Mechanical behaviour of trabecular bone of the human femoral head in females

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The ultimate stress, Young's modulus, energy absorbed to ultimate stress, actual and apparent densities were determined for specimens of human trabecular bone taken perpendicular to the subchondral plate from female patients undergoing hip replacement for osteoarthrosis or fracture of the neck of femur and from age matched female cadavers. Higher mechanical properties were found in the major than in either the partial minor weight bearing areas of the femoral head in the cadaveric and the fractured neck of femur groups as well as in the eburnated when compared to the non-eburnated areas of the osteoarthrotic groups. For all areas, the mechanical properties were higher in the osteoarthrotic than the cadaveric femoral heads which were again higher than those in the osteoporotic group. It is concluded that the major weight bearing areas are most affected by the pathological processes which are responsible for either fracture of the neck of femur or osteoarthrotic degradation. Regression analysis was used to relate the mechanical properties with the bone density providing evidence that cadaveric and fractured neck of femur bone can be regarded as mechanically uniform.

1. Introduction

Most of the studies of mechanical properties of trabecular bone have attempted to understand the behaviour of normal bone [1–14]. There has been little consideration of the changes in the mechanical properties with the consequences of degenerative joint and metabolic disease. Lereim *et al.* [15], Schoenfeld *et al.* [4] and Reimann *et al.* [16] studied the behaviour of trabecular bone in response to osteoarthrosis but the effect of loading on the bone was not considered. Previous work of this group, Tanner *et al.* [17], has shown that the mechanical properties and density of male trabecular osteoarthrotic bone are increased in the weight bearing areas of the femoral head, but not in the non-weight bearing areas when compared with the equivalent areas of cadaveric bone.

The high incidence of fracture in cancellous bone tissue in older people, and especially in postmenopausal women, has been well documented. Clinical and radiographic studies have disclosed that in cases of fracture of the neck of the femur the bone density is reduced compared to normal [18].

The mechanical properties of female bones and especially of female trabecular bone has not been studied extensively and in most of the studies on trabecular bone there is no distinction between male and female bone. Sonoda [19] determined the tensile, compressive and torsional properties of fresh vertebral bodies from 26 subjects varying from 22 to 76 years of age. No significant differences between male and female bone were found in the tensile, compressive and torsional strengths, however the torsional moment at failure in females was only 80% of that in males. According to the data of Chalmers and Weaver [20] the mean compressive strength of fresh vertebral and calcaneal cancellous bone in females is approximately 82% of that in males. Evans and King [1] found that specimens of trabecular femoral bone from two females had a lower modulus of elasticity than all but one of the males, absorbed less energy to yield than most of the males and were less dense than any of the male specimens.

The correlation of the mechanical properties of trabecular bone with density has been shown to be important. The idea of correlating the mechanical properties of cellular materials, such as trabecular bone, with density is not new. The classical equation that has been widely used to relate the properties of cellular materials to the density is

$$E = K\rho^n \qquad (1)$$

where K and n are empirically determined constants, n lies in the range $1.0 < n < 3.0$ and Equation 1 has been shown to be valid for both elastic and strength properties [21, 22]. In particular, for trabecular bone, Carter and Hayes [7, 8] concluded that the Young's modulus, E, depends upon the apparent density, ρ, to the third power and the strain rate, $\dot{\varepsilon}$, to the 0.06

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power

$$E = 3790\dot{\varepsilon}^{0.06}\rho^3$$

$$(E \text{ in MPa, } \rho \text{ in g cm}^{-3} \text{ and } \dot{\varepsilon} \text{ in s}^{-1}) \quad (2)$$

and the axial compressive strength, S, depends upon the square of apparent density and the strain rate to the 0.06 power

$$S = 68\dot{\varepsilon}^{0.06}\rho^2$$

$$(S \text{ in MPa}) \quad (3)$$

More recently further attempts have been made to verify these relationships theoretically. Gibson [23] presented a theoretical and experimental study of closed cell and open celled porous materials and argued that the prevailing mode of failure at low apparent densities (open cell structures) is elastic buckling, while at high densities (closed cell structures) the trabeculae fail by plastic yielding, but that the Young's modulus in all cases is controlled by bending of the cell walls. These models show that the Young's modulus is proportional to the square of apparent density for open cell materials and to the cube of apparent density for closed cell materials and that the strength is proportional to the square of apparent density for both open and closed cell models when modelled as an isotropic material with cells of geometrical similarity. Rice *et al.* [24] using data from the same sources as Gibson [23] concluded, without making any distinction between open and closed cell material, that both the Young's modulus and the strength are proportional to the square of the apparent density and thus that the Young's modulus and strength are linearly related. From this analysis, they conclude that the variations in the correlation with apparent density among the different investigators are due to variations in species, direction and stress (tensile or compressive) rather than to properties of a particular bone or laboratory.

In this paper, the compressive mechanical properties (ultimate stress, Young's modulus, energy absorbed to ultimate stress) of female femoral heads in cases of fractured neck of femur and osteoarthrosis were studied and compared with the corresponding properties for normal bone. Furthermore, an attempt was made to correlate the mechanical properties of osteoarthrotic and normal trabecular bone with apparent and actual densities using bone from a single species, a single site and of the same sex tested in a uniform manner and to compare these results and those of cadaveric bone. By actual density is meant the density of the whole specimen as removed from the femoral head and measured prior to mechanical testing or defatting [17]. The apparent density is the mineralized tissue mass per total volume of the specimen.

2. Methods

Femoral heads were collected from females between sixty and seventy years old from three clinical groups. Patients undergoing total hip replacement for osteoarthrosis; cadavers, and patients with femoral neck

Figure 1 Typical specimens, on the right taken from a cadaveric femoral head showing the cartilage, subchondral plate and trabecular bone and on the left an osteoarthrotic femoral had showing the bare (eburnated) bone surface and underlying trabecular bone.

fractures. For all these groups, the femoral heads were collected, wrapped in saline soaked swabs and kept frozen at $-20\,^{\circ}$C. The osteoarthrotic patients were sub-divided into idiopathic hypertrophic or secondary to either mechanical dearrangement of the joint, these groups being defined according to the criteria of Solomon *et al.* [25] from their clinical histories and radiographs. According to Healey [26] osteoarthrosis is a negative risk factor for osteoporotic compression fractures, and the Singh index [18] was determined for all the osteoarthrotic specimens and none had low, that is osteoporotic, values, but the fractured neck of femur patients did have low values. Cylindrical specimens of trabecular bone 9.5 mm diameter (Fig. 1) were trephined perpendicular to the articular surface from reproducible positions on the femoral heads, with up to 18 specimens taken from each femoral head and X-rayed to check that the trabeculae were perpendicular to the joint surface. The specimens were divided into those from the eburnated or non-eburnated areas in the osteoarthrotic femoral heads, depending on the absence or presence of articular cartilage and into major, partial and non-weight bearing areas for the fractured neck of femur and cadaveric specimens (Fig. 2), based upon the work of Brown and Shaw [27]. The major weight bearing area is that which is always in contact with the acetabulum when the hip is moved within its physiological ranges of motion, partial weight bearing areas are those which sometimes are and sometimes are not in contact and the non-weight bearing areas are those which are never in contact with the acetabulum.

The two ends of each specimen were squared off and the actual density, that is the density of the bone including the inter-trabecular contents, was measured. The specimens were subjected to compression testing at 100% min^{-1} ($0.017\,\text{s}^{-1}$) between polished steel plates using a Schenk Trebel materials testing machine. The load versus crosshead displacement was recorded and a typical stress–strain curve is shown in Fig. 3 and from these the ultimate stress, Young's modulus and energy absorbed up to the ultimate stress were calculated. After mechanical testing the

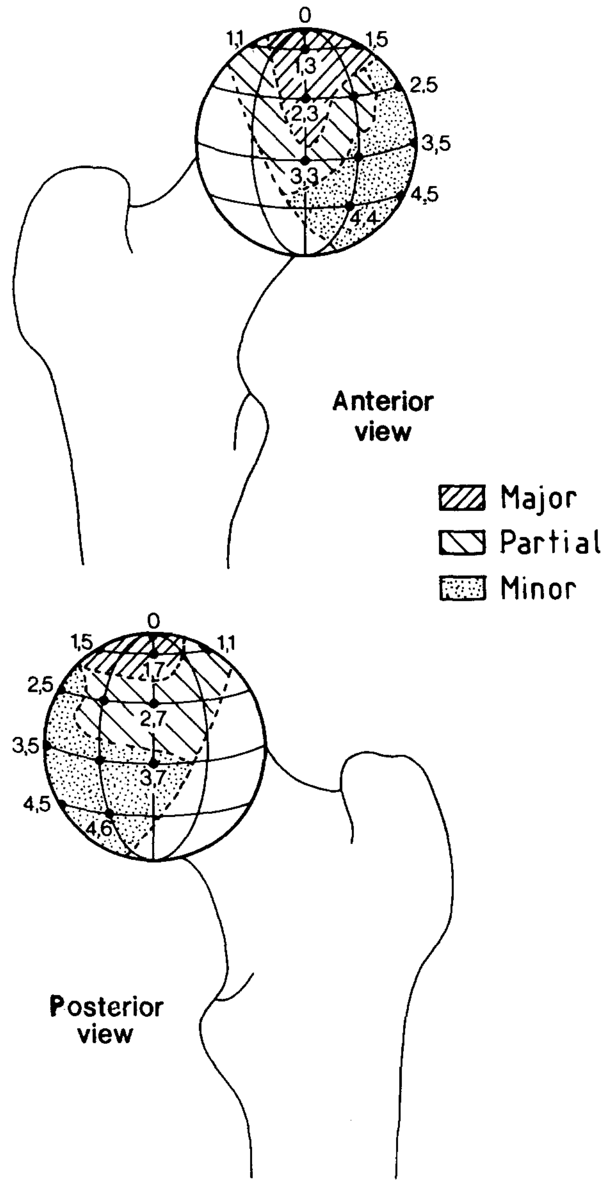

Figure 2 The specimens taken from the femoral heads with the major, partial and minor weight bearing areas, the delineation being based on the work of Brown and Shaw [27].

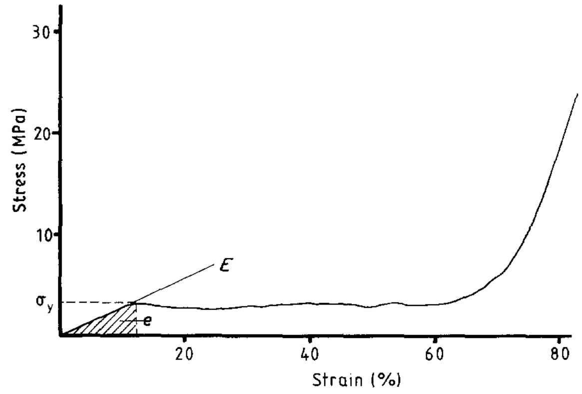

Figure 3 A typical stress–strain curve for trabecular bone showing ultimate stress (σ_u) Young's modulus (E) and energy absorbed to ultimate stress (e).

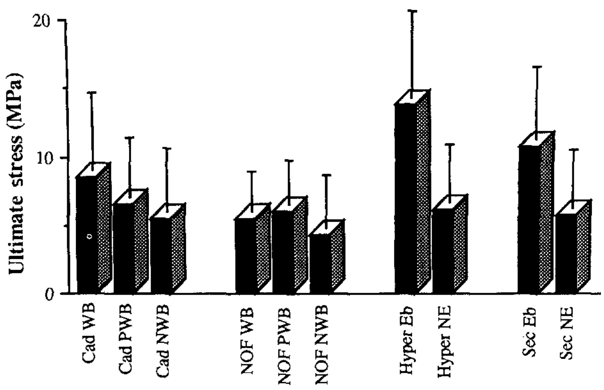

Figure 4 Ultimate stress in MPa for cadaveric bone (Cad) and fractured neck of femur patients (NOF) divided into weight bearing (WB), partial weight bearing (PWB) and non-weight bearing (NWB) areas and for two types of osteoarthrosis, idiopathic hypertrophic (Hyper) and secondary (Sec) divided into bone from the eburnated (Eb) and non-eburnated (NE) areas.

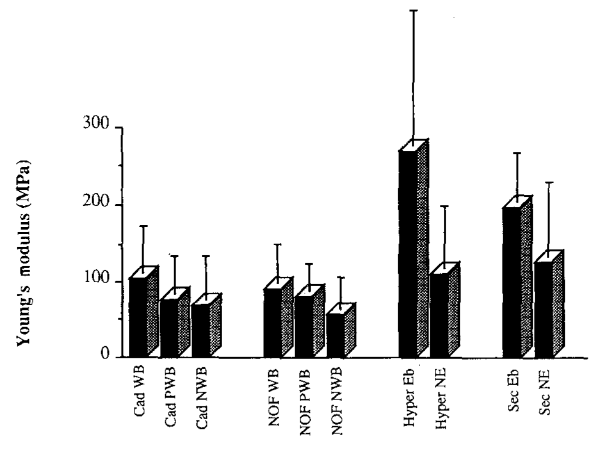

Figure 5 Young's modulus in MPa for the groups defined in Fig. 4.

specimens were defatted in trichloroethylene for 4 h in an ultrasound bath, rehydrated in distilled water under vacuum and the apparent density was measured using the method of Sharp *et al.* [28].

3. Results

The results obtained for ultimate stress, Young's modulus, energy absorbed to ultimate stress, actual density and apparent density are shown in Figs 4–8. The cadaveric (Cad) and fractured neck of femur (NOF) specimens are divided into major weight bearing (WB), partial weight bearing (PWB) and non-weight bearing (NWB) areas. The osteoarthrotic specimens are divided into two clinical groups, idiopathic hypertropic (Hyper) and second (Sec) and each disease group sub-divided into eburnated (Eb) and non-eburnated (NE) areas.

3.1. Mechanical properties and densities

As determined for male femoral head cadaveric trabecular bone [17], in the major and partial loading bearing areas all the compressive mechanical properties and the densities were higher than in the non-weight bearing areas, but in females, unlike in males, this difference was not statistically significant.

In the bone which came from femoral heads removed during partial or total hip replacement, or after

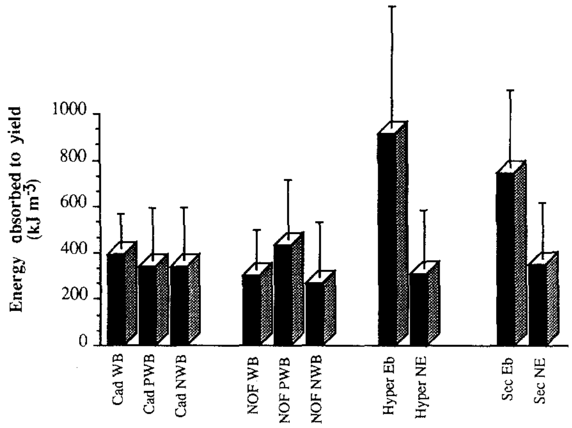

Figure 6 Energy absorbed to ultimate stress in $\mathrm{kJ\,m^{-3}}$ for the groups defined in Fig. 4.

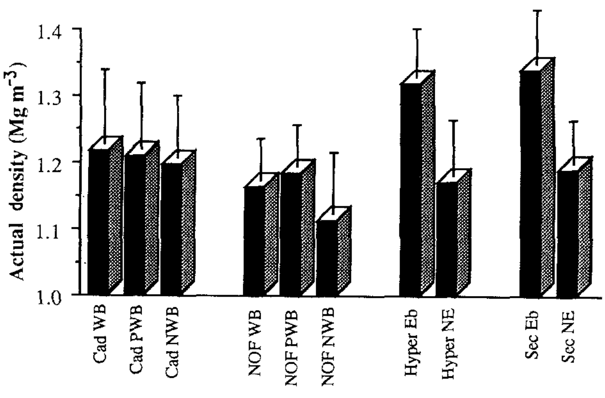

Figure 7 Actual density in $\mathrm{Mg\,m^{-3}}$ for the groups defined in Fig. 4.

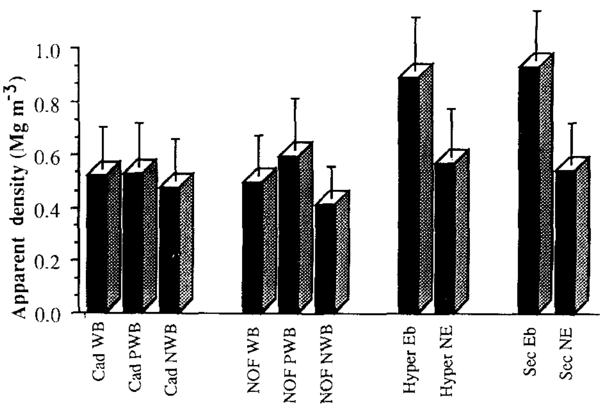

Figure 8 Apparent density in $\mathrm{Mg\,m^{-3}}$ for the groups defined in Fig. 4.

fractures of the neck of femur, similar trends were seen, in that the major and partial weight bearing areas had higher mechanical properties and the densities than the non-weight bearing areas. This finding is unlike the equivalent results for the female cadaveric bone in which there were differences in mechanical properties and densities between the major and the partial weight bearing areas.

When the fractured neck of femur specimens were compared with the cadaveric specimens the mechanical properties were reduced in the weight bearing area only. There was a statistically significant difference ($p < 0.05$) in the ultimate stress in the major weight bearing area but all the other mechanical properties were not significantly different.

In both of the osteoarthrotic groups there were significantly ($p < 0.001$) higher values in the eburnated areas when compared with the non-eburnated areas for ultimate stress, Young's modulus, energy absorbed to ultimate stress, actual and apparent densities. When the osteoarthrotic specimens were compared with the cadaveric ones the mechanical properties ($p < 0.05$) and densities ($p < 0.001$) were significantly increased in the eburnated areas when compared with the weight bearing areas in the cadaverics. No increase was noticed in the non-eburnated areas when compared with the non-weight bearing ones.

3.2. Correlation of the mechanical properties with densities

Possible correlations of the compressive mechanical properties (ultimate stress, Young's modulus, energy absorbed to ultimate stress) will each of actual density, apparent density and the apparent density squared and cubed, were examined.

Specimens from each area of the cadaveric, fractured neck of femur and osteoarthrotic bone was correlated with each of the independent variables separately, and as complete clinical groups (Tables I–III) and ultimate stress versus apparent density plots are shown in Figs 9–11. For ultimate stress all the correlation coefficients for most of the cadaveric and osteoporotic groups in the correlation with apparent density and squared apparent density had higher values than those with actual density. In the osteoarthrotic groups the correlation coefficients with actual density for cadaveric specimens ($R^2 = 68.38\%$) and

TABLE I Correlation coefficients of ultimate stress (σ_u) with apparent density (ρ_{app}) to the first, second and third powers and actual density (ρ_{act}) for the three clinical groups

σ_u	Cadaveric $n = 55$	Fractured neck of femur $n = 49$	Osteoarthrotic $n = 60$
ρ_{app}	$R^2 = 68.38\%$	$R^2 = 63.32\%$	$R^2 = 63.24\%$
ρ_{app^2}	$R^2 = 66.69\%$	$R^2 = 59.41\%$	$R^2 = 64.57\%$
ρ_{app^3}	$R^2 = 61.95\%$	$R^2 = 53.72\%$	$R^2 = 63.71\%$
ρ_{act}	$R^2 = 62.76\%$	$R^2 = 60.98\%$	$R^2 = 71.58\%$

TABLE II Predictor equations and correlation coefficients of Young's modulus (E) with apparent density (ρ_{app}) to the first, second and third powers and actual density (ρ_{act}) for the three clinical groups

E	Cadaveric $n = 55$	Fractured neck of femur $n = 49$	Osteoarthrotic $n = 60$
ρ_{app}	$R^2 = 51.39\%$	$R^2 = 38.74\%$	$R^2 = 45.49\%$
ρ_{app^2}	$R^2 = 48.40\%$	$R^2 = 37.65\%$	$R^2 = 49.09\%$
ρ_{app^3}	$R^2 = 43.40\%$	$R^2 = 36.24\%$	$R^2 = 50.99\%$
ρ_{act}	$R^2 = 47.53\%$	$R^2 = 37.86\%$	$R^2 = 52.27\%$

TABLE III Predictor equations and correlation coefficients of energy absorbed to ultimate stress (e) with apparent density (ρ_{app}) to the first, second and third powers and actual density (ρ_{act}) for the three clinical groups

e	Cadaveric $n = 55$	Fractured neck of femur $n = 49$	Osteoarthrotic $n = 60$
ρ_{app}	N.S.	$R^2 = 60.67\%$	$R^2 = 53.17\%$
ρ_{app^2}	N.S.	$R^2 = 58.95\%$	$R^2 = 52.22\%$
ρ_{app^3}	N.S.	$R^2 = 55.24\%$	$R^2 = 49.28\%$
ρ_{app}	$R^2 = 41.08\%$	$R^2 = 63.50\%$	$R^2 = 57.27\%$

for fractured neck of femur specimens ($R^2 = 63.32\%$) and squared apparent density (for cadaveric bone $R^2 = 66.7\%$ and for osteoporotic bone $R^2 = 60.99\%$) had higher values than those with actual density ($R^2 = 62.75\%$ for cadaveric bone, $R^2 = 59.41\%$ for osteoporotic bone). In osteoarthrotic groups the correlation coefficient with actual density ($R^2 = 71.60\%$, for the complete clinical group) is much higher than the other two ($R^2 = 63.24\%$ with apparent density and $R^2 = 64.17\%$ with squared apparent density). The same is observed in the correlation of Young's modulus and energy absorbed to ultimate stress with densities.

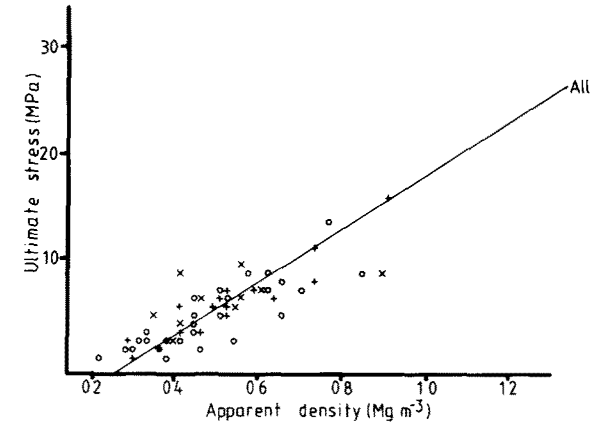

Figure 9 Ultimate stress in MPa versus apparent density in Mg m^{-3} for the female cadaveric bone from the, (×) major, (+) partial and (○) minor weight bearing areas showing the least squares fit (——).

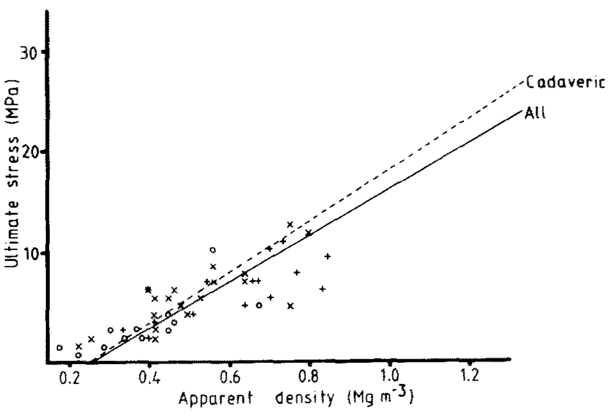

Figure 10 Ultimate stress in MPa versus apparent density in Mg m^{-3} for the trabecular bone from female fractured neck of femur cases divided into the, (×) major, (+) partial and (○) minor weight bearing areas showing the least squares fit (——) and that obtained for the cadaveric cases (----).

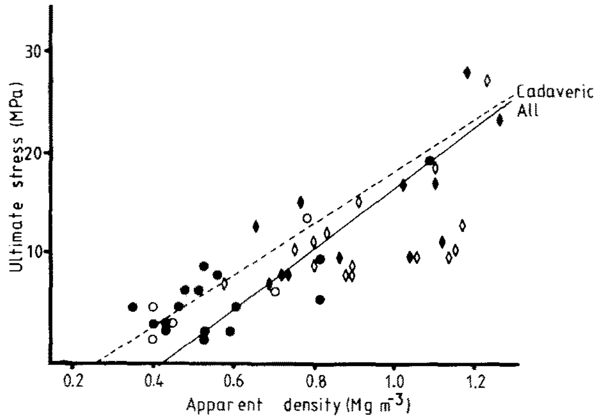

Figure 11 Ultimate stress in MPa versus apparent density in Mg m^{-3} for the trabecular bone from female osteoarthrotic cases divided into idiopathic hypertropic (◆) eburnated and (◇) non-eburnated and secondary (●) eburnated and (○) non-eburnated weight bearing areas showing the least squares fit for all four groups (——) and that obtained for the cadaveric cases (----).

4. Discussion

Hence the major weight bearing areas of the femoral head in females seem to be the areas most affected by the pathological processes which are responsible for either fractured neck of femur or osteoarthrosis. In the case of fractured neck of the femur this agrees with the radiological findings of Singh *et al.* [18] namely that it is the major trabecular structure which has reduced radiographic density in the osteoporosis which normally precedes fractures of the neck of femur in postmenopausal women. The findings on the osteoarthrotic femoral heads agree with the findings of Tanner *et al.* [17] on males of equivalent ages that it is the eburnated areas where the mechanical properties are primarily affected, rather than osteoarthrosis damaging the entire joint. However the density results are dissimilar as an increased density was found throughout the femoral head in male osteoarthrotic patients.

Trying to find a function which predicts the ultimate stress or the Young's modulus or the energy absorbed to ultimate stress from its apparent density, it is concluded, in agreement with Rice *et al.* [24] that almost none of the intercepts (or constant terms) of the predictor equation equal zero (except for the equation $\sigma_u = a\rho^2 + b$, where σ_u is the ultimate stress, ρ is the apparent density the constant term, b is zero ($p < 0.01$) unlike the results of Carter and Hayes [7, 8]. It should be noted that Carter and Hayes tested their specimens in confined compression while ours are tested in unconfined compression.

As Rice *et al.* [24] argue, this conclusion can be considered to be consistent with the findings of Parfitt *et al.* [29] that there is a minimum size for a trabeculum to remain in equilibrium during remodelling and if a trabeculum thins beyond this minimum size, it simply disappears. This effect means that a mechanical property which is a function of apparent density need not be forced to vanish when the apparent density becomes zero. Considering the dependence of yield stress upon apparent density for complete clinical groups (Table I) it is seen that the maximum value of the squared correlation coefficient R^2 can be seen when correlating the ultimate stress with apparent density in cadaveric and fractured neck of femur bone, while in osteoarthrotic bond the maximum R^2 is with squared apparent density. Similar results were obtained for the correlation of Young's modulus with apparent density (Table II).

These experimental findings are not consistent with the theoretical predictions of Gibson [23], our specimens are closed cell or fully plate-like, according to micrographs of Whitehouse and Dyson [30], as all but eight specimens have densities higher than $350\,\mathrm{kg\,m^{-3}}$ the density at which open cell bone ceased to be found and only closed cell was obtained. Gibson's analysis suggests that strength (ultimate stress) should vary with the square of apparent density and Young's modulus with the cube of apparent density. The correlation coefficients of ultimate stress and Young's modulus with squared apparent density are only slightly lower than those with apparent density and there is significant correlation with squared apparent density. Rice *et al.* [24] found similar results where the correlations with $\rho^2 + \rho^3$ differ slightly from the correlations with ρ^2 and using a model of the type

$$E = a_0 + a_1\rho + a_2\rho^2 + a_3\rho^3 \qquad (4)$$

they increase still further.

Gibson's theoretical work predicts a linear dependence of ultimate stress and Young's modulus on apparent density for certain open and closed cell structures in cases of axial compression and uniaxial plastic yielding. This mode of deformation occurs in a columnar network of rods or plates and this type of bone where uniaxial loading prevails such as in vertebrae [20, 30]. All this theoretical analysis is based on cells with constant wall thickness within each cell, but the structure of cancellous bone does not match these idealized models. The trabeculae have a distinct orientation and the bone is highly anisotropic [8, 11].

The energy absorbed to ultimate stress can be estimated for a linear elastic material, as cancellous bone may be regarded at low strain rates. If the ultimate stress is σ_u and Young's modulus, E, the strain at ultimate stress will be σ_u/E, so the energy absorbed to ultimate stress is

$$\frac{\text{stress} \times \text{strain}}{2} = \frac{\sigma_u^2}{2E} \qquad (5)$$

thus energy must be correlated with

$$\frac{(\rho)^2}{\rho} = \rho \qquad (6)$$

The best correlation between energy and density is with the first power of density which agrees with the present experimental results for cadaveric and fractured neck of femur bone, as it is seen in Table III. The same holds true for the osteoarthrotic bone the best correlation is with

$$\frac{\sigma_u^2}{2E} = \frac{(\rho^2)^2}{\rho^3} = \rho \qquad (7)$$

(Table III). These results are similar to those of Carter and Hayes [8] in that both compressive strength and energy absorbed to yield of bovine subchondral trabecular bone increase linearly with apparent density.

Thus cadaveric and fractured neck of femur bone can be regarded as uniform from a mechanical point of view. While osteoporosis reduces simply the density, osteoarthrosis does not just increase the density but causes some changes in the structure of bone. Grynpas *et al.* [32] have found alterations in the mineral fraction of osteoarthrotic bone with more bone of lower mineral content found when compared with controls. This result implies that architecture plays a significant role in the values of mechanical properties, agreeing with the opinion of Currey [33] that bone from different sites of the body can have a wide variety of different mechanical properties depending upon its function.

From the preceding discussion it is clear that trabecular bone is a complex material and that, despite the analytical arguments for the dependence of the elastic and strength properties upon apparent density, the inconsistency in experimental results shows that the mechanical behaviour cannot be explained in such simple terms and that there are factors other than density contributing to the mechanical properties of trabecular bone including material distribution, the size of the specimen and anisotropy of the structure. The obvious dependence of material properties on the architecture of trabecular bone has been noted by virtually all the investigators involved in trabecular bone research.

A surprising result is that the regression lines of ultimate stress with apparent density are quite similar ($p < 0.05$) for the cadaveric major and partially weight bearing specimens and the corresponding fractured neck of the femur specimens. The regression lines between eburnated and cadaveric major and partially weight bearing bone differ significantly ($p < 0.001$) (Table IV). Similar relations were found correlating Young's modulus and energy absorbed to ultimate stress with apparent density (Tables V and VI). This is another indication for architectural similarity between cadaveric and osteoporotic bone, which does need further microscopic study.

5. Conclusions

The mechanical properties and densities were higher in the weight bearing than the non-weight bearing areas of femoral heads from females for all pathological groups. The mechanical properties were higher in the osteoarthrotic groups than the cadaverics which were again higher than the fractured neck of femur group. The major weight bearing areas of the femoral head are the areas most affected by the pathological processes responsible for either fracture of the neck of

TABLE IV Correlation coefficients, prediction equations and statistical significance of the terms of prediction equations of ultimate stress from apparent density

Type of bone	R^2 (%)	Equation (σ_u in MPa)	Probability Coef of R	Intercept
Cadaveric (WB + PWB)	64.86	$\sigma_u = 16.49\rho - 2.54$	0.0000	0.0002
Fractured NOF (WB + PWB)	63.35	$\sigma_u = 16.06\rho - 2.46$	0.0000	0.0008
Osteoarthrotic (Eb)	67.19	$\sigma_u = 21.70\rho - 5.42$	0.0000	0.0275
Cadaveric (NWB)	70.1	$\sigma_u = 17.15\rho - 2.71$	0.0000	0.0016
Fractured NOF (NWB)	50.45	$\sigma_u = 15.86\rho - 3.22$	0.0065	0.1410
Osteoarthrotic (NE)	62.02	$\sigma_u = 16.92\rho - 4.05$	0.0000	0.0304

TABLE V Correlation coefficients, prediction equations and statistical significance of the terms of prediction equations of Young's modulus from the apparent density

Type of bone	R^2 (%)	Equation (E in MPa)	Probability Coef of R	Intercept
Cadaveric (WB + PWB)	51.86	$E = 221.86\rho - 33.81$	0.0027	0.3621
Fractured NOF (WB + PWB)	55.75	$E = 274.83\rho - 52.80$	0.0000	0.0245
Osteoarthrotic (Eb)	57.08	$E = 459.02\rho - 166.07$	0.0000	0.0237
Cadaveric (NWB)	64.55	$E = 350.96\rho - 111.16$	0.0000	0.0043
Fractured NOF (NWB)	43.2	$E = 198.12\rho - 33.54$	0.0064	0.4371
Osteoarthrotic (NE)	43.15	$E = 211.07\rho - 15.71$	0.0000	0.6357

TABLE VI Correlation coefficients, prediction equations and statistical significance of the terms of prediction equation of energy absorbed to ultimate stress from the apparent density

Type of bone	R^2 (%)	Equation (e in kJ m^{-3})	Probability Coef of R	Intercept
Cadaveric (WB + PWB)	29.10	$e = 757.05\rho - 37.40$	0.0211	0.8190
Fractured NOF (WB + PWB)	52.36	$e = 910.52\rho - 160.21$	0.0000	0.0422
Osteoarthrotic (Eb)	53.49	$e = 1532.29\rho - 467.72$	0.0000	0.0771
Cadaveric (NWB)	30.54	$e = 968.73\rho - 168.26$	0.0174	0.4031
Fractured NOF (NWB)	43.36	$e = 880.34\rho - 160.32$	0.0144	0.2432
Osteoarthrotic (NE)	57.67	$e = 1091.38\rho - 289.10$	0.0000	0.0395

femur or osteoarthrosis. Although bone from a single species, a single site and a single sex has been compressed in a uniform manner, the correlation of the mechanical properties with apparent density is no stronger than when bone from a variety of species and sites and both sexes is used. There is a strong correlation of the mechanical properties with the apparent density and the apparent density squared. The highest correlation for both ultimate stress and Young's modulus with apparent density is with the first power of the density for cadaveric and fractured neck of femur patients. For patients with osteoarthrosis the best correlation for the same properties was with apparent density squared. The energy absorbed to ultimate stress relates linearly with apparent density for all the specimens. The regression lines of ultimate stress with apparent density across cadaveric and fractured neck of femur bone are similar while those between cadaveric and osteoarthrotic bone are dissimilar. This result provides an indication of mechanical similarity of cadaveric with fractured neck of femur bone.

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