

# Timing of Peak Bone Mass: Discrepancies between CT and DXA

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**Context:** The time of life in which peak bone mass in the axial skeleton is attained has been the subject of considerable controversy, with estimates ranging from the time of sexual and skeletal maturity to the fifth decade of life.

**Objective:** The objective was to examine whether dual energy x-ray absorptiometry (DXA) and computed tomography (CT) values for bone mass and bone density (BD) in the axial skeleton increase after sexual and skeletal maturity.

**Design/Participants:** Measurements of vertebral bone mineral density and bone mineral content (BMC) by DXA and vertebral BD and BMC by CT were obtained in 50 sexually and skeletally mature white females at baseline and 3 yr later. CT BMC values were calculated through analysis of vertebral volume in relation to density (BMC = vertebral volume × BD).

**Results:** Although neither CT BD nor BMC measures changed with time, DXA bone mineral density and BMC values were significantly higher at follow-up ( $P < 0.0001$ ). Despite strong correlations between DXA and CT bone measures, DXA yielded greater changes in bone values in 47 of 50 subjects.

**Conclusions:** Bone acquisition in the lumbar spine as measured by CT reaches its peak by sexual and skeletal maturity. In contrast, bone values by DXA continue to increase after puberty and cessation of longitudinal growth. Increases in DXA measures are likely a reflection of inhomogeneous changes in soft tissues around the spine or of disproportionate increases in the posterior elements of the vertebrae rather than of changes within the vertebral body. (*J Clin Endocrinol Metab* 92: 938–941, 2007)

THE AMOUNT OF bone gained during adolescence is the main contributor to peak bone mass, which, in turn, is a major determinant of osteoporosis and fractures in the elderly, most commonly in the vertebrae (1). Because current treatment for osteoporosis in elderly women does not significantly restore loss of bone, efforts are being directed toward developing preventive measures that increase bone mass before it reaches its peak (2). However, the time of life in which peak bone mass is attained is the subject of considerable controversy, with estimates for the axial skeleton ranging from soon after the completion of sexual and skeletal maturity at the end of the second decade to the fifth decade of life. Most, but not all, indicate that bone mass does not significantly increase after the third decade (3–25).

Previous studies on the timing of peak bone mass were mostly conducted using dual-energy x-ray absorptiometry (DXA), a technique that is low in cost, has minimal radiation exposure, and is readily accessible and easy to use (27). However, DXA bone values are influenced by changes in body size and soft tissue composition around the bone measured (28–30), which may account for the conflicting results of previous studies. In this study, we examined whether bone mass in the axial skeleton continues to increase after sexual and skeletal maturity using DXA and computed tomography

(CT), a technique that provides measures that are not influenced by soft tissues (31), in a cohort of 50 young women.

## Subjects and Methods

### Subjects

The study subjects were 50 healthy white females 14 to 20 yr of age. The protocol for this study was approved by the institutional review board for clinical investigations at our institution, and all participants and/or their parents signed informed consent.

An initial interview was conducted to describe the purpose and aims of the study and the tests to be performed. Candidates for this study were excluded if they had a diagnosis of any underlying disease or chronic illness, if they had been ill for longer than 2 wk during the previous 6 months, if they had been admitted to the hospital at any time during the previous 3 yr, or if they were taking any medications, including oral contraceptives. Subjects who were pregnant, had ever been pregnant, or who had missed menses for more than 4 consecutive months or two cycle lengths after establishing regular cycles were also excluded.

All potential candidates underwent a general physical examination, including assessments of the degree of sexual development and a radiographic examination of the left hand and wrist. Only subjects who had reached sexual maturity, defined as Tanner V of sexual development (32), and skeletal maturity, defined as physeal closure in the phalanges and metacarpals using the radiographic atlas of Greulich and Pyle (33), were included in the study. Height and weight were measured, and body mass index (BMI) was calculated. Thereafter, CT and DXA measures were obtained at baseline and 3 yr later.

### Bone measurements

All participants were assessed by CT using the same scanner (General Electric Hilite advantage; General Electric, Milwaukee, WI) and the same mineral reference phantom for simultaneous calibration (CT-T bone densitometry package; General Electric), and were performed by the same technologist. Identification of the sites to be scanned was performed with lateral scout views, and the integral density of bone (in-

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Abbreviations: BD, Bone density; BMC, bone mineral content; BMD, bone mineral density; BMI, body mass index; CT, computed tomography; DXA, dual-energy x-ray absorptiometry.

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cluding both cortical and cancellous bone) of the vertebral body was obtained from the 10-mm mid-portion of the L1, L2, and L3 vertebral bodies. Excluded from the determinations were the transverse process and the posterior elements. The cross-sectional areas at the same sites were also determined. The volume of each vertebra was calculated by multiplying the cross-sectional area by vertebral height from the scout view. The average volumetric bone density (BD) and volume of L1–L3 were determined by averaging the values for L1, L2, and L3, and bone mineral content (BMC) was calculated as  $CT - BMC = BD \times volume$ . The coefficients of variation for repeated CT measurements of vertebral BD, vertebral body cross-sectional area, and vertebral BMC range between 0.6 and 1.5% (34). The time required to complete CT scans in individual patients was approximately 10 min, and the effective radiation dose was approximately 0.1 mSv (35).

Subjects also underwent DXA scanning by the same radiology technologist using the same densitometer (Hologic QDR4500; Hologic, Inc., Bedford, MA). For the axial skeleton, anterior–posterior scans were obtained at L1–L3. The manufacturer's software calculated BMC and areal bone mineral density (BMD) for each vertebra. The average BMC and BMD of L1–L3 were determined by averaging the values for L1, L2, and L3. The coefficients of variation for repeated DXA measurements of vertebral BMC and BMD have been reported to range from 0.7 to 1.7%. The time required for the procedure was approximately 5 min, and the radiation exposure was negligible (36).

### Statistical analysis

Statistical analysis was performed using Statview (version 5.0.1; SAS Institute Inc., Cary, NC). Two-tailed paired *t* tests were used to examine changes in CT and DXA bone measures from baseline to follow-up, and simple regressions were used to study the relationship between the baseline and follow-up measures. Simple regression was also used to examine relationships between the CT and DXA measures and Pearson's correlation coefficients were reported to indicate the strength of relationships.

## Results

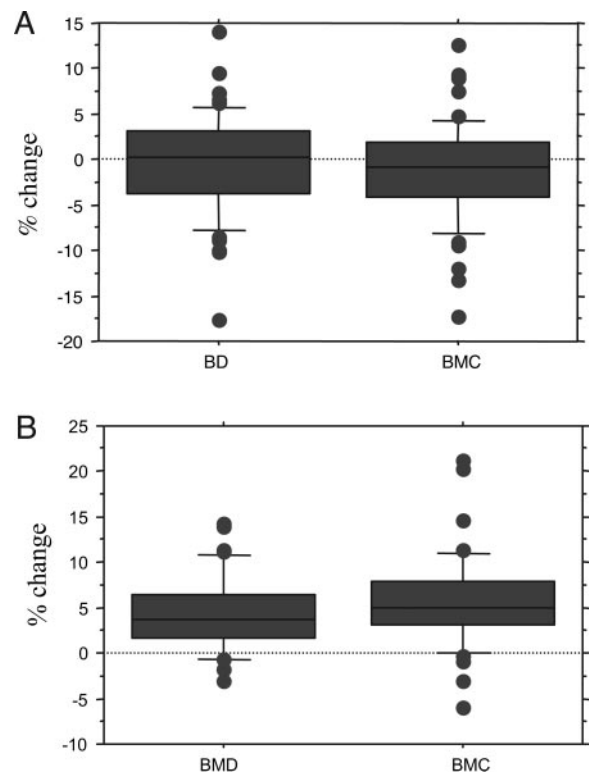
Age and anthropometric data at baseline and follow-up in the study subjects are described in Table 1. There was no significant change in height, although both weight ( $P = 0.003$ ) and BMI ( $P = 0.008$ ) increased at follow-up, on average, 3 yr later. No significant changes in CT measures of vertebral BD or BMC were observed between baseline and follow-up studies (Fig. 1A). In contrast, DXA vertebral BMD and BMC were significantly higher (4.3 and 5.7%, respectively) at follow-up ( $P < 0.0001$ ) (Fig. 1B).

Regardless of technique, bone measures at baseline strongly correlated with values at follow-up (Fig. 2). There were also statistically significant correlations between CT and DXA bone determinations, with the strongest between CT and DXA BMC (Fig. 3). Despite these strong associations, comparisons between DXA and CT BMC measures showed greater percentage changes by DXA in 47 of the 50 subjects.

**TABLE 1.** Age, anthropometric characteristics, and bone measurements in 50 women at baseline and follow-up

	Baseline	Follow-up	<i>P</i>
Age	16.7 ± 1.5	19.7 ± 1.5	<0.0001
Height (cm)	162.5 ± 5.7	162.8 ± 5.4	NS
Weight (kg)	65.6 ± 14.7	68.6 ± 15.9	0.003
BMI (kg/m <sup>2</sup> )	24.8 ± 5.2	25.8 ± 5.5	0.008
CT BD (mg/cm <sup>3</sup> )	219.4 ± 30	218.7 ± 30	NS
CT BMC (g)	7.84 ± 1.7	7.76 ± 1.7	NS
DXA BMD (g/cm <sup>2</sup> )	0.98 ± .11	1.03 ± .10	<0.0001
DXA BMC (g)	12.7 ± 2.2	13.5 ± 2.2	<0.0001

All values are mean ± SD. NS, Not significant.



**FIG. 1.** Box and whisker plots of CT BD and BMC (A) and DXA BMD and BMC (B) showing no significant changes between baseline and follow-up values by CT, but highly significant changes when using DXA.

## Discussion

The results of the current study indicate that in the axial skeleton, CT values for vertebral BMC and BD reach their peak around the time of sexual maturity and cessation of longitudinal growth. Our findings are consistent with previous CT studies of the lumbar spine and histological examinations of the vertebrae and iliac crest showing evidence that the loss of cancellous BD may occur as early as the third decade (3, 4, 37–41). In contrast, like other investigations using DXA, we found that vertebral BMC and BMD DXA values continued to increase beyond sexual and skeletal maturity. Previous studies using DXA to assess the timing of peak bone mass in the axial skeleton have varied greatly, with estimates ranging from the second (5, 6), to the third (7–10), fourth (11–16), and even fifth (17, 18) decades. Although these discrepancies may be attributed, at least in part, to differences in the technique and methodology of previous studies, the current longitudinal study supports the finding that DXA values peak later than the end of the second decade.

The conflicting results between CT and DXA are likely a reflection of the influence of soft tissues or the inclusion of the posterior elements of the vertebrae in DXA measurements, or both. DXA values are based on the assumption that the composition of soft tissues and proportion of fat around the bone is the same for all subjects regardless of body mass, and errors can occur if this composition varies and fat is distributed inhomogeneously around the bone measured (28–30). In addition, DXA measurements

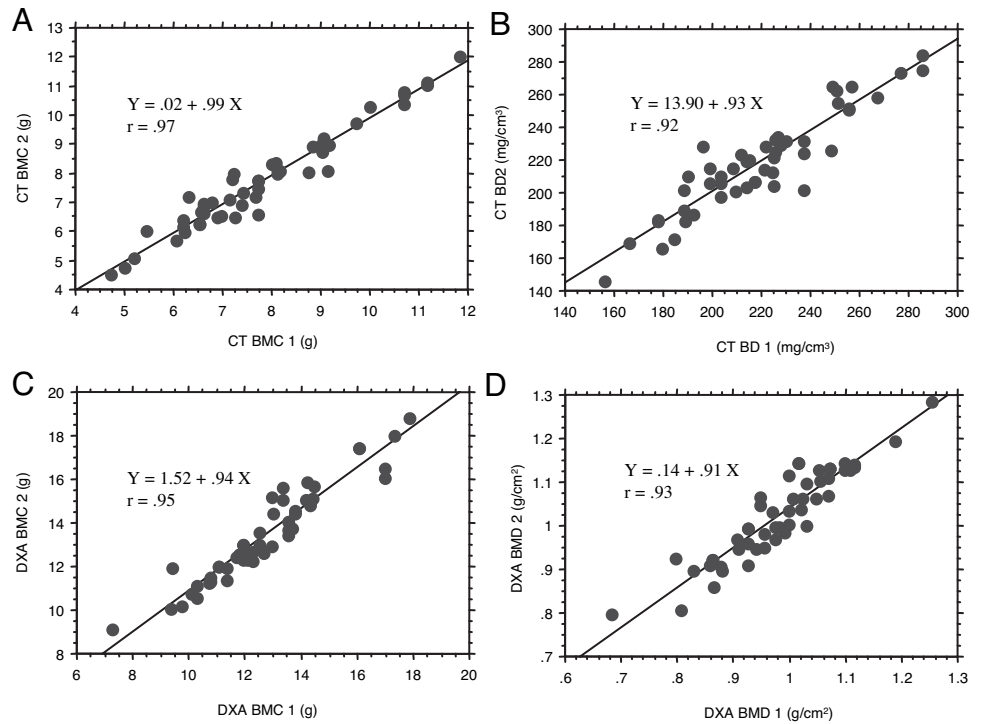


FIG. 2. Univariate correlations between baseline and follow-up measures of CT BMC (A), CT BD (B), DXA BMC (C), and DXA BMD (D).

in the axial skeleton assess the entire vertebra, whereas CT only includes the vertebral body, allowing for the possibility that disproportionate increases in cortical bone at the posterior arch and spinal processes also contribute to these differences (26, 42).

The use of two modalities to assess peak bone mass, the use of the same technologist to obtain all CT and DXA measures, the longitudinal design, and the rigorous assessment of the sexual and skeletal development of the subjects studied are strengths of the current study. Future studies are needed to

establish whether these results also hold for males and for other racial groups, and to evaluate accurately the timing of peak bone mass at other skeletal sites.

In conclusion, this study supports the contention that bone acquisition in the axial skeleton of women reaches its peak at the time of sexual and skeletal maturity, and that reported increases in DXA measures of bone are likely due to the influence of soft tissues and/or the posterior elements, rather than to changes in bone acquisition within the vertebral body. This information may help define the narrow window

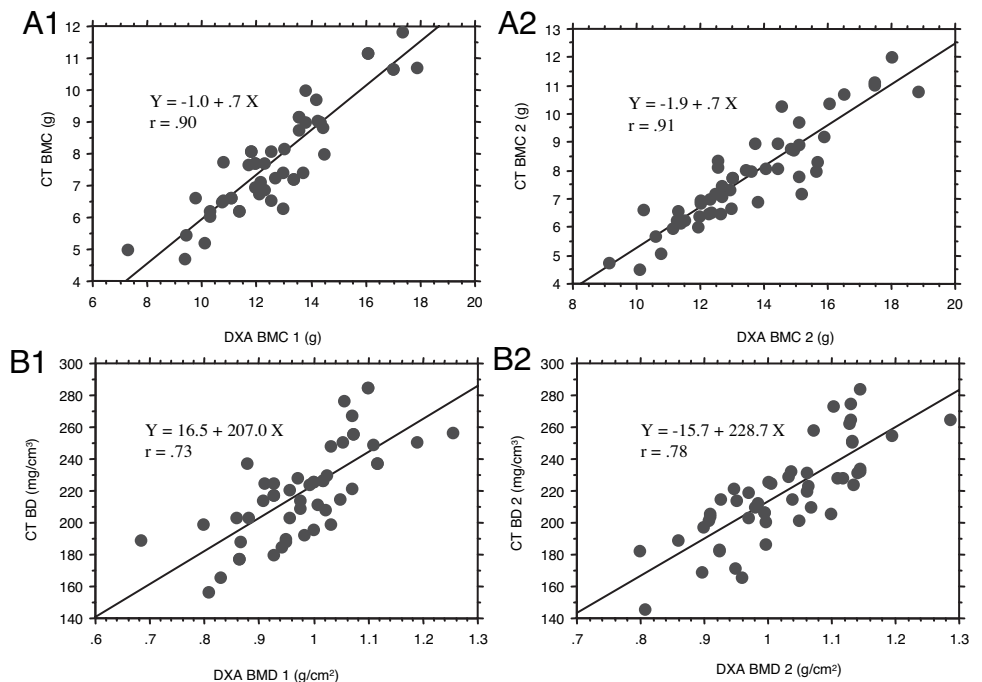


FIG. 3. Univariate correlations between DXA BMC and CT BMC at baseline (A1) and follow-up (A2), and DXA BMD and CT BD at baseline (B1) and follow-up (B2).

of time during which interventions to enhance bone acquisition are likely to be most effective.

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