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Age-related changes in femoral trabecular bone in arthrosis

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Age-related changes in the cancellous bone in selected regions of the proximal femur and iliac crest were assessed. An arthrosis group and a control cadaver group, partitioned into subjects younger and older than aged 50 years, were compared. The control group comprised 69 heads of femur and iliac crest samples. The arthrosis group comprised 28 consecutive heads of femur affected by primary arthrosis and an iliac crest biopsy taken during hip arthroplasty.

Cancellous bone was sampled from four selected regions in the proximal femur. Histomorphometric estimates of percentage bone volume were determined using image analysis. In the young controls the bone volume was higher than that in the old controls for all the regions. In the arthrosis group the bone volume was higher than that of the old controls except for the subchondral principal tensile and medial to the greater trochanter regions.

The old controls had regression of bone volume on age for the subchondral and medial principal compressive regions and the iliac crest. The arthrosis group had a minimal dependence of bone volume on age.

Our study showed that primary arthrosis modulates the age dependence of bone volume in the proximal femur.

Although only 20 percent of the total bone present at maturity is trabecular, its lattice-type structure occupies a much larger area than the surrounding cortical bone (Hofeldt 1987). Whitehouse and Dyson (1974) showed that as the density of the trabeculae in the femur varies so does the microstructure. Fazzalari et al. (1983) found that histomorphometric estimates of percentage bone volume (BV/TV; Parfitt et al. 1987) in the proximal femur varied according to age and the region sampled. In the medial principal compressive region, BV/TV was greater than in the subchondral principal tensile region.

Radin et al. (1984) proposed that geometric and mechanical changes in the subchondral bone may lead to increased stress and, ultimately, damage to the overlying cartilage; they felt that this may be the process by which arthrosis is initiated.

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We have examined age-related changes in the BV/TV of selected regions of the proximal femur in normal and arthrotic subjects.

Materials and methods

The control group comprised normal proximal femora and a sample of iliac crest taken at autopsy and immediately placed in 10 percent buffered formalin. The iliac crest wedge was obtained from a point 3 cm posterior to the anterior superior iliac spine. Subjects with evidence of any chronic debilitating disease affecting bone status were excluded from the normal group.

The study group comprised 28 consecutive patients operated on for severe primary arthrosis. Half of the patients had vertical iliac crest biopsies taken during surgery. Patients suspected of having secondary arthrosis, inflammatory joint disease, Paget's disease, or other conditions that may have affected the trabecular bone architecture and quality were excluded.

Table 1. Test for normality of the pooled male and female age distribution of the regions studied. Shapiro-Wilk statistic (W) greater than the critical value (Wc) identifies a normal distribution. Mean *SD*

Region	Group	n	Age	W > Wc[a] *P*-value
SC	L	35	28 *12*	0.001
	G	32	73 *10*	0.323
	A	27	72 *6*	0.507
MC	L	35	27 *11*	0.001
	G	29	74 *10*	0.237
	A	25	72 *6*	0.564
ST	L	37	28 *12*	0.001
	G	32	73 *10*	0.323
	A	26	72 *5*	0.608
MG	L	36	28 *12*	0.002
	G	31	74 *10*	0.338
	A	21	72 *5*	0.834
IC	L	27	27 *12*	0.005
	G	12	71 *9*	0.502
	A	13	72 *4*	0.125

[a] Normal if $P > 0.05$.
SC Subchondral principal compressive region
MC Medial principal compressive region
ST Subchondral principal tensile region
MG Region medial to the greater trochanter
IC Iliac crest
L Controls under 50 years of age
G Controls more than 50 years of age
A Arthrosis group

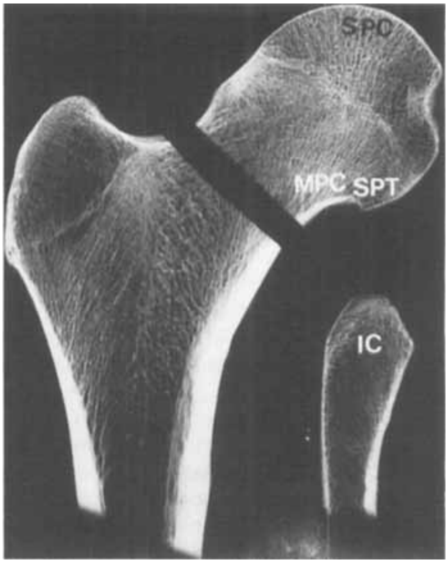

Figure 1. Blocks taken from the proximal femur and iliac crest wedge for measurement of percentage mineral bone volume. SPC—subchondral bone in the principal compressive region; MPC—bone in the principal compressive region near the medial cortex; SPT—subchondral bone in the principal tensile region; IC—iliac crest.

The mean age of the 9 male and 19 female arthrosis patients was 72 (60–83) years. The 69 controls were divided into two groups: one with 32 subjects (9 males and 23 females) older than aged 50 years (73 [57–95] years), and another group with 37 subjects (20 males and 17 females) younger than aged 50 years (27 [10–49] years; Table 1).

A 5-cm coronal slice was cut through the center of each femoral head. From this slice, three blocks of cancellous bone (approximately 1 cm^2) were obtained from the subchondral principal compressive, medial principal compressive and subchondral principal tensile stress regions (Figure 1). Using preoperative radiographs, the femoral anatomy, and the axial geometry of the resected femoral neck, we determined the coronal plane of the surgical specimens. A contact radiograph of the 5-mm coronal slice was made using a faxitron radiographic system (Hewlett-Packard Co., McMinville, OR, USA). Thus, from the detailed coronal radiograph, we obtained autopsy and surgical femoral blocks from reproducible locations.

In addition, in the autopsy specimens a block in the upper shaft taken medial to the greater trochanter was taken from a 5-mm coronal slice. For the surgical cases, a 1-cm diameter tube saw sample was obtained. Detailed instructions were provided to the surgeon on the procedure to be used following femoral head resection and cutting of the greater trochanter notch, to ensure biopsies were always taken from the same location.

From each of 69 control cadavers and 28 arthrosis patients, blocks were processed for undecalcified tissue sectioning and embedded in Araldite epoxy resin. Each block was then sectioned on a Jüng K microtome (Reichert, Heidelberg, West Germany). Three sections of 8-μm thickness, cut at approximately 200-μm intervals, were stained with silver by the von Kossa/van Gieson technique to distinguish the mineralized bone, the osteoid and cellular components of the marrow.

Histoquantitation was performed on each section using a Quantimet 720 image analyzing computer (Cambridge Instruments Ltd., UK; Fisher 1971, Fazzalari et al. 1983). Each section was scanned in the principal direction of trabecular orientation avoiding any osteophytic bone overlying the original articular contour. The estimate of BV/TV for each block is presented as a mean of the three sections per block.

Table 2. Percentage bone volume (BV/TV) in four selected stress regions of the proximal femur and the iliac crest. Mean *SD*

Region	Group	n	BV/TV–Male		n	BV/TV–Female[a]		n	BV/TV[b]	
SC	L	18	28	*5.9*	17	27	*4.5*	35	27	*5.2* *
	G	23	24	*6.6*	9	24	*4.8*	32	24	*6.0*
	A	9	36	*11*	18	32	*9.8*	28	33	*10* *
MC	L	18	31	*7.5*	17	33	*6.1*	35	32	*6.8* *
	G	22	25	*8.8*	8	28	*7.2*	29	27	*7.5*
	A	8	38	*12*	17	24	*8.8**	26	29	*12*
ST	L	20	20	*6.0*	17	21	*4.1*	37	27	*5.1**
	G	23	15	*6.8*	9	13	*4.7*	32	15	*6.3*
	A	9	12	*3.6*	17	13	*6.2*	27	13	*5.3*
MG	L	19	15	*8.3*	17	15	*5.0*	35	14	*5.4* *
	G	23	9.1	*5.6*	8	10	*6.5*	31	9.4	*5.8*
	A	7	14	*2.8*	14	9.2	*2.6**	22	12	*3.5* *
IC	L	15	20	*4.8*	12	18	*2.8*	27	19	*4.0* *
	G	8	12	*7.9*	5	12	*2.2*	12	11	*3.5*
	A	4	9.7	*3.8*	9	17	*3.8**	13	15	*5.0* *

[a] *Significant difference between males and females ($P < 0.05$).
[b] Pooled male and female samples. *Significant difference from the controls more than 50 years of age in each region. Symbols as in Table 1.

Where the sample numbers differ from the number of collected specimens, this occurs because of technical failures in tissue processing and/or specimen cutting.

For the assessment of the reproducibility of the histoquantitation, a sample of 16 (10 control and six arthrosis) blocks was resubmitted for quantitation without the operator's knowledge. The sections from each block were quantified and compared with the original estimate of the block BV/TV. The mean difference and standard deviation of the mean difference were calculated. These represent the bias and random error, respectively, between the two group estimates (Grubbs 1948).

Statistics. To test whether the data groups had a normal distribution, the Shapiro-Wilk statistic was calculated and tested for significance using PC-SAS software. Analysis of the data was performed using parametric statistical models. The Student's t-test was used to compare means, taking the pooled sample variance as the estimate of the t-distribution variance. The signficance of a regression relationship was determined using a one-tailed F-test. Analysis of covariance was used to test for differences between regression curves (Kleinbaum and Kupper 1978). The critical value for significance was set at $P < 0.05$.

Results

The mean (SD) of the difference between repeated estimates of BV/TV was –3.2 (7.4) percent; the mean difference was not a significant bias.

The control groups had considerable variation without difference between males and females for BV/TV in each region (Table 2; Figures 2–6; Table 3).

The arthrosis patients had more BV/TV than the old controls in the subchondral principal compressive, medial greater trochanter, and iliac crest regions (Table 2). The BV/TV of the young controls was greater than that of the old controls in all regions. The greatest difference in BV/TV detected by the Student's t-test was that for the iliac crest region.

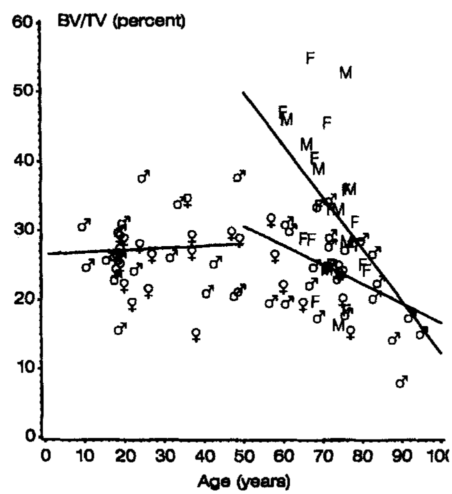

Figure 2. Regression of BV/TV on age for the subchondral principal compressive region. ♀ and ♂—male and female controls. M and F—male and female arthrosis.

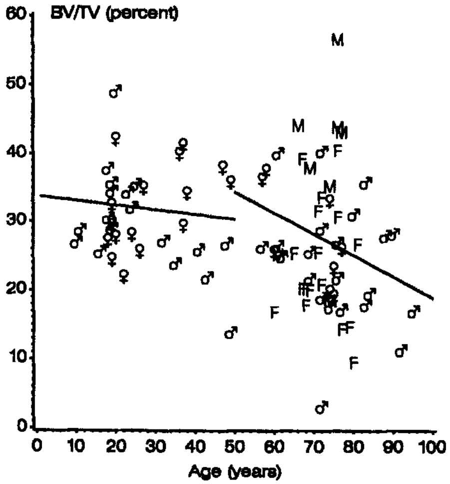

Figure 3. Regression of BV/TV on age for the medial principal compressive region. Symbols as in Figure 2.

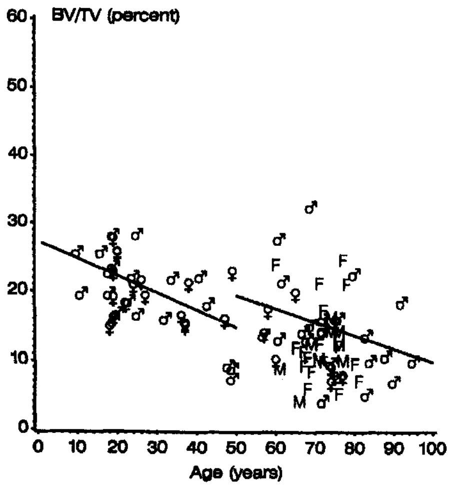

Figure 4. Regression of BV/TV on age for the subchondral principal tensile region. Symbols as in Figure 2.

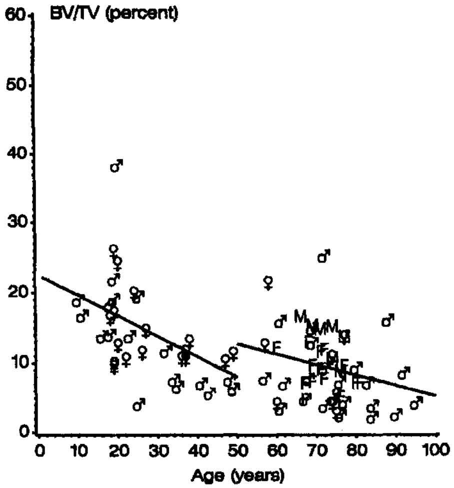

Figure 5. Regression of BV/TV on age for the region medial to the greater trochanter. Symbols as in Figure 2.

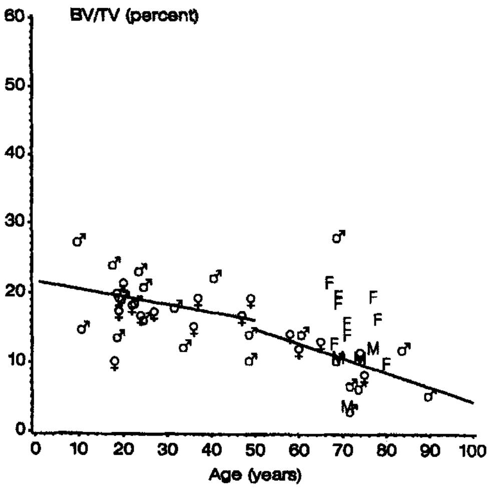

Figure 6. Regression of BV/TV on age for the iliac crest. Symbols as in Figure 2.

Although regression of BV/TV on age in the subchondral principal compressive region for both old controls and the arthrosis group reached significance, the arthrosis data was more widely dispersed than that of the controls (Figure 2).

Regressions of BV/TV on age for the young controls showed a decrease in the amount of bone with age in the subchondral principal tensile region and medial to the greater trochanter (Figures 4 and 5), whereas the amount of bone in the subchondral prin-

Table 3. Regression of BV/TV on age in four selected stress regions, individual data in Figures 2–6

		Regression	n	*r*	*P*
SC	L	26.6 + 0.028 Age	35	0.064	NS
	G	44.7 – 0.279 Age	32	–0.473	< 0.01
	A	87.6 – 0.754 Age	28	–0.437	< 0.025
MC	L	33.8 – 0.073 Age	35	–0.121	NS
	G	49.8 – 0.313 Age	29	–0.443	< 0.04
	A	11.7 + 0.241 Age	26	0.123	NS
ST	L	27.2 – 0.246 Age	37	–0.554	< 0.001
	G	28.8 – 0.194 Age	32	–0.315	NS
	A	8.3 + 0.063 Age	27	0.069	NS
MG	L	24.3 – 0.338 Age	36	–0.576	< 0.001
	G	20.3 – 0.148 Age	31	–0.266	NS
	A	24.3 – 0.189 Age	22	–0.300	NS
IC	L	21.7 – 0.106 Age	27	0.303	NS
	G	25.4 – 0.206 Age	12	–0.557	0.05
	A	32.1 – 0.241 Age	13	–0.210	NS

Symbols as in Table 1.

Table 4. Intercepts and slopes for BV/TV regression on age. Male and female data pooled. Mean *SD*

		Intercept		*P*	Slope		*P*
SC	L	27	*2.3*	< 0.001	0.028	*0.076*	NS
	G	45	*7.0*	< 0.001	–0.279	*0.095*	< 0.005
	A	88	*22*	< 0.005	–0.754	*0.304*	< 0.01
MC	L	34	*3.1*	< 0.001	–0.073	*0.104*	NS
	G	50	*9.1*	< 0.001	–0.313	*0.122*	< 0.025
	A	12	*29*	NS	0.241	*0.395*	NS
ST	L	27	*1.9*	< 0.001	–0.246	*0.063*	< 0.001
	G	29	*7.9*	< 0.005	–0.194	*0.106*	NS
	A	8.3	*13*	NS	0.063	*0.182*	NS
MG	L	24	*2.5*	< 0.001	–0.338	*0.082*	< 0.005
	G	20	*7.4*	< 0.01	–0.148	*0.100*	NS
	A	24	*9.7*	< 0.02	–0.189	*0.135*	NS
IC	L	22	*2.0*	< 0.001	–0.106	*0.067*	NS
	G	25	*7.0*	< 0.005	–0.206	*0.097*	< 0.05
	A	32	*24*	NS	–0.241	*0.339*	NS

Symbols as in Table 1.

cipal compressive and medial principal compressive regions remained constant up to the age of 50 years (Figures 2 and 3; Table 4).

For the old controls, regressions of BV/TV on age were significant in the subchondral principal compressive, medial principal compressive, and iliac crest regions (Figures 2, 3, and 6). The analysis of covariance showed that the intercepts and slopes of the regressions for the subchondral and medial principal compressive regions were not different (Table 4). Regressions of BV/TV on age for the arthrosis group were not significant for any region other than that of the subchondral principal compressive region.

Discussion

This study has shown that there is a nonuniform loss of bone with age throughout various stress regions of the proximal femur and iliac crest. This is contrary to the observation of Roh et al. (1974), who reported similar trends for the bone mineral content in the second metacarpal and radius of both males and females. Bone loss from the subchondral principal tensile region and medial to the greater trochanter starts at an early age, as indicated by the regression curves for the young controls under aged 50 years. The amount of bone in the subchondral and medial principal compressive regions is relatively constant until approximately 50 years of age, similar to the trends reported for bone mineral content in the radius by Roh et al. (1974).

In the proximal femur the magnitude of the difference in BV/TV between the young and old controls was less than that of the iliac crest region, presumably because of mechanical factors, since the femoral head is exposed to larger strains than the iliac crest (Nordin and Frankel 1980). The resultant bone remodeling that occurs may be influenced by local paracrine and autocrine mechanisms dependent on the bone strain (Huffer 1988). The increase in the iliac crest BV/TV for the arthrosis group over the old controls supports the findings of Gevers et al. (1989) of increased BV/TV with increased arthrotic grade. This increased BV/TV, in their view, indicates that a generalized bone alteration could be of importance in the pathogenesis of arthrosis.

Previous studies have found a decrease in BV/TV with age for the iliac crest and spine (Parfitt et al. 1983, Mosekilde 1988). However, few investigators have sought to make a distinction between the amount of bone in more than one region of a single joint. That is, trabecular bone is usually sampled from a single region and generalizations are made regarding the quality of bone within the whole joint.

Variations in the BV/TV for the five regions studied suggest that large fluctuations in local remodeling may occur according to the mechanical and physiologic function of the region (Huffer 1988). These findings are supported by those of Fazzalari et al. (1989), who showed that the bone of the iliac crest is not representative of that in the proximal femur. Consequently, predicting the amount of cancellous bone present in another joint of the same individual, given BV/TV measurements from the hip, would not be feasible.

In regions where the trabecular network is subject to high compressive stress, values of BV/TV will tend to be elevated (Carter et al. 1989). Our findings indicate that the remodeling process can occur in such regions without any net loss of bone volume until beyond 50 years of age, whereas in regions of low and tensile stress, BV/TV may decrease even earlier.

Our study has demonstrated that in arthrosis the cancellous bone of the proximal femur is not dependent on age as was the case in controls. Although in arthrosis BV/TV is increased in the region medial to the greater trochanter—the implant bed of a femoral stem prosthesis—the question of mechanical competence (Martens et al. 1983) and the remodeling potential of bone in this region remains unresolved.

Acknowledgements

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