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CAN RADIOGRAMMETRY PREDICT THE MECHANICAL STRENGTH OF THE PROXIMAL FEMUR? AN IN VITRO COMPARISON WITH BONE MINERAL DENSITOMETRY.

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INTRODUCTION

Numerous anthropometric studies from radiographs of normal femurs have been used for design analysis of implants to be used in patients with different musculo-skeletal disorders of the hip (Noble et al., 1988). Similarly, in-vitro biomechanical testing and finite element modelling of the proximal femur with or without implant often have involved the use of either a single normal femur (Couteau et al., 1998), or many femurs (e.g. 36 used by Keyak et al., 1998), or of a single synthetic composite (analog) femur (Cristofolini et al., 1996; McKellop et al., 1991). Few papers have demonstrated validation of the material properties used in composite bones, but almost none for structural properties (Cristofolini et al., 1996; McNamara et al., 1998). However, in few biomechanical research studies radiographs are taken of the proximal femur to screen out pathological specimens to minimize variability associated with the diversity of femurs with different intrinsic (material) and extrinsic (structural) properties among normal femurs and particularly among femurs with musculo-skeletal pathology. The purpose of this investigation is to assess the feasibility of radiographic characterization of extrinsic (structural) properties related to the mechanical strength of the proximal femur and to compare the results with intrinsic (e.g. bone

mineral density (BMD)) properties as measured with dual-energy x-ray absorptiometry (DEXA).

PROCEDURES

Comparative in-vitro analysis of femoral strength was performed in thirty-eight unilateral (right-sided) femurs (13 females, 25 males) with an average age being 61.7 ± 20.3 years at the time of death. The analysis included biplanar orthogonal radiogrammetry, bone mineral densitometry using DEXA, and mechanical testing (simulating a fall on the greater trochanter as per Courtney et al., 1995). Radiogrammetric indices of the proximal femur included external cortical dimensions (width of the femoral head, neck and shaft as a measure of bone size), femoral cortical index (Gruen, 1997), cortical cross-sectional area (as a measure of axial stiffness) and cross-sectional moments of inertia (as a measure of flexural stiffness). All cross-sectional geometric properties were derived from external and internal cortical dimensions made at the site for measurement of the cortical index. All bone mineral densitometry measurements, with a Lunar DPX- α system by an experienced observer at another hospital, were made with the three standard regions of interest as well as at a customized region at the level of measurements for radiogrammetry. The mechanical

test done on each femur was performed using the protocol of Courtney et al., 1995.

RESULTS AND DISCUSSION

Strong significant correlation was found between measured load at fracture of the femur and femoral BMD measurements ($0.94 > r > 0.78$; $p < 0.0001$). This corroborates the well-known relationship between the in-vitro strength and BMD of the proximal femur. Moderate to good relationships were noted for all radiogrammetric indices ($0.82 > r > 0.42$; $p < 0.01$) except for the external (size) dimensions of the femoral head, neck, and shaft ($r = 0.29, 0.24, \text{ and } 0.29$ respectively). The correlation between fracture load and femoral cortical index as measured in the anterior-posterior and lateral films was highly significant (r -values of 0.73 and 0.75 respectively; $p < 0.0001$). As expected a moderately good inverse significant relationship was found between measured fractured load, BMD, and cortical index with age (Table 1)

Table 1. Relationship between mechanical strength, bone densitometry, and cortical index with age.

	<u>r-value</u>	<u>p-value</u>
Mechanical strength	-0.615	<0.001
Femoral neck BMD	-0.52	<0.01
Femoral shaft BMD	-0.48	<0.01
Cortical index(AP)	-0.44	<0.01

A strong relationship was also noted between cortical index and femoral BMD with $r = 0.811$ and 0.866 for the femoral neck and femoral shaft respectively ($p < 0.0001$).

SUMMARY

Overall, the results of this study suggest a strong biomechanical interdependency between the extrinsic (cortical geometry) and intrinsic properties (bone mineral

density) for the proximal femur. It is apparent that the structural characteristics of the femoral cortical bone can contribute to the strength of the proximal femur. This includes the use of the cortical index, a dimensionless ratio, as a first-order approximation of structural strength, which unlike other radiogrammetric parameters is relatively insensitive to problems inherent with clinical radiography, i.e. magnification as well as rotational and obliquity variation due to specimen positioning.

This biomechanical study corroborates previous studies suggesting that cortical bone is important to its strength and resistance to loading (Courtney et al., 1995). It is acknowledged that radiogrammetry is not recommended for monitoring longitudinal studies of changes in either material or structural properties of a single patient, but it does appear to be practical for cross-sectional population-based studies. This would then allow better characterization of normal and abnormal femoral specimens with pathologies associated with different musculo-skeletal disorders.

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