DEVELOPMENTAL BIOMECHANICS OF THE CERVICAL SPINE: COMPRESSION AND TENSION

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Introduction

Epidemiological data and clinical indicia reveal devastating consequences associated with pediatric neck injuries. Unfortunately, few experimental data exist characterizing cervical spine developmental biomechanics. This paucity of basic age-related properties of the neck make it impossible to fully understand the mechanical function of the developing cervical spine and subsequently develop models to expose injury prevention and management schemes to eliminate the catastrophic effects of pediatric neck injuries.

The cadaveric baboon *(Papio anubis)* cervical spine, an anatomic and kinematic analog to the human cadaveric cervical spine, serves as our model to investigate maturing tissue mechanics across the developmental spectrum. Compression, and tension inputs were provided to functional spinal units of the cervical spine to evaluate their mechanics (constituent properties) and injury-tolerance levels (failure loads) throughout development. These data fill a dearth in the literature concerning the biomechanical function of the cervical spine and will eventually lead to the refining of injury prevention schemes.

Background

Examination of the developmental morphology of the human cervical spine reveals a highly dynamic and interdependent system within which the tissue morphology and mechanics are coupled.[1,4] The spine develops from a cartilaginous state in utero to an osteoligamentous fully formed spine in adulthood. This development confers rapidly changing and diverse mechanical properties to the spine giving it unique functional responses throughout maturation.[3] The paucity of data pertaining to this basic functional biomechanics of the developing neck has been manifest in numerous spinal injuries to the pediatric populace with catastrophic outcomes. Prevention of these injuries has been attempted using unvalidated models with neck injury thresholds established in the absence of experimental data. The lack of understanding of the progression of these injuries and the tissues at risk precludes the development of clinical management or injury prevention procedures.

Methods

Sixteen, fresh cadaveric baboon cervical spines were obtained through the Washington Regional Primate Research Center. All of the specimens were male and had human equivalent ages ranging from 2.5 to 18-years based upon radiographic assessment using a skeletal maturity method.[2]

Specimen Preparation. Each specimen was dissected free of all musculature leaving intact the full osteoligamentous cervical spine and inspected for previous injury or spinal pathology prior to testing. The specimens were then further dissected into functional spinal units: Occiput-C2, C3-4, C5-6, C7-T1. Computed Tomography scans of each specimen enabled the assessment of skeletal maturity. In preparation for testing, each vertebra was wired and then fixed in poly-methylmethacrylate.

Experimental Procedure. The compressive and tensile inputs were provided by a MTS (Model 858 Bionix, MTS Corp., Eden Prairie, MN) servohydraulic testing system at 0.5-mm/sec. Each specimen was preconditioned 5 cycles to 40% body weight and then held at that load for 3-minutes to examine the creep response for another study. This was repeated for compression loading. Following this non-destructive testing, the specimen was pulled to failure in tension at 0.5-mm/sec. The six-axis load cell mounted inferiorly measured the force/moment response from the input and the displacements were recorded using an LVDT linearly and video analysis for angular displacements. This data was collected at 200-Hz using LabVIEW (National Instruments, Austin, TX) data acquisition software.

Data Analysis. Both the ultimate (failure) load and stiffness were determined directly from the measured load-displacement data. The ultimate load was established as the maximum load on the load-displacement curve and the stiffness was computed as the slope of the linear portion of that relationship. A regression analysis was performed to determine correlation between these properties and human–equivalent age. Finally, an ANOVA was performed to establish significance of the above correlations and post-hoc (Tukey) tests were used to examine differences between spinal levels.

Results

Evaluation of the functional mechanics of spinal units in tension and compression revealed significant changes in the tensile stiffness with age ($r=0.638$, $p<0.001$) and compressive stiffness with development ($r=0.651$, $p=0.003$). Further, the ultimate tensile load was significantly correlated with spinal maturation ($r=0.722$, $p=0.001$). An examination of the compressive and tensile stiffness of the developing functional spinal units revealed level-specific differences in the mechanics (Figs 1 and 2). A significant difference between the compressive stiffness of the Occiput-C2 level and each of the other levels exists ($p<0.028$). With regard to the tensile stiffness, the only significant differences were between the innermost (C3-4 and C5-6) and outermost (Oc-C2 and C7-T1) levels. The tensile ultimate failure load was found to be statistically different ($p<0.05$) between the Oc-C2 and the lower cervical levels.

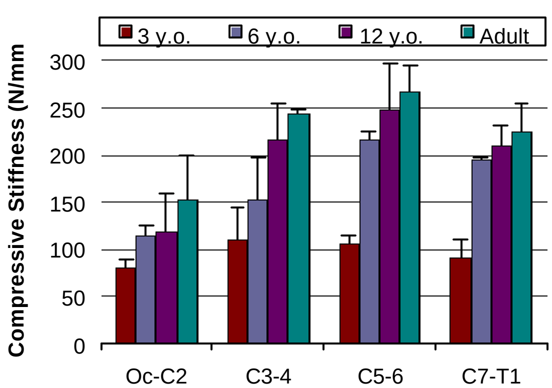

Figure 1. Developmental Compressive Stiffness by Spinal Level (grouped by age).

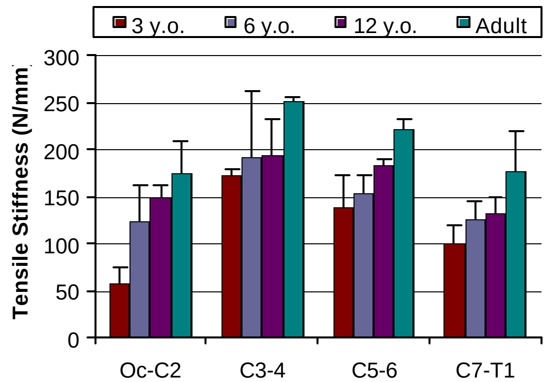

Figure 2. Developmental Tensile Stiffness by Spinal Level (grouped by age).

Discussion

The compressive and tensile mechanical properties of isolated spinal levels were measured and correlated with spinal development. These data clearly demonstrate age-related differences in the spinal biomechanics. Moreover, level-specific differences were exhibited indicating differing mechancial properties along the length of the cervical spine throughout development. The stiffness and ultimate failure data reveal a clear relationship between the adult and child cervical spine tissues. These data will provide modeling efforts the values necessary to scale adult safety systems to effectively protect children. Ultimately, this project aims to fully characterize the mechanics of the developing cervical spine in an effort to minimize pediatric neck injuries.

References

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