Structural development of cortical bone morphology in the human femoral and tibial diaphyses indicates age- and site-specific biomechanical competence

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Abstract

Developmental structural differentiation in human long bone morphology is a key element in the variability of adult bone structure. This study tests whether the ontogeny of long bone biomechanical competence, assessed via cross sectional cortical shape and surface change in the human femoral and tibial diaphyses, is age- and anatomical site-specific. Dimensional scaling methods currently used for determining subadult injury thresholds assume geometric similarity between children and adults (Ash et al., 2009). Given the unique biomechanical demands of locomotor ontogeny and longitudinal growth, a more nuanced understanding of the developmental timing and spatial variability of long bone morphological characteristics is needed in order to develop accurate child response targets. High resolution x-ray CT scans collected for femora and tibiae (n=46) ranging developmentally from neonate to skeletally mature were obtained from the Norris Farms No. 36 Native American skeletal series. Whole-diaphysis cortical drift patterns and relative bone envelope modeling activity across ages were assessed in five locations per bone (at 20, 35, 50, 65, and 80% of total bone length) by measuring the distance from the section centroid to the endosteal and periosteal margins in eight sectors in ImageJ. Pearson correlations were performed to test the relationship between the cross-sectional shape (I_{max}/I_{min}), TA, CA, and MA for each slice location and age for both the femur and tibia. Differences in cross-sectional shape between age groups at each cross-sectional position were assessed using nonparametric Mann-Whitney U tests. Results demonstrate that the proximal and distal femoral diaphysis and the proximal tibial diaphysis may be more sensitive to developmental mechanical load shifts than midshaft of either bone. Developmental cortical surface differentiation is also age and location specific. These findings indicate a significant limitation in current geometric scaling procedures. Future research should combine age- and site- specific morphometrics with experimentally-derived subadult injury threshold data.