Introduction

A 1994 epidemiology study of the National Pedicatric Trauma Registry (NPT) determined that injuries to the thorax pose a risk of fatality that is second only to head injuries in children [1]. Motor vehicle accidents are the leading cause of mortality and injury due to head and thoracic trauma in children 1 year and older [1, 2]. In an effort to protect child occupants, passenger restraint systems originally designed for adults have been adapted to protect children. Being that the clavicle and thorax are the only bony structures of the upper body to interact with seatbelts in frontal crash scenarios (as demonstrated in Figure 1), the response of the thorax in minor vehicle accidents helps dictate the position and kinematics of the spine, neck, and head. The effectiveness of these child restraint systems in preventing injury is evaluated using anthropomorphic test devices (ATDs) representative of children’s stature and mass.

However, the design of the biofidelic response of the child ATD is based largely on scaled down adult post mortem human subject (PMHS) data and testing with animal surrogates. The lack of mineralization of pediatric bones results in material properties that are weaker, more compliant, and less than those seen in skeletal mature adult bones. Figure 2 illustrates the difference in geometry of the adult and pediatric thorax, in which the pediatric ribs are more horizontal, the sternum is more superior, and the overall shape is more narrow and less flat [2].

Objectives

- Design a procedure utilizing nonparametric system identification techniques to characterize the response of the adult and pediatric thorax to compressive loading in a non-injurious manner that is relevant to improving safety in motor vehicle accidents.
- Design and build a test device capable of loading the anterior of the thorax with small repeated perturbations in accordance with nonparametric system identification techniques that have been previously utilized to characterize nonlinear biological systems [3, 4, 5]. The fixture should be robust enough for adult thorax and versatile enough for pediatric thoraces.
- Test Device

The test device is comprised of a 3 horsepower high inertia vector motor ZDM3764T (Baldor Electric Company), VSG120Vac single phase input drive (Baldor Electric Company), a 5.76:1 ratio parallel shaft speed reducer FT77GM213 (SEW Eurodrive Inc.), a high inertia shelve SC500 used as a flywheel (Browning), a custom cam, custom pushed with loading carriage, and an adjustable seat fixture. A maximum perturbation velocity of 2.5 m/s was chosen based on the compression velocity of the Hybrid III 50th percentile adult (PMHS) male ATD in a New Car Assessment Program (NCAP) 48 km/h test. The energy storing flywheel allows the device the capability of applying a sequence of the 10 mm compression perturbations to the thorax for 10 seconds. Thoracic response forces are collected at the posterior of the thorax via a load cell attached to the seatback. A single-pivot wide plate was chosen as the loading plate because it helps to eliminate the confounding variables seen with belt loading, such as thoracic squeeze and the belt’s tendency to move superiorly during testing. The plate will not load the clavicle as a belt would. Relative size loading is also possible with different size plates. The plate will load from the manubrium superiorly to the xiphoid process inferiorly.

Discussion

Two Hybrid III trials and an adult PMHS trial have been completed to-date. Figure 8 shows the displacement time history for two of the Hybrid III tests. It should be noted that the original cam used in these tests produced a 12.5 mm perturbation magnitude. While the results from the first three trials were not ideal, they are promising. The input displacement perturbations exhibited an overshoot effect beyond the 12.5 mm perturbation magnitude in the high rate tests due to the large inertia of the moving parts, as seen in the red line in Figure 8. Improvements to the device are currently being implemented to eliminate this condition.

Once completed, an additional Hybrid III trial will be performed followed by another PMHS trial. Upon successful completion of these two trials the adult PMHS pilot study will commence, followed by the pediatric PMHS study. In this study a new procedure for characterizing the biofidelic response of the pediatric thorax is being developed. Utilization of nonparametric system identification techniques is a novel approach for this task and development is proving well.

H(s) = \frac{1}{ms^2 + bx + k}

Figure 6: Compliance Model.

![Figure 1: 10YO Child ATD Proper Restraint Frontal Loading, NHTSA.](image1)

![Figure 2: Comparison of Neonate and Adult Human Skeleton, Franklinly 2007.](image2)

![Figure 3: Convolution Integral Equation.](image3)

![Table 1: Pediatric Test Matrix.](image4)

![Figure 4: Example of Input and Output Sequence (Moorhouse 2005).](image5)

![Figure 5: Example of Resulting Perturbed IRF (Moorhouse 2005).](image6)

![Figure 7: Thorax Test Apparatus.](image7)

![Figure 8: Hybrid III Displacement Time History: 1.5 m/s, 15% Initial Chest Compression-Blue, 2.9 m/s, 5% Initial Chest Compression-Red.](image8)