Micro-CT in forensic anthropology: Implications for estimating age-at-death in infants, recent and ancient.

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Aims

Forensic scientists and anthropologists have employed computed tomography since the late 1970s [1], but the application of high resolution micro-computed tomography has only emerged in recent years [2, 3]. The number of medico-legal investigations employing this technology as a means of avoiding invasive autopsy or capturing otherwise inaccessible evidence is still relatively low. One key area for methodological development is pediatric forensic identification, and in particular the refinement of methods of estimating age at death and identifying evidence of physical trauma. Infants have a greater risk of becoming the victim of homicide than any other age group, with official estimates of the incidence of infant homicide in Britain being approximately 45 per year [4, 5]. Estimating the age at death of fetal and neonate remains is a central issue for cases in which cause of death, or fetal rights verses maternal rights, are at stake. While there is no uniform gestational age that defines viability, establishing the age at death of a fetus is essential. Efforts to achieve this may be made even more complex where the remains are disarticulated or damaged. The primary goal of this study is therefore to describe the growth of the human prenatal and neonatal bone cross sectional geometry and development of limbs and spine using micro-CT, and further examine whether the growth and development of fetal and infant skeleton is bone (i.e. femur vs humerus), region (i.e. proximo-distal vs midshaft) or sex specific. These findings are then applied to two case studies, one forensic and one evolutionary.

Method

Overall summary: A museum collection of human (*n*=43) and Neanderthal (*n*=6) fetal and infant specimens, and one forensic specimen, ranging from 4 months to 2.5 years was included in the study, and analysed using 3D micro-CT based measures of cross sectional geometry and biomechanical properties. Diaphyseal cross sections were collected at the proximal, mid and distal aspects of the femur and humerus. The morphology of bone was visualised using scans derived from three different micro-CT systems to take account of ethical constraints on specimen relocation (including Bruker Skyscan 1172, 1272, and ACTIS BIR 420 ⁄ 600). The reconstruction was performed on NReconServer v.1.6.9.4 (Bruker SkyScan, Belgium) with GPU acceleration, employing back projection algorithm. Digital diaphyseal cross sections from homologous bone regions were collected, thresholded, segmented and measured using CTAn. Cortical geometry and biomechanical properties (i.e. features that are indicative of biomechanical performance) were measured in three cross sections at 80% (proximal), 50% (mid) and 20% (distal) of the way along the diaphysis. The binary segments were used to collect measurements of cortical geometry and biomechanical properties. Spherical volumes of interest from the vertebrae (Fig 1) were then defined, thresholded and measured using 3D bone analysis software; *BoneJ*, a plugin for *ImageJ* (National Institutes of Health, USA; http://rsb.info.nih.gov/ij/index.html) and *Quant3D* (University of Texas at Austin*;* http://www.ctlab.geo.utexas.edu). Architectural measures were collected including trabecular: bone volume fraction (BV/TV); thickness (Tb.Th, mm) and degree of anisotropy (DA). One way ANOVA with Tukey's post-hoc was used for statistical analysis to compare development of vertebral trabecular architecture across the modern human individuals.

Results

With advancing age femoral sections exhibited proportionately stronger and stiffer cross-sections in relation to the humerus. In both the femur and humerus the cross-sectional geometric properties of the proximo-distal aspects became proportionately larger in relation to the midshaft, with advancing age. There was no evidence of sexual dimorphism in cortical geometry. Overall gestational patterns of variation in cortical morphology appear to be bone and region but not sex specific. The age at death of the forensic specimen could therefore be estimated, but not the sex. Proportional variation in cortical geometry across the femur and humerus, and between the proximo-distal sections and midshaft, can either be explained as mechanical adaptation to loads or developmental preprogramming. However, patterns of sexual dimorphism, or rather the lack thereof, appear to oppose presumed patterns of mechanical loading and, therefore can only be explained as preprogrammed growth. Taken together these finding suggest that the development of fetal cortical geometry is genetically determined as opposed to an adaptive response to loading. In the spine, modern human prenatal trabecular bone was characterised by high volume fraction and a tightly packed relatively anisotropic structure, from which the neonate modelled an organised (anisotropic) configuration by removing 2/3^{rds} of the bone volume (Fig. 3). An infant/adult vertebral trabecular arrangement, which is characterised by elements strongly orientated along the infero-superior axis in both modern humans and Neanderthals, appears before 1 year. The overall pattern is one of initial overproduction (fetal) followed by constructive regression (neonatal) and subsequent refinement (infant). This pattern may be a functional response to the up regulated calcium mineral release immediately after birth, followed by adaptation to bipedal mechanical loading in the first year or so of life. Although numbers of specimens in this study are small, the microarchitecture of the Neanderthal specimens appears to present a pattern of change very similar to that of modern humans, except for a more gradual decrease in BV/TV in the early months of life.

Figure 1: Development of modern human cancellous architecture (youngest to the left). After birth trabeculae become preferentially aligned along the intero-superior axis. Each sphere represents a volume of interest from L1.

References:

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