SHORT COMMUNICATION
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Novel use of a Halo Orthosis on Pediatric Anthropomorphic Test Devices (ATDs) in Frontal Sled Tests

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ABSTRACT – Children recovering from cervical spine injuries may need a halo orthosis, which rarely fits into traditional child restraint systems (CRS) during motor vehicle travel. The objectives are to affix a halo orthosis to a 3-year-old anthropomorphic test device (ATD) and to explore the effectiveness of alternative safety restraints for these occupants. The head of the ATD was modified to allow proper insertion of halo pins. The ATD was restrained in either a backless booster or a RideSafer Travel Vest (RSTV) with and without the halo orthosis. The shoulder belt routing over the halo bars caused axial rotation of the occupant during frontal impacts, which increased lateral and torsional neck loads compared to tests without the halo. The halo decreased frontal neck shear and bending compared to tests without the halo. Loose fit between the halo vest and the torso of the ATD likely contributed to a concentration of loads in the cervical spine.

INTRODUCTION

Cervical spine injuries in young children may require the use of a halo orthosis during the long recovery period (Arkader et al. 2007). The purpose of the halo orthosis is to inhibit movement of the head and cervical spine to allow for bone healing and fusion to occur. Children who are discharged home in halo orthoses face challenges fitting into traditional motor vehicle child restraint systems (CRS, or child safety seats). The bars of the halo prevent a traditional five-point harness from routing over the shoulders. The bulk of the halo and accompanying vest interfere with the small seating area and large side wings of traditional CRS. Backless boosters and travel safety vests provide a potential solution, as these safety devices are more accommodating of the halo hardware. To the authors' knowledge, the crash performance of these devices for children in halos has not been studied.

Collection of relevant crash data is complicated by the difficulties of securing a halo orthosis onto an anthropomorphic test device (ATD). The pins of the halo must be seated 1-2 mm into the skull of the patient to achieve proper stability. ATD heads are constructed of a thick vinyl "skin" which covers a polyester casting resin "skull" (NHTSA, 2001). Neither of these materials are ideal for pin insertion due to their flexibility (vinyl) and brittleness (polyester casting resin). This study explored a novel methodology of affixing samples of human skull bone onto the polyester casting resin skull of the ATD, such that the halo orthosis pins could be properly seated into the human bone.

The goals of the study are to test the feasibility of this novel method of affixing a halo orthosis to a pediatric ATD and to analyze pilot data on the effectiveness of a backless booster and a travel safety vest for pediatric patients in halo orthoses involved in frontal motor vehicle crashes.

METHODS

A 3-year-old Hybrid III ATD was instrumented with standard head and T4 chest accelerometers (Endevco/Meggitt Sensing Systems, Irvine, CA), and a six-axis upper neck load cell (Denton, now Humanetics Innovative Solutions, Plymouth, MI). A fresh (i.e, non-fixed) adult human cranium was obtained from The Ohio State University Body Donation Program. Portions of the frontal and parietal bones were dehydrated and degreased. The specimen was cut into sections measuring approximately 3 cm by 3 cm. The bone sections were glued to the ATD

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skull on top of a layer of gaffer tape. Twelve layers of gaffer tape were then wrapped overtop of the skull to represent a "scalp" interface for the pins.

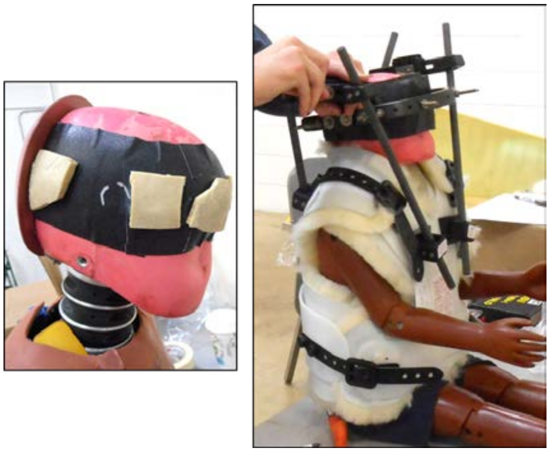

Figure 1: Halo application methodology

A neurosurgeon applied the halo orthosis (PMT Halo System, size small, PMT Corporation, Chanhassen, MN) to the ATD in the standard fashion. Ten pins were screwed through the simulated scalp and seated in the underlying bone using 4 in-lbs of torque.

Frontal impacts were conducted on the Federal Motor Vehicles Safety Standards (FMVSS) 213 test bench, using the 30 mph pulse identified in the test procedures (Configuration I Acceleration Function; NHTSA, 2014). Four conditions were tested: backless booster with and without halo, and RideSafer® Travel Vest (RSTV, including top tether) with and without halo (Youth Booster Car Seat, Harmony Juvenile Products, Saint-Laurent, Quebec, Canada. RideSafer® Delight RSTV, Size Large, Safe Traffic System, Inc., Franklin Park, IL).

Figure 2: ATD with halo seated in backless booster (left) and RSTV (right)

RESULTS

Resultant chest and head accelerations are shown in Figure 3. The booster trial without the halo showed evidence of chin-to-chest contact, which may have inflated head accelerations for that trial. Accelerations are below the Injury Assessment Reference Values (IARV) for a 3-year-old: 92 g for chest and 175 g for head (Mertz et al. 2016).

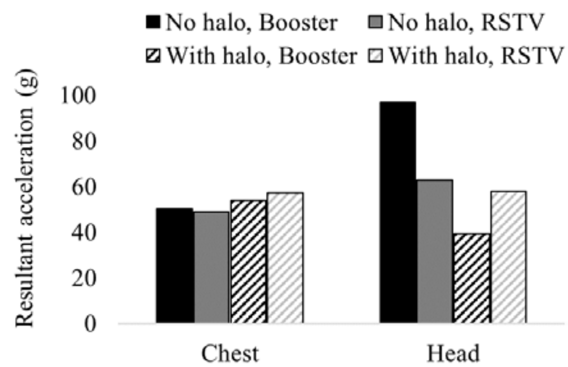

Figure 3: Resultant accelerations

Neck forces are shown in Figure 4. Compared to trials without the halo, the halo orthosis reduced frontal shear forces but increased lateral shear forces and axial tension in both the booster and RSTV. IARVs are 1070 N for frontal and lateral shear and 1430 N for axial tension (Mertz et al. 2016).

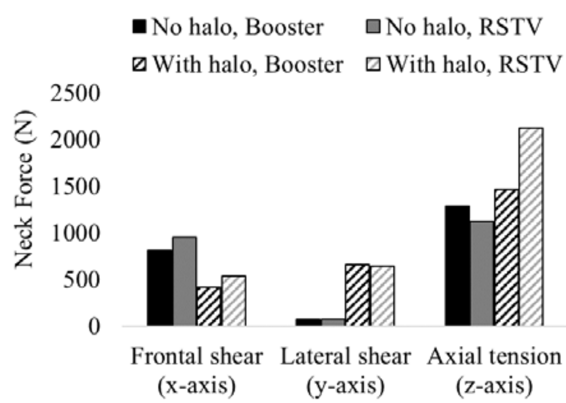

Figure 4: Neck forces

The booster and RSTV performed similarly to one another in terms of neck moments (Figure 5). Compared to trials without the halo, the halo orthosis reduced neck flexion moment but increased lateral bending and torsion moments in both the booster and RSTV. IARVs are 32 Nm for lateral bending, 42 Nm for flexion, and 21 Nm for torsion (Mertz et al. 2016).

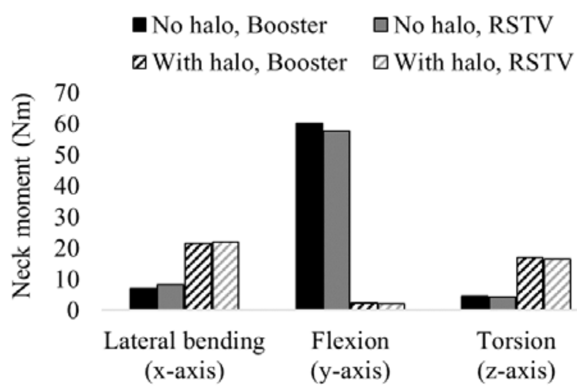

Figure 5: Neck moments

No damage was visible on the halo hardware or the pin/skull attachment points throughout testing. Post-test inspections found the halo orthosis was still snug to the touch on to the ATD's skull, although a torque wrench found that the pins loosened from roughly 4 in-lbs to 2 in-lbs of torque after each trial.

DISCUSSION

The halo orthosis withstood the frontal crash forces without mechanical failure. The results are a testament to the durability of the device, which, to the authors' knowledge, has never been documented under such extreme conditions. The pins stayed engaged with the skull and the orthosis was snug to the touch during post-test examinations. The novel application method may be useful to future studies which require the application of a halo to non-human testing tools.

Compared to trials without the orthosis, the halo decreased the forward flexion of the neck but increased the lateral shear, lateral bending, and torsion moments. Large z-axis head rotation was caused by routing the shoulder belt over the vertical halo bar on the ATD's right side (Figure 2). The bar held the shoulder belt approximately 3 inches forward of the torso. During the crash event, the belt tensioned around the bar and created a fulcrum in front of the ATD's right side, about which the torso rotated.

The bottom of the halo vest prevented proper positioning of the lap belt against the ATD's pelvis. When the backless booster was used, crash forces pulled the lap belt into the space between the bottom of the halo vest and the tops of the thighs. When the RSTV was used, the lap belt remained on top of the halo vest throughout the crash event. The head and upper torso were restrained by the halo and the top tether, but the pelvis continued to travel forward while compressing the soft interior of the halo vest. These kinematics result in a high neck tension load (2128 N) as the head was held back but the pelvis travelled forward.

The fit of the halo vest likely played a role in the neck loads during the crash event. The interior of the halo vest is lined with soft sheepskin. This lining provides a comfortable interface for a patient who might wear a halo for several months without removal. However, the compliant interior of the halo vest allowed for relative movement between the torso and the exterior shell of the halo vest during the crash event. Any movement of the torso within the halo vest manifests as loading in the neck, because the head is fixed to the halo ring and cannot move with the torso.

This pilot study includes several limitations. The same halo was tested twice, which introduced the possibility of weakened structures on the device after the first trial. The human skull pieces were from adult donors, not pediatric donors, and had been dried and preserved. The mass of the ATD head assembly was 0.61 kg less than regulatory standards due to the removal of the vinyl head skin and addition of the bone pieces and gaffer tape. The biofidelity of the Hybrid III 3-year-old neck has not been well validated.

ACKNOWLEDGMENTS

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