INTRODUCTION
Pediatric cervical spine injury diagnosis, treatment, and prevention require an integrated knowledge of spinal development anatomically and biomechanically. Anthropometric patterns of cervical spine maturation have been well documented in the literature [Fesmire, 1989]. Despite the fact that head and neck injuries are the leading cause of death for children in the U.S., there exists a dearth of data describing the biomechanical response of the human cervical spine throughout development [FARS, 2003].

A number of studies have examined spinal maturation biomechanics in post-mortem animal models, discovering spinal level, loading rate, and sex specificity with unique ontogenetic growth curves describing the material and structural properties of the maturing spine [Nuckley, 2006; Pintar 2000]. Ouyang et al.[2005] examined ten human head and neck complexes from 2-to-12 years of age and reported sagittal bending curves and tensile failure loads. This study did not evaluate the spectrum of maturation mechanics, but provided excellent data describing spinal mechanics in the young.

Therefore, this research effort aimed to define relationships between spinal maturation and the functional (prior to injury) and failure mechanics of the human cervical spine in multi-axis loading.

METHODS
A correlation study design was used to determine the relationships linking spinal tissue maturation and biomechanics. Eleven human cadaver cervical spines from across the developmental spectrum (2-to-28 years) were dissected into segments (C1-C2, C3-C5, and C6-C7), wired and embedded in PMMA for biomechanical testing (Figure 1). Utilizing a servohydraulic MTS and custom Spine Motion Simulator, non-destructive (functional) and failure experiments were performed. Non-destructive flexibility tests were performed in tension, compression, flexion, and extension. After measuring their intact biomechanical responses, each specimen was failed to measure the tissue tolerance in tension (C1-C2), compression (C3-C5), and extension (C6-C7).

RESULTS AND DISCUSSION
The non-destructive spinal mechanics exhibited maturation dependent increased stiffness (p<0.014) and decreased range of motion. Nonlinear flexibility curves described the functional properties of the cervical spine throughout maturation and
elucidated age, spinal level, and mode of loading specificity (Figures 2 & 3).

![Sagittal Bending Flexibility as a Function of Age](image1)

**Figure 2.** Sagittal Bending Flexibility as a Function of Age. Moment controlled inputs to C6-C7 segments elucidated these response curves as a function of maturation.

![Compression / Tension Flexibility as a Function of Age](image2)

**Figure 3.** Compression / Tension Flexibility as a Function of Age. Response of the C3-C5 spinal segment to displacement controlled axial loading.

Together these functional data describe the biomechanics of the maturing cervical spine in multiple axes of loading. The failure mechanics (load/moment) were also found to significantly increase with advancing age (Figure 4). Classical injury patterns were observed in all of the specimens tested.

![Scaling of Spinal Mechanics](image3)

**Figure 4.** Scaling of Spinal Mechanics. The functional mechanics from all tests are grouped, displaying the maturation function of spinal stiffness. Failure data are overlaid defining the tolerance in multiple axes.

### SUMMARY/CONCLUSIONS

The age dependent biomechanics of the human cervical spine are reported for functional and failure experiments. The adult data collected herein are consistent with the literature validating our maturation scaling curves. These data support previous animal studies and together facilitate the generation of injury prevention or treatment schema to mitigate child spine injuries.

### REFERENCES


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