Geometrical properties of the pediatric cervical spine with a focus on C1 vertebra from birth to 18 years: applications to age-specific human body computational models

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I. INTRODUCTION

Child dummies and injury criteria have been based on the overall scaling from adult and/or between children of different ages. Cartilage-to-bone ossification, spinal canal and joint developments at various vertebral levels, and strength attainments are nonlinear. To accurately model the growing spine, it is important to account for nonlinear geometric growth. Although clinical studies have described growth patterns, quantifications are lacking. This study quantified longitudinal growths of various regions of the first cervical vertebrae, responsible for transmitting the axial load from the base -of-the-skull through the condyles to the neck/torso.

II. METHODS

Pediatric cervical spine radiographs and high-resolution CT scans were retrospectively obtained following IRB approval. Excluded patients were: evidence of congenital/developmental disease, neoplastic growth, adverse neurological conditions, vertebral and muscular abnormalities, fracture/dislocation, epiphyseal injury, spine surgery, and scoliosis. Sequential axial and sagittal images were used to determine the 3-D geometry of entire C1 vertebra. Axial images were used to determine bilateral neuro-central synchondroses widths; width of posterior synchondrosis; area of anterior ossification nucleus; outer and inner antero-posterior and transverse diameters; and spinal canal inner area. Heights of anterior and posterior arches were obtained from sagittal images. Intra-observer and inter-observer repeatability were assessed from repeated measurements from different patients. All geometrical measurements were expressed using mathematical functions across the entire age spectrum. Specific parameters are extracted considering the one-, three-, six-, and ten-year-old as dummy classifications groups.

III. INITIAL FINDINGS

Of the 54 subjects, 39 were boys and 15 were girls. Ages ranged from one-day to 211 months. Coefficients of repeatability for intra- and inter-observer analyses: 4 to 6%. Intra-observer repeatability: 2% less than inter-observer repeatability across all measurements. Logarithmic expressions as a function of age best described: outer and inner antero-posterior and outer transverse diameters, canal area, and anterior and posterior ring heights. Inner transverse diameter was age independent. Details of equations will be presented. The ratio of outer antero-posterior to transverse diameters was 20 and 50% greater in the middle and oldest groups compared to youngest groups. The outer and inner antero-posterior and outer transverse diameters were different (p<0.05) between the two youngest groups; maturity attained for the oldest group. The spinal canal area was significantly smaller (p<0.05) in youngest group. Using 18-years as full maturity and present results, 90% of adult values reached at ten-years for ring heights, -three years for the outer and inner antero-posterior and outer transverse diameters.

IV. DISCUSSION

CT is best suited to extract skeletal geometry as x-rays only provide integrated images and MRIs are more suited for soft tissues. However, it is difficult to obtain pediatric geometry especially at younger ages as normal "volunteer" IRB-studies are hard to justify from ethical perspectives and because of radiation exposures. CT scans are uncommon for routine clinical examinations for this population. While the sample size is small, this is a unique normative dataset from which many load-bearing pertinent anatomies for human body modeling are quantified. The Inclusion of age-specific 'plateau' effects in the maturation processes occurring in different load-bearing regions of the cervical spine (quantified in specific geometrical measures) will enhance accuracy of computational models, allowing improved predictions of injuries in different age groups. This is the first CT study to extract 3-D geometry of age-specific pediatric populations with very controlled inter- and intra-subject variability. These quantified results which will be published in a future full-length paper will lead to more accurate 3-D geometrical definitions of all pediatric cervical spines of all ages & assist computational modelers.

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