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27. **Collagen Fiber Orientation in the Turkey Ulna Supports a Role for Variant Strain Stimuli in Cortical Bone Construction.** J. G. Skedros, P. E. Hughes, M. D. Zirovich. Orthepaedic Hospital, Los Angeles, CA.

There is evidence that bone tissue can differentiate between specific mechanical strain features. This study examines the idea that variant mechanical factors (i.e., those that are vectorial), if recognized as being important in cortical bone construction, would be seen as differences in collagen fiber orientation (CFO) between regions that are habitually loaded in compression, tension, and shear. Transverse segments from midshafts of 12 skeletally mature domestic turkey ulnas were embedded in polymethyl methacrylate. Transverse sections from the shafts of calcanei from skeletally mature sheep (n=8) and mule deer (n=8), and one mature horse radius, were used as "control" bones since strain gauge analyses have show that they have a customary tension, compression, and shear (neutral axis, NA) distribution. Undecalcified sections were milled to 100+/-5 microns and viewed under circularly polarized light. CFO is expressed as the mean graylevel in each microscopic field (approx. 2.3mm2) at each location. Cortical locations in the turkey bones included: dorsal (D), dorsal-cranial (DCr), cranial (Cr), cranial-volar (CrV), volar (V), medial-volar (MV), medial (M), and dorsal-medial (DM) cortices. Locations in the control bones included: Cr, Cd, M, and L cortices. Graylevels were quantified from pixel histograms obtained from digitized images. Data from turkey ulnas were analyzed in accordance with in vivo strains during wing flapping ("compression" region of group 1 = DM, D, DCr; group 2 = Cd, DM, D; group 3 = D, DCr, Cr). Results showed that in all bones the customary "compression" cortex exhibited relatively more oblique-to-transverse CFO (greater mean graylevel) and the "tension cortex" had more longitudinal CFO; immature and mature turkey ulnas showed similar variations (One-way ANOVA, Fisher's LSD post-hoc testing: deer calcanei 113.8+/-8.6 vs. 97.2+/-13.6 (p<0.05); sheep calcanei 155.7+/-10.4 vs. 108.6+/-5.2 (p<0.001); turkey ulna 185.7+/-16.4 vs.114.2+/-16.6 (p<0.001); horse radius 110.1 vs. 70.5). Turkey ulnas (group 1) and all control bones showed that CFO of the NA distinctly differed from corresponding "compression" and "tension" cortices. Differences along the NA were minor in each bone (<10%, p>0.05). Data showing consistent CFO differences between compression and tension cortices of these avian and mammalian bones, and absence of important differences along each NA (shear), supports the hypothesis that specific forms of variant mechanical stimuli are important in their tissue construction. Such stimuli are not considered important in most modern algorithms of bone adaptation and development.

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Age Changes in Mechanical Strength and Distribution of Bone in the Human Mid-shaft Femur. R. Bruns,*[1] J. G. Clement,*[1] C. D. Thomas,*[1] S. Feik,*[1] H. M. Goldman.[2] [1]School of Dental Science, University of Melbourne, Victoria, Australia, [2]Hunter College, CUNY, New York, NY.

In a study of aging trends in bone quality and quantity, beams of bone were mechanically tested. Results from these tests were examined relative to variability in the distribution of bone tissue and voids.

In this study, the proximal 2/3rds of 28 right femora were collected at autopsy. These were derived from two groups: age 20-40 and over 65. Height, weight, sex, age and cause of death were known for each individual. The femora were radiographed *in situ* to ascertain any femoral neck fractures or underlying bone diseases. After excision, femora were stored in 70% ethanol.

Bone blocks, each 2cm long, were taken from the mid-shaft. Beams measuring 2mm in width and depth were then taken from different aspects of the block, and weighed. The density was determined for each beam (kg/m^3), and the beams were tested to mechanical failure by three-point bending. All beams were labeled so that their position and orientation within the femoral cortex could be identified.

Thick sections, each 300μm, were taken 1cm either side of the mid-shaft, and manually ground to 100μm with 1200 grade carborundum paper. These sections were microradiographed and analysed using automated imaging techniques.

It was found that breaking stress (Pa) was positively correlated with bone density (r^2=0.41) and negatively correlated with age (r^2=0.52). No relationship was found between the breaking stresses of bone between the two sexes (r^2=0.01). The posterior region was significantly more variable in breaking stress compared with the other regions ($p < 0.001$). Lateral and medial regions were least variable, with no significant difference between them. We (Feik *et al.*, 1997, J. Anat. 191:407-416) have previously reported increased pore size variability posteriorly and anteriorly in the mid-shaft femur. Age trends in porosity distribution may explain some trends in the mechanical testing data. Preliminary results from porosity data from this sample will be discussed relative to mechanical testing data.

The regional variability identified thus far in bone quantity and quality indicates the need to examine multiple aspects of bone's structural and material properties to enhance our understanding of the bone aging process.

F108

BMD Predicts the Maximum Compressive Load-Bearing Properties of Vertebrae, but Not the Maximum Torque-Bearing Properties of Long-Bones. D. Pienkowski, T. Doers,* R. Maitra,* M. C. Faugere, H. H. Malluche. Divisions of Orthopaedic Surgery and Nephrology, Bone and Mineral Metabolism, University of Kentucky, Lexington, KY.

The relationship between bone mineral density (BMD) and the load-bearing properties of bone was studied in 1,981 tibiae, femora, whole vertebrae, and cancellous vertebral specimens from 248 dogs. BMD was measured by using dual energy X-ray absorptiometry. A materials testing system was used to quantify the torsional biomechanics of the long bones, and the compressive biomechanics of the vertebral specimens (whole and cancellous cores).

BMD could not explain the maximum torque withstood by the tibiae (Fig. 1) or the femora. BMD could explain half of the maximum compressive load-bearing properties of the whole vertebrae (linear relationship, $r^2 = 0.54$, $p < 0.01$), and almost two-thirds of the maximum compressive load-bearing capabilities of the cancellous cores (second-order relationship, Fig. 2).

Fig. 1

BMD vs. Maximum Torque of Tibiae

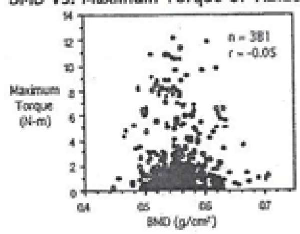
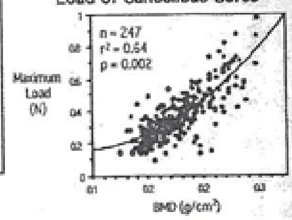


Fig. 2

BMD vs. Maximum Compressive Load of Cancellous Cores



These data are consistent with previous studies showing that mid-shaft long bone and femoral neck fractures do not correlate well with BMD. Long bone and femoral neck fractures commonly result from torsion, bending, or combined loading modes in which the BMD-independent geometry and shear properties of bone have important roles in determining bone strength. The results of the present study are in excellent agreement with the known correlation between BMD and spinal fracture incidence. Because vertebrae typically fail in compression, BMD is a useful partial predictor of vertebral mechanical competence.

F109

Alterations in pQCT-derived bone geometry and volumetric density and in structural properties of femoral neck in senescent rats. Susan A. Bloomfield, Harry A. Hogan, Elizabeth T. Dresser,* Jennifer A. Groves.* Texas A&M University, College Station, TX.

Few data are available on the relationship of bone morphometry and bone mineral density (BMD) to mechanical properties of the femoral neck in senescent rats. Therefore, we studied femoral necks excised from 6-mo-old (n=8) and 24-mo-old (n=8) male Fischer rats using peripheral quantitative computed tomography (pQCT; Stratec XCT-Research SA, Norland Corp.) A single slice at the center of the femoral neck was assessed for volumetric BMD and area of the entire bone as well as of cortical (CRT) and trabecular (TRB) components. Polar strength-strain index (SSI_p ; estimates torsional bone strength), section modulus, and polar cross-sectional moment of inertia ($CSMI_p$) for total bone were calculated from area and density values. Bones were then subjected to mechanical testingwith an Instron 1125 device. With the femoral shaft fixed vertiaclly, quasi-static loading was applied to the femoral head parallel to the femur's long axis at 2.54 mm/min. Maximal (MAX) load at fracture and stiffness were calculated from the load-displacement curve. Means (± S.E.) for the two groups were compared by unpaired t-tests.

Variable	6-mo-old	24-mo-old	p value
CRT BMD (mg/cm^3)	1209 ± 22	1220 ± 32	0.79
CRT area (mm^2)	2.99 ± 0.12	3.35 ± 0.17	0.11
TRB BMD (mg/cm^3)	822 ± 17	650 ± 43	0.002
TRB area (mm^2)	1.26 ± 0.05	1.35 ± 0.10	0.42
Total BMD (mg/cm^3)	1098 ± 16	1048 ± 29	0.16
Total bone area (mm^2)	4.62 ± 0.13	5.12 ± 0.18	0.04
SSI_p (mg/cm^3)	1.98 ± 0.06	2.20 ± 0.14	0.16
Section modulus (mm^3)	2.38 ± 0.10	2.67 ± 0.12	0.09
$CSMI_p$ (mm^4)	3.36 ± 0.16	4.12 ± 0.19	0.009
MAX load (N)	105.8 ± 3.5	130.3 ± 4.8	0.002
Stiffness (N/mm)	102.7 ± 10.3	155.8 ± 7.9	0.004

Direct measurement of structural properties shows that MAX load is higher by 23% and stiffness by 52% in older rats, even as TRB BMD declines by 21%. Multiple linear regression analyses of pooled data suggest that variations in femoral neck morphometry (i.e., $CSMI_p$) are largely responsible for the higher MAX load and stiffness of femoral necks in aged male rats, and that alterations in TRB and CRT bone mineral density of the femoral neck minimally affect its strength.