

The Effect of Age on Fat and Bone Properties along the Vertebral Spine

Chantal Parenteau, Sven Holcombe, Peng Zhang, Carla Kohoyda-Inglis, and Stewart Wang
University of Michigan

ABSTRACT

The human body changes as it becomes older. The automotive safety community has been interested in understanding the effect of aging on restraint performance. Recent research has been focused on assessing the structural and material changes associated with age. In this study, structural tissue distribution was determined using the computed tomography (CT) scan data of more than 19,000 patients, aged 16 and up. The data consisted of subcutaneous fat cross-sectional area, visceral fat cross-sectional area, and trabecular bone density taken at each vertebral level. The data was quantified as a function of five age groups with the youngest group defined as 16-29 years old and the oldest group as 75 and up. An additional analysis stratified on gender was carried out.

Overall, visceral fat increased with age. Compared to the 16-29 group, the visceral fat measured at the L1 level was 1.97 in the 30-44 group, 2.55 in the 45-59 group, 3.33 in the 60-74 group and 3.21-times greater in the 75+ group. Subcutaneous fat also increased with age up to the 60-74 year-old group. The subcutaneous fat measured at L1 level was 1.34 in the 30-44 group, 1.39 in the 45-59 group, 1.38 in the 60-74 group and 1.09-times greater in the 75+ group than in the 16-29 group. A significant association between trabecular bone density and age was found. Trabecular bone density in Hounsfield units (HU) decreased as a function of age, by $2.57 \cdot \text{age} + 0.0056 \cdot \text{age}^2$ for females and $2.57 \cdot \text{age} + 0.0082 \cdot \text{age}^2$ for males.

Gender differences were also observed. Females had 1.43-times more subcutaneous fat and 1.10-times higher trabecular bone density than males at L1, while males had 1.88-times more visceral fat than females. Females gained more subcutaneous fat at L1 as they increased in age up to the 45-59 group and then progressively lost subcutaneous fat. Males and females gained more visceral fat at L1 as they aged up to the 60-74 group. Both consistently lost bone density at L1 as they grew older.

The data was also analyzed for a male subgroup approximating the height and weight of a 50th percentile male dummy. Visceral fat increased with age while trabecular bone density decreased. There was an overall-trend for an increase in subcutaneous fat with age. The results obtained in this study provide insight on the quantified effect of bone and fat distribution as a function of age, gender, and vertebral level. Fat and bone distribution needs to be considered in human mathematical models used to develop safety countermeasures for the older population.

CITATION: Parenteau, C., Holcombe, S., Zhang, P., Kohoyda-Inglis, C., et al., "The Effect of Age on Fat and Bone Properties along the Vertebral Spine," *SAE Int. J. Trans. Safety* 1(2):2013, doi:10.4271/2013-01-1244.

INTRODUCTION

The proportion of the older population is growing. The older population is generally defined as 65 years and older. It is projected to be twice as large in 2030 as in 2000 ([Federal Interagency Forum on Aging-Related Statistics, 2012](#)). The proportion of older vehicle occupants is also increasing. Older adults are keeping their drivers' licenses longer and driving more miles on the roadways than they used to ([Levi S. De Leonardis 2008](#)). [Lyman et al. \(2002\)](#) reported that older drivers have the highest fatal crash involvement rates

per capita. [Li et al. \(2003\)](#) found that drivers 80 or older have the highest death rates per crash. [Evans \(1991\)](#) reported that the fatality risk was 3 times higher in 70-year-old occupants than in 20-year-olds. In addition to increased involvement in fatal crashes, older occupants are more likely to be seriously injured. As a result, safety for older occupants has become a public health issue ([Wang et al. 2003](#)).

[Li et al. \(2003\)](#) assessed the effect of involvement rate and fragility in older drivers and reported that fragility was more important than crash over-involvement. Older occupants are more at risk of injury than young occupants because of their

fragility (Pintar et al. 1997, Kuppa et al. 2003) and decreases in muscle and bone strength (Zhou et al. 1996). As a result, interest for understanding older occupant response in a vehicle crash has been growing.

Focus has first been placed on better understanding chest responses since older occupants have higher risk for serious chest injuries (Wang 2001, Augenstein et al. 2005). Older occupants have a lower thoracic injury threshold and sustain more rib fractures than younger occupants (Foret-Bruno et al. 1998, Cavanaugh and Koh 2001, Kent et al. 2005a). The mortality rate associated with rib fracture is higher in older occupants than in younger occupants with similar injuries (Bulger et al. 2000, Bergeron et al. 2003). Studies have been carried out to assess the effect of age on the thorax properties. Kent et al. (2005b) reported that rib angle varied with age, with the ribs of older occupants more perpendicular to the spine than those of young adults.

In a recent ICAM study (Zhang et al. 2012), increased subcutaneous fat, visceral fat and decreased trabecular bone density were associated with an increase in serious thoracic injury in frontal impacts. Decreases in bone density results were consistent with decreased bone strength reported in prior studies. However, the effect of fat tissue has not been well documented with respect to injury risks. It was hypothesized that the changes in fat and bone density were associated with age. Bone density, fat mass and tissue distribution has been shown to change with age. Cartwright et al. (2007) reported that fat mass peaked by middle-age (40-70 years old) and declined with advanced old age (70+ years old). The distribution of fat was different for older adults than for young adults. The authors reported changes in fat patterns with age. The older adults had less subcutaneous fat than the middle age adults. However, older individuals had more visceral fat and fat in non-adipose tissues such as in the muscle, bone marrow and other locations.

In this study, a large sample of CT scans was analyzed to quantify the effect of fat and trabecular bone density distribution as a function of age, gender and vertebral level along the thoracic and lumbar spine. The data was also assessed for males with similar height and weight as a 50th percentile male dummy.

METHODS

CT Scans

Computed tomography (CT) scans of the chest, abdomen, and pelvis regions were used. The spatial resolution for the CT scans varied between 0.5 mm and 0.9 mm. The CTs were obtained from patients admitted between 2000 and 2012 at the University of Michigan Hospital under institutional review board approval (HUM00041441), from quantitative CT scanner architectures with automatic exposure control. Only patients 16 years or older were included in this study. The scans were processed semi-automatically using custom algorithms written in MATLAB 2012a (The Mathworks Inc., Natick, MA).

CT Scan Measurements

The measurements consisted of bone density taken at each thoracic and lumbar mid-vertebra (T1 to L5), and fat areas taken at the inferior aspect of the vertebra (T6 to L5). The CT scan measurements are illustrated in Figure 1 and consist of:

A. Subcutaneous fat area: The cross-sectional area between skin and fascia meeting fat density thresholds of CT intensity between -205 and -51 Hounsfield Units (HU). The results are given in mm².

B. Visceral fat area: The cross-sectional area inside the fascia meeting equivalent fat density thresholds. The results are given in mm².

C. Trabecular bone density (TBD): The average pixel intensity within a circular core sampled at the mid-level of each vertebra along a resampled plane oriented to the vertebra being measured (in roll, pitch, and yaw). The circular sample is centered between the medial anterior and medial posterior aspects of the vertebral body, with a diameter equal to half that distance. Similar techniques for quantitative measurement of trabecular bone density have been presented by Bauer (2007) and Budoff et al. (2010). The results are given in Hounsfield Units (HU).

The fascial envelope separating the visceral and subcutaneous regions in any cross-sectional view of the body was defined on the superficial boundary of abdominal (rectus abdominis, transverse abdominis, external oblique) and paraspinous musculature, superficial also to the bony pelvis and chest wall.

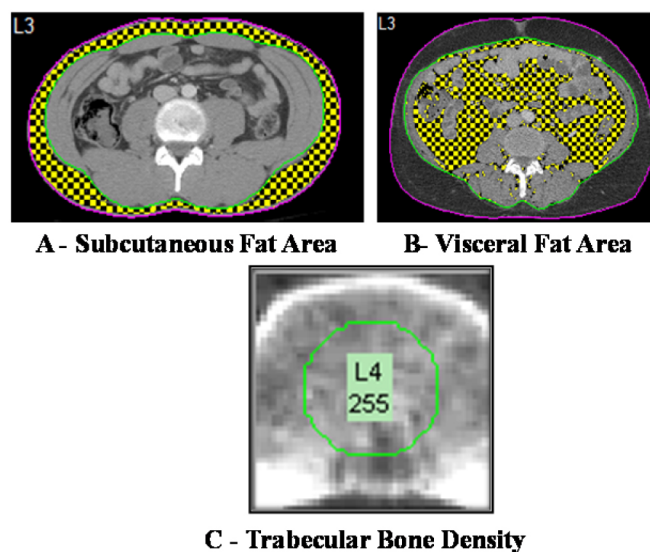


Figure 1. Study measurements: A. Subcutaneous fat, B. Visceral fat and C. Trabecular bone density.

Table 1. Height and weight distribution by age groups and gender.

Age groups	All			Males			Females		
	avg	sd	n	avg	sd	n	avg	sd	n
Height (m)									
All	1.710	0.111	10,443	1.778	0.084	5,645	1.630	0.080	4,798
16-29	1.716	0.118	1,486	1.788	0.106	765	1.640	0.075	721
30-44	1.710	0.113	1,906	1.785	0.095	913	1.640	0.079	993
45-59	1.715	0.105	3,312	1.782	0.076	1,773	1.639	0.078	1,539
60-74	1.711	0.111	2,667	1.773	0.075	1,621	1.614	0.085	1,046
75+	1.684	0.108	1,072	1.760	0.074	573	1.597	0.066	499
Weight (kg)									
All	80.50	24.68	19,230	85.38	26.09	10,451	74.69	21.50	8,779
16-29	76.64	21.84	2,561	82.18	21.64	1,308	70.86	20.53	1,253
30-44	82.37	23.78	3,474	90.26	23.84	1,660	75.14	21.30	1,814
45-59	82.73	27.47	6,114	86.38	30.01	3,238	78.62	23.64	2,876
60-74	81.60	24.14	4,878	85.55	25.89	2,979	75.40	19.57	1,899
75+	73.41	19.98	2,203	79.35	20.75	1,266	65.38	15.65	937

Age Groups

The data was divided into 5 age groups: 16 to 29, 30 to 44, 45 to 59, 60 to 74 and 75 and up year olds. Table 1 summarizes patients' height and weight data by age and gender. Height was available for 10,443 patients CT scans and weight for 19,230. Overall, the height and weight of the patients were similar within the various age groups up to 75+, irrespective of gender. The height and weight of patients in the 75+ group were smallest. The average weight in the 16-29 group was smaller than the average weight of all patients.

Data Representing a 50th Percentile Male

Using similar methods, the data was investigated for male patients with a height ranging from 1.65 to 1.85 m, and a weight from 73.2 to 83.2 kg. The height and weight ranges were based on the height and weight for a 50th percentile male Hybrid III dummy (Mertz et al. 2001).

Data Comparison

The average, standard deviation, median, and count information was tabulated by age group and gender. The data is given in the [Appendices](#). To provide an overall comparison between two groups (such as age groups, gender and vertebral level), ratios between the averages were taken. P-values were obtained from two-sample t-tests.

Notched box plots were used to graphically represent the measurements as a function of age groups. The L1 vertebral level was chosen since not all levels were visible in all scans. L1 is representative of an abdominal level and is generally present in the largest number of individual scans.

RESULTS

[Appendix 1](#) summarizes the subcutaneous fat measurements as a function of age and vertebral level from T6 to L5. The CT scans of more than 19,000 patients were analyzed. Fat area measurements were not always available for each vertebra. Accordingly, the number of observations at each individual vertebral level is shown as (n). Similarly,

[Appendix 2](#) summarizes the visceral fat measurements from T6 to L5, and [Appendix 3](#) shows the trabecular bone density recorded at each vertebral level from T1 to L5 if visible within the scan window.

Age Comparison

The results in [Appendix 1](#) show that the subcutaneous fat area was 1.20 to 1.62 times greater in the 45-59 group than in the 16-29 group, and 1.16 to 1.74 greater in the 75+ group ($p < 0.01$). The visceral fat area, shown in [Appendix 2](#), was 1.43 to 2.69 greater in the 45-59 group ($p < 0.01$) and 1.92 to 3.37 greater (with $p < 0.01$) than the 75+ group. Bone density, shown in [Appendix 3](#), decreased with age and varied depending on the vertebral level. Compared to the 16-29 group, the bone density was 13% to 27% less in the 45-59 group, and 35% to 49% in the 75+ group. The decrease in bone density was higher in the lumbar spine than in the thoracic spine.

To illustrate the trends in fat and bone density changes across all age groups, a single vertebral level (L1) was chosen as representative of each individual. The average subcutaneous fat at L1 increased with age for patients in the 16-29 group to the 45-59 group and then decreased in the 75+ group. The average visceral fat also increased with age for patients less than 75 years. Bone density progressively decreased with age for all age groups. The average bone density at L1 was 23% lower in the 30-44 group and 41% lower in the 75+ group than in the 16-29 group.

[Figure 2](#) shows the box plots for the subcutaneous fat area, visceral fat area, and bone density at L1 as a function of age. The band in the middle of the box represents the median (50th percentile). The edges of the box are the 25th and 75th percentiles. The whiskers extend to the most extreme data points not considered outliers, and outliers are plotted individually. There was a steady increase in the subcutaneous fat median from age groups 16-29 to 45-59. The median decreased in the 75+ group. Similar findings were observed for visceral fat; visceral fat area increased with age except for the 75+ group.

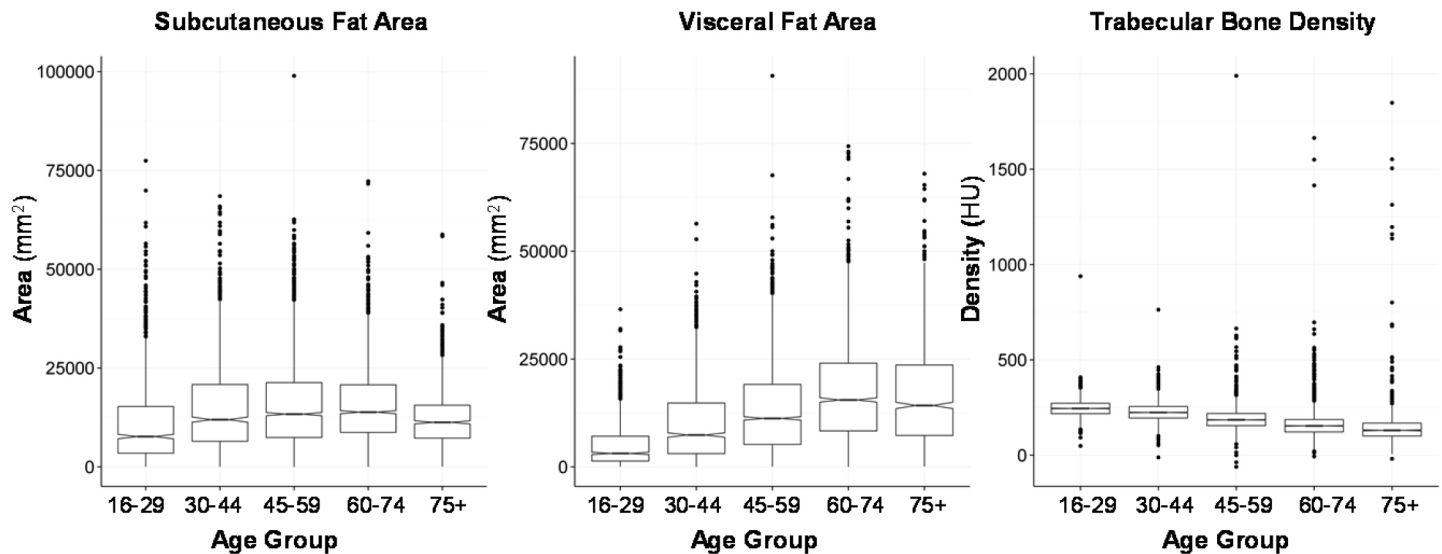


Figure 2. Boxplots of subcutaneous fat, visceral fat and trabecular bone density at L1 as a function of age groups.

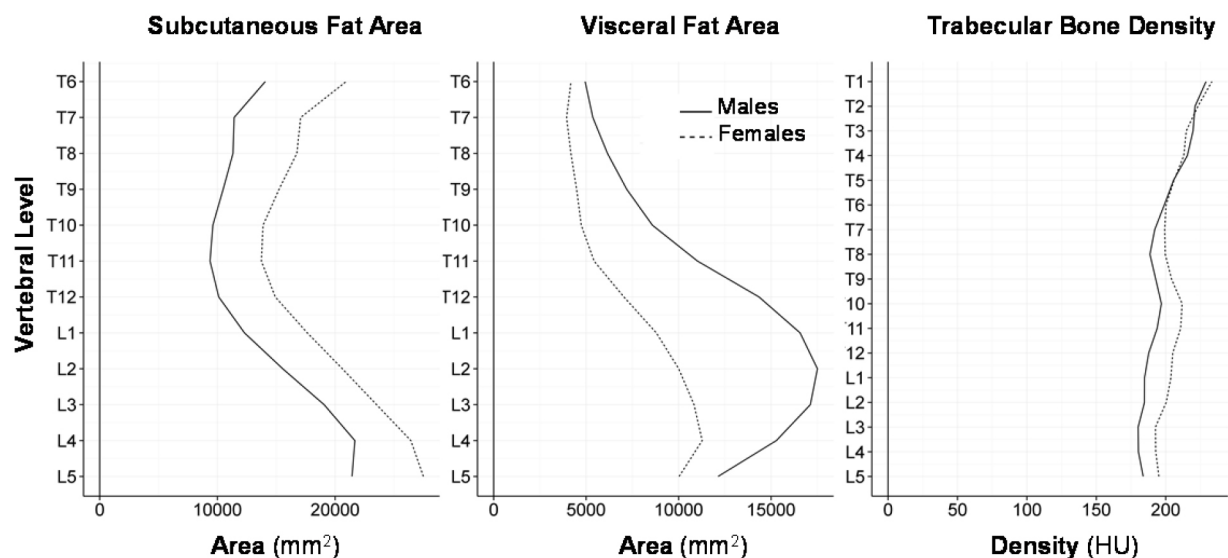


Figure 3. Subcutaneous fat area, visceral fat area and trabecular bone density by gender as a distribution over vertebral levels.

Age and Gender Comparison

Though the objective of this study was to assess the effect of age on fat and bone measurements, an additional analysis stratified on gender was performed. Subcutaneous fat area, visceral fat area and trabecular bone density were assessed by gender and age. [Appendix 1](#) tabulates the data for subcutaneous fat, [Appendix 2](#) for visceral fat, and [Appendix 3](#) for trabecular bone density. [Figure 3](#) compares the average for the three measurements by gender and vertebral level. The subcutaneous and visceral were significantly different in males than in females; males had less subcutaneous fat and more visceral fat than females, irrespective of vertebral level. Females had 1.22 to 1.49-times more subcutaneous fat than

males ($p < 0.01$), while males had 1.18 to 2.04-times more visceral fat than females.

The trabecular bone density was similar in both genders in the upper thoracic spine. Females had however higher bone density in the lower thoracic spine and lumbar spine. The average trabecular bone density varied between males and females depending on vertebral level. The ratio of female and male results was 0.98 at T3 and 1.10 at L1.

For males, the subcutaneous fat area at L1 was about 1.4 times greater in the 30-44 and 60-74 groups and 1.2 times greater in the 75+ group compared to the 16-29-year-old group. Females gained more subcutaneous fat at L1 as they increased in age up to the 45-59 group and then progressively lost subcutaneous fat. Males and females gained more

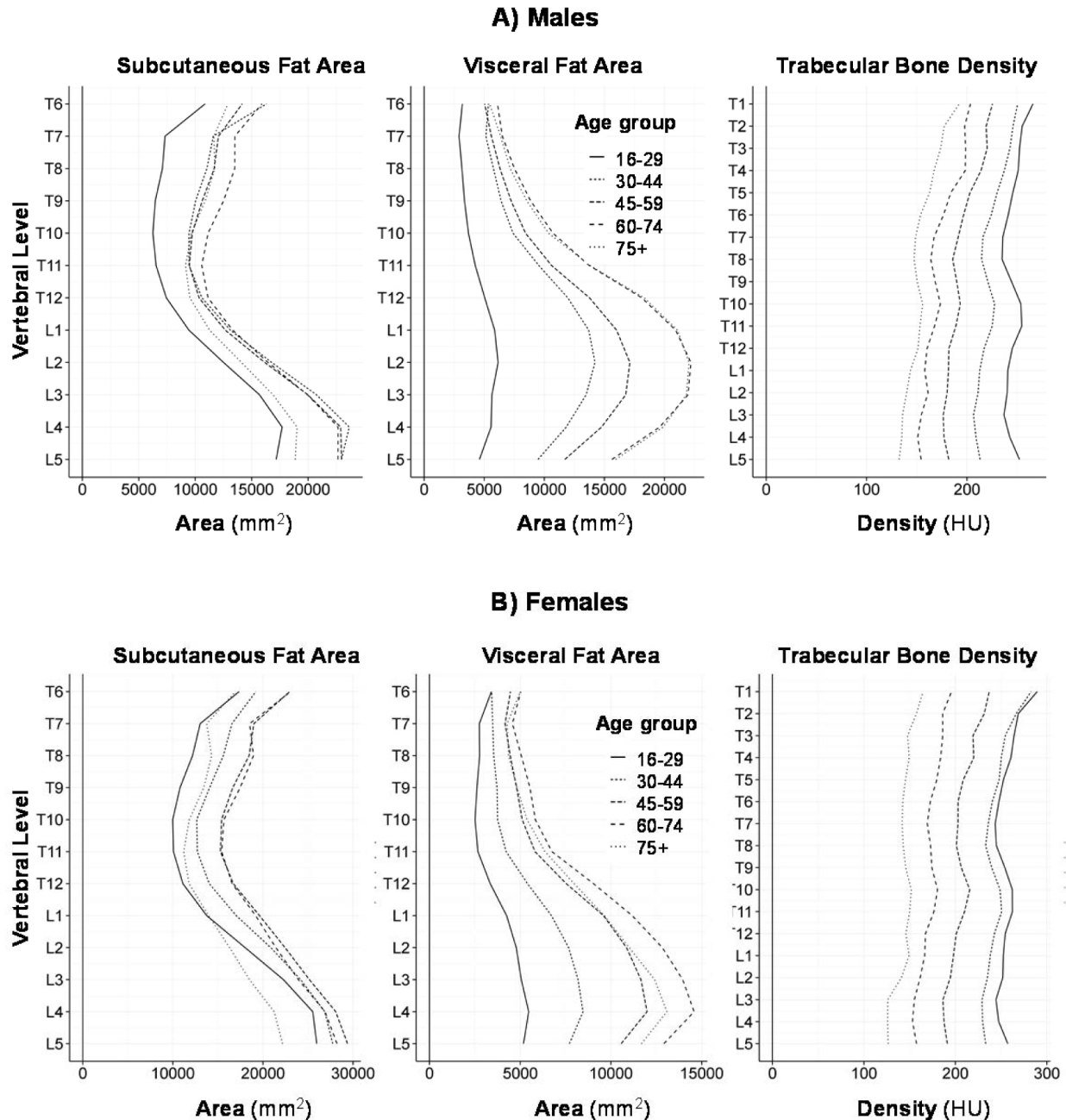


Figure 4. Average subcutaneous fat area, visceral fat area, and trabecular bone density by age groups in A) males and B) females as a distribution over vertebral levels.

visceral fat at L1 as they aged up to the 75+ group. The visceral fat gain was greater in males than in females in the 75+ group compared to the 16-29 group (3.59 v. 2.27). Both consistently lost bone density at L1 with age.

Figure 4 shows a breakdown for visceral and subcutaneous cross-sectional fat areas and trabecular bone density at each vertebral level for males (A) and females (B) by age groups. The figure shows an increase in both visceral and subcutaneous fat areas at all vertebral levels (T6 to L5) for both males and females in the 45-59 group compared to the 16-29 group. Differences were observed between visceral

fat and subcutaneous fat accumulation patterns. Males show the greatest increase with age (relative to the 16-29 group) in visceral fat area at the L2 vertebral level. In females, the greatest increase is shown at the L4 level. For subcutaneous fat accumulation, females show greatest accumulation of subcutaneous fat with age in the lower thoracic region (T7-L1), with relatively less accumulation at lumbar regions. Relative to the female group, males show greater accumulation of subcutaneous fat with age, particularly at the L4-L5 level.