealing with the measurement of lateral vertebral areas in adult females, and on our own modifications for vertebral area calculation, we defined 8 morphometric points per vertebral body for measurements on lateral and anteroposterior radiographs (Fig. 1A).