ASSESSMENT OF THE SUSCEPTIBILITY OF FEMORAL NECK CORTEX TO LOCAL BUCKLING DUE TO AGE-RELATED BONE LOSS

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INTRODUCTION

Numerical simulations of loaded trabeculae in osteoporotic bones illustrate that individual trabeculae fail by Euler buckling. Euler buckling is an instability mode that becomes probable in structures loaded at ends that are too slender and lack lateral support. Trabecular degradation caused by osteoporosis leads to increase in slenderness and loss of transverse elements. Subsequently, applied loads are mainly borne by the cortex, its stability may be more critical. Aging and osteoporosis cause thinning of cortices, expansion of their mean diameter and loss of internal trabecular support which could lead to local buckling, a distinct form of instability. In this pilot study we performed a series of stability analyses on tubular structures representing femoral neck geometries.

METHODS

Seven cross-section models of the femoral neck cortex from human cadaver specimens (4 female, 3 male, mean age: 61.3, range: 52-68) were analyzed using dimensions from CT studies of hip fracture cases and non-fractured controls. Sections were chosen such that they span the range of cortical slenderness based on the buckling ratio (BR). Two different types of models were considered in this study: one non concentric circle and seven realistic sections from CT scans of the femoral neck [1].

To investigate the potential for local instability, we developed finite strip models of each cross-section and determined the elastic critical local buckling stress (f_{crl}). The finite strip method [2] is a specialized variant of the finite element method which is aimed at instability analysis of thin-walled structures. The model considers the cross-section as an extrusion (no variation along the length). Local buckling occurs at lengths as short as half the section diameter, so the assumption of a straight extrusion is acceptable. Since the cross section changed considerably along the femoral neck, such small half wave lengths were chosen. The material properties were assumed to be E=18800MPa, G=13620MPa, Poisson's ratio=0.31 [3]. Subsequently, we investigated the reduction in material failure load (f_n) due to local buckling as a function of the local slenderness $\left(\sqrt{f_y / f_{crl}}\right)$. The results plotted in figure 1 correspond to geometrically remodeled cross section models at old age (~80 years old) that were obtained by modifying original middle age (~60 years) models.

RESULTS AND DISCUSSION

It can be noticed from the results (Figure 1) that even cross-sections with relatively low slenderness ratio demonstrate a reduction in predicted fracture load due to local instability. The significance of more realistic cortical dimensions is highlighted by the CT results, for example numbers 2 and 3 have similar BR values but control number 2 experienced no reduction in strength; while fracture case number 3 shows a small reduction. This more realistically simulated case is expected to experience some reduction, while number 7 modeled as a circle does not experience the same. These results suggest that BR values and regular-shaped models may not be adequate to describe instability at the femoral neck.

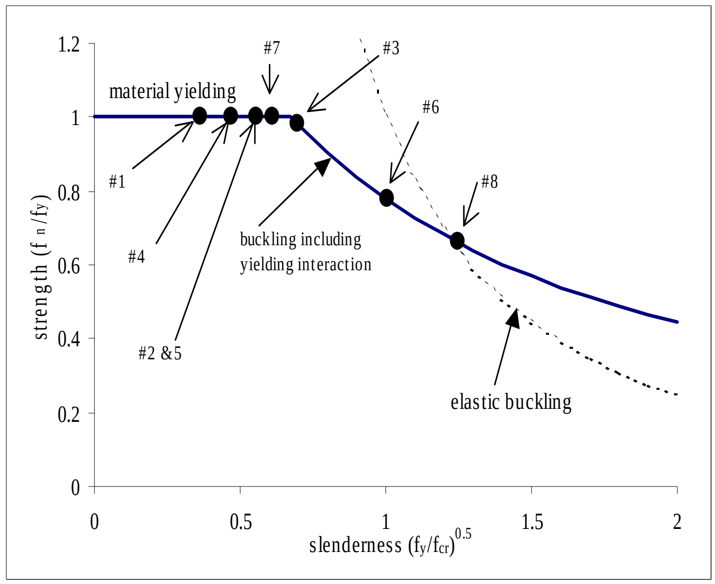

Figure 1: Predicted reduction in compressive strength for the femoral neck due to effect of local buckling.

CONCLUSIONS

Under uniform loading conditions, buckling phenomena progressively reduced the failure stress with aging process, as can be observed in 2/7of the middle age (by 9-15%) and 5/7 of the old age (by 7-32%) related models. Age-related geometric adaptation to bone loss might preserve the bending strength under physiologic loads, but cortical thinning impacts the strength when the buckling ratio reaches a critical threshold that would make the bone prone to local buckling at the femoral neck increasing the risk of fracture in a fall.

REFERENCES

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