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COMMENTARIES

Measuring Femoral Neck Strength: Lost in Translation?

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Commentary on: Yang L, Maric I, McCloskey EV, Eastell R. Shape, structural properties, and cortical stability along the femoral neck: a study using clinical QCT. *J Clin Densitom*. 2008 Jul-Sep;11(3):373-82.

Areal bone mineral density (aBMD), a two-dimensional areal projection of a three-dimensional structure, is used to identify individuals at risk of fracture. This 'shadow' cast by the mineral content is used as a surrogate of bone strength but lacks sensitivity and specificity. More than half of all hip fractures occur in women without osteoporosis (T score < -2.5 SD) and most women with osteoporosis do not sustain fractures. During drug therapy, only a small proportion of the fracture risk reduction is explained by the increase in aBMD (1;2).

This lack of sensitivity and specificity occurs, in part, because structural failure – fracture – reflects changes in bone's material and structural properties are not captured by the degree of photon attenuation produced by the mineralized mass (3). Consequently, in an attempt to improve the identification of individuals at risk of fracture, efforts are underway to derive structural measures of strength such as a section modulus (Z) and cross-sectional moment of inertia derived directly using quantitative computed tomography (QCT) or indirectly using DEXA scans and algorithms such as the Hip Structure Analysis (HSA) (4;5).

However, indices of strength can only be derived if the structure has been modelled, *i.e*., represented in an idealized form so that engineering formulae can be applied. Modeling a structure usually involves simplifications whereby some details are eliminated and others are emphasized. The features highlighted depend on the purpose for which the model is created. Currently, models used to estimate the structural strength of tubular bones such as the femoral neck (FN) are based on beam theory. These models represent the FN as a pipe with a single cortical thickness around the cross-section, single internal and external diameters along its length. Consequently, one structural index of bending (Z), compressive (total bone area) or torsional strength is computed for a whole bone.

As highlighted by Yang *et al*. in the July-September 2008 issue of the *Journal of Clinical Densitometry*, the FN is not a beam – the structure of each cross-section along its length vary at each point around the perimeter (6). This finding supports and extends several earlier reports emphasizing that the spatial organization of cortical and trabecular bone varies greatly around a perimeter of a single cross-section and from cross-section to cross-section along the FN (7-9) (Fig. 1).

This complex design is the result of differing absolute and relative degrees of periosteal apposition and endocortical resorption along the FN fashioning cross-sections of different size, shape, with differing proportions and spatial distribution of cortical and trabecular bone to accommodate the varying stresses along the FN. Because of this complexity in design, modeling the FN is challenging, and representing it as a pipe or tube is likely to misrepresent its structural strength; this is the subject of the report by Yang *et al*. (6)

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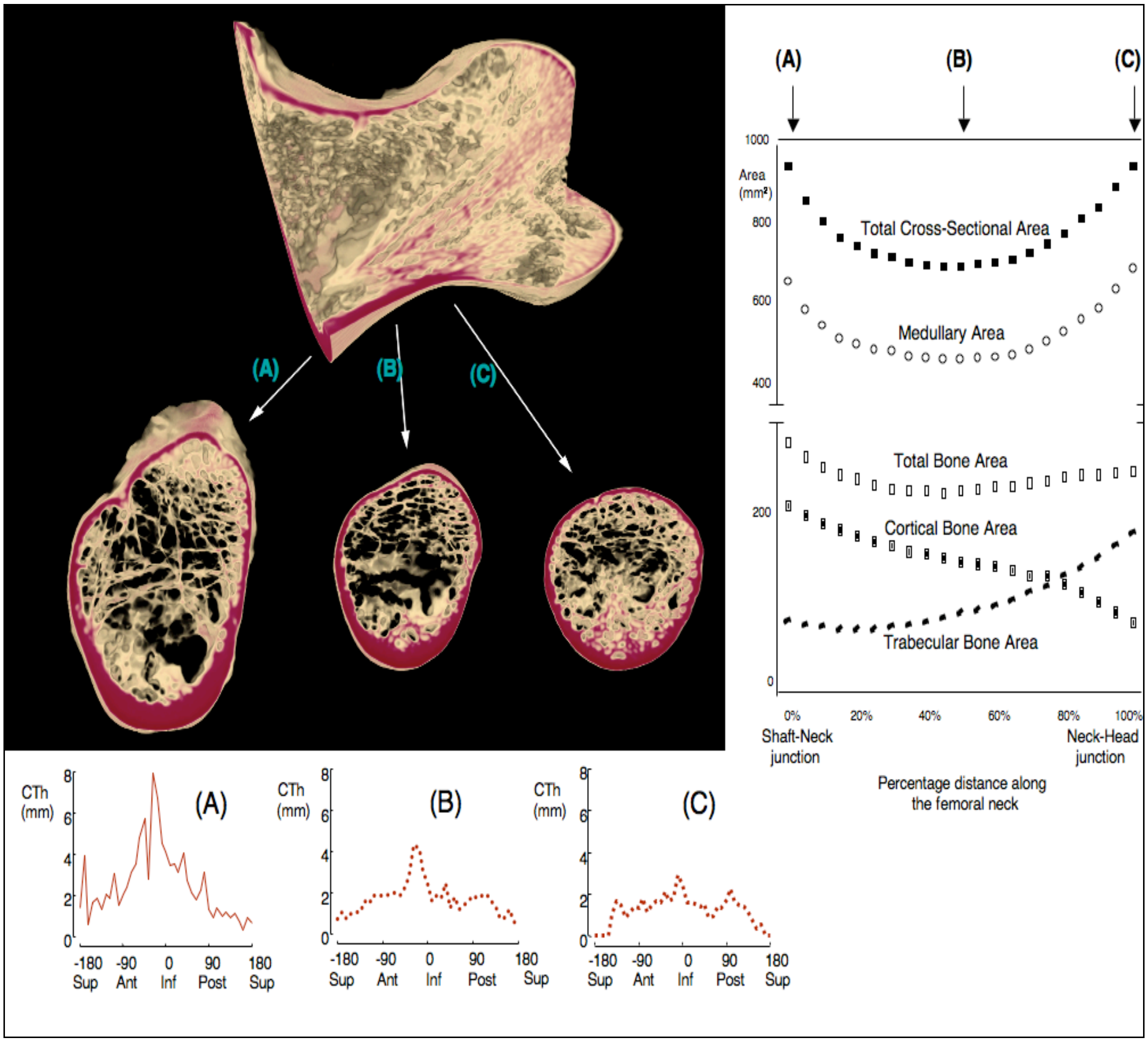

Fig 1. Femoral neck structure varies point by point around the perimeter of the cross-section and along the length from cross-section to cross-section. Adapted from Zebaze *et al.* with permission from the American Society for Bone and Mineral Research (8). CTh = cortical thickness.

Yang and colleagues examined the effects of the structural diversity of the FN on parameters and indices of strength around the perimeter of the cross-sections and along its length using QCT. Their comprehensive analysis suggests that a single parameter of strength in an individual is unlikely to accurately represent the diversity of FN strength from region to region within an individual and between individuals differing in age, sex and ethnic group.

These investigators report that the FN bone area from cross-section to cross-section was almost constant along its length. They suggest that this was an adaptation to loading along its length. Rather than using more material, the increasing bending forces from the proximal to the distal half of the FN are accommodated by fashioning the constant amount of material into a more elliptical structure distally that increases the section modulus.

Yang *et al.* report that the FN section modulus depended on the direction in which the measurement was made and suggest that cross-sectional resistance to bending depends on the fall orientation. Furthermore, they estimate that bending strength was highest when falling 20 degree anteriorly and lowest (by ~ 1/3 of the maximal value) when falling 50 degree posteriorly on the greater trochanter. While it is known that fractures are associated with sideways falls onto the greater trochanter, not all falls result in fracture and it is unclear if there is a falling angle that confers greater risk than other angles. Accounting for the structural diversity of the FN as done by these investigators raises the possibility that a single section modulus calculated in the supero-inferior direction at the mid-FN or at the narrowest part of the FN might not be the most relevant one when predicting fracture due to falls onto the greater trochanter.

The study of the determinants of FN structural fragility might be enhanced by identifying bones' weakest 'link'. The cortex of the FN is thinnest superiorly and undergoes the greatest loss of bone (9); Yang *et al*. confirm this observation. As suggested by Mayhew *et al*. (9), studies directed at modifying this aspect of the FN using drug therapy or other means might be fruitful.

The usefulness of a model is the degree to which it conforms to the original structure in terms of properties to be studied but the risk with modeling is oversimplification. While the need to simplify this complex design is necessary, the dangers of misrepresentation of the underlying biology may invalidate the use of these estimates of bone strength.

Yang *et al*. suggest that the model of a single cross-section with a uniform cortical thickness is an oversimplification. To remedy this, these investigators suggest the assessment of multiple sites along the FN. Whether a single site or the use of multiple sites will provide higher sensitivity and specificity in fracture prediction remains uncertain. Given the complexity of FN structure, it seems appropriate to at least explore this suggestion.

As the magnitude and direction of forces and stresses from a given loading condition may differ along the FN and around a cross-section, different measures of strength may be relevant. For example, bending strength might be more discriminating in distal cross-sections so that the accurate estimation of size and shape may be more discriminating. Compressive strength might be more discriminating at proximal cross-sections so that accurate measure of bone area may be more relevant than shape at this location.

Models such as HSA are not ends in themselves; they are a means to an end. The endpoint is the robust estimation of bone strength which in turn requires an accurate representation of structure. At this time, there has been excessive attention to the models such as HSA while FN structure itself has received limited attention. A good model of the structure cannot be achieved unless the original structure itself is accurately quantified. The FN has been modeled as a circular cylinder for almost two decades and it is only recently that reports highlighting the need to account for its elliptical shape have been emerging (6;8). Modeling of the indicator of structural strength of an elliptical cross-section is not more complicated than modeling a circular cross-section.

The diverse structure of the FN is lost in translation when represented as a pipe or tube and the pathophysiology underlying the assembly of its unique design is obscured by doing so. A new perspective for the assessment of FN structural strength such as that provided by Yang and colleagues is a step in the right direction. We should follow their lead.

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