CHILD INJURY TOLERANCE THROUGH CASE RECONSTRUCTION

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ABSTRACT

A basis for verification of child dummy injury criteria performance limits, ICPLs, is needed. Presently, the ICPLs used for child dummies are derived from the Hybrid III adult dummies using scale factors for size and strength considerations. This study presents the preliminary results of an ongoing effort to verify the ICPLs through reconstructions of real world incidents which have resulted in child injuries.

Incident cases which have the potential for reconstruction were identified utilizing various sources. Tests were then conducted utilizing available case information in order to best approximate the pre-injury positioning of the injured child. A comparison of injury measurements collected from a child crash test dummy could then be made to real-life injuries as a method of ascertaining validity of current child dummy injury criteria.

Test results are presented for three case studies. This paper summarizes the results.

INTRODUCTION

Incident cases which had the potential for reconstruction were identified utilizing various sources. Case selection criteria were applied to determine which cases were viable for reconstruction. Cases were evaluated against the following criteria:

1. Age and anthropometry of the victim. Cases were sought in which the injured child's size and mass approximated that of one of three available crash test dummies - the CRABI 12-month-old, the Hybrid III 3-year-old, or the Hybrid III 6-year-old.
2. Type of injury. The focus of this research was primarily on head and neck injuries, with chest injuries being of secondary importance.
3. Ability to reproduce the injury mode. Cases involving complex occupant kinematics were not considered.

CASE RECONSTRUCTIONS

Overview

Based on the selection criteria, three cases (1) were chosen for reconstruction (Table 1). Though not ideal, all the cases selected to date resulted in child fatalities; optimally, a range of injury levels would allow for greater discernment among injury criteria performance limits. Two cases involved 5 month-old infants and the third case included a 7 year-old child.

Table 1.
Summary of Cases Selected for Reconstruction

Case	**1000**	**1200**	**1100**
Age	5 month	5 month	7 year
Height (cm)	66	66	127
Weight (kg)	9	9	41
Restraint	rear-face child seat	rear-face child seat	None
Injuries	skull fracture/ brain injury	skull fracture/ brain injury	transect cervical spinal cord

The injury criteria specified in Federal Motor Vehicle Standard No. 208 for the head and neck, namely HIC (15 msec), Nij, neck tension, and neck compression, were examined in this study. Since the dynamic component of the crash was not believed to be a significant factor in the type or severity of the head and neck injuries, static air bag tests were used for the reconstructions.

Reconstruction Case #1000

Case Summary Case #1000 (Table 2) involved a child fatality in a rear-facing child seat. A 5-month-old infant (66 cm, 9 kg) was seated in a Century S.T.E Car Seat 2000 utilizing a T-shield configuration located in the right front passenger seat. The child seat was positioned rear-facing. The seat was not installed properly since the harness straps of the child seat were routed through the top slots rather than the lower slots intended for rear-facing positioning. In addition, the lap and shoulder belts of the vehicle seat belt system were routed improperly through the child seat in the position intended for front-facing occupants. The right front seat was forward of the mid-track position situating the child seat near the air bag module cover.

Table 2.
Reconstruction Case #1000 Summary

Age	5 month-old
Sex	Male
Height	66 cm (26")
Weight	9 kg (19.8 lb)
Vehicle Restraint	3 point-belt incorrectly routed through child seat
Child Seat	Century S.T.E. Car Seat 200 with T-shield installed rear-facing in passenger seat - incorrect belt routing and no locking clip
Child's Major Injuries	Crushed skull (rear) with brain lacerations

Table 3.
Summary of Injuries for Reconstruction Case #1000

Summary of Child's Injuries - case #1000	
Fatal?	Yes
Head	Crushed skull with brain lacerations; primarily fractures on rear of skull
Neck	None
Thorax	None
Spine	None

The front of the occupant's vehicle impacted the side of a second vehicle, initiating air bag deployment. The module and deploying air bag struck the back of the Century child seat and broke off a 15 cm segment of the left rear vertical ribbed portion of the child seatback. The rearward force of the deploying air bag and module propelled the child restraint seatback into the back of the child's head resulting in fatal severe head injuries including a crushed skull with brain lacerations.

Injuries The fatal injuries (Table 3) to the 5-month-old infant consisted of blunt impact injuries of the head resulting from the direct contact between the child's head and the back of the child seat as a consequence of air bag deployment. The skull fractures were numerous, with most on the posterior side of the child's head. Brain lacerations were also evident. No neck or chest injuries were observed.

Reconstruction Tests This case was reconstructed using static air bag deployment tests in a vehicle of the same make and model as the actual crash and a Century S.T.E. Car Seat 2000. Although the child was a 5-month-old, she was similar in weight and size (9 kg, 66 cm) to a CRABI 12-month-old dummy (10 kg, 74 cm), which was utilized in the reconstruction of the case.

Test Setup Three passenger side static air bag deployments were conducted in a representative vehicle of the same make and model as the actual crash. The CRABI 12-month-old infant was positioned in a rear facing Century S.T.E. Car Seat 2000. The right front seat was forward of the mid-track position situating the child seat near the air bag module cover (Figure 1).

As in the actual case scenario, the child seat was set up incorrectly with the harness improperly routed through the top slots. The vehicle seat belts were also routed incorrectly with the lap and shoulder belts inserted through the holes intended for the forward facing configuration (Figure 1).

Figure 1. **Set up for Reconstruction Test #1000.**

Results and Conclusions Results from the three reconstruction tests relative to the injury criteria performance limits are presented in Table 4. The first static air bag deployment was not representative of the real-world case for several reasons. First, high speed film analysis revealed that the air bag deployed up and over the top of the child seat and then downward on the dummy's head. Consequently, the HIC was lower than expected. At 346, the HIC was below the injury threshold of 390. Since the injuries suffered by the child were injuries to the back of the head due to contact with the child seat, HIC would likely be significantly greater than the 390 criteria.

Table 4.
Injury Values for Reconstruction Series #1000

Inj Criteria	Performance Limit	Test 1	Test 2	Test 3
HIC (15)	**390**	346	1817	2492
Nij	**1.0**	1.41	0.93	0.65
Peak Tension (N)	**780**	44	451	573
Peak Compr. (N)	**960**	1412	417	313
(Note: Table values are peaks occurring during air bag interaction interval which physical evidence suggests as the primary injury mechanism.)				

Further evidence of the air bag pushing the head downwards can be seen in the high value for neck compression, 1412 N (Table 4, Figure 2). Additional analysis of the data in the first test indicated head Z acceleration (Figure 3) was higher than anticipated (all processed data follows SAE- J211 sign convention).

In addition, the neck injury criteria, Nij, was also elevated in Test 1. Since the child occupant in the actual case suffered no evident neck injuries, it was apparent that the air bag was causing neck compression that was not likely present in the actual crash scenario.

Therefore, for the second test, the child seat back was placed at a more upright angle than in the previous test. This would allow the air bag cover and the air bag itself to more fully contact the back of the child seat, rather than ride over the top. As a result of these changes in the initial test setup, high speed film demonstrated an air bag interaction that was more consistent with the case being simulated. Results of this test revealed that neck compression was no longer elevated (Table 4, Figure 2), and HIC increased to over 1800. The final test in the series (Test 3) was repeated with the same configuration and also exhibited a HIC value well above the 390 performance limit. Nij values also decreased below the injury criteria limit of 1.0.

Reconstruction Case #1200

Case Summary Case #1200 (Table 5) involved a child fatality in a rear-facing child seat. A 5-month-old infant (66 cm tall, 9 kg weight) was positioned in a rear facing Fisher Price Model 9100 child seat in the right front passenger position of a vehicle. A frontal impact initiated deployment of the air bags in the vehicle.

Table 5.
Reconstruction Case #1200 Summary

Age	5 month-old
Sex	Female
Height	66 cm (26")
Weight	9 kg (19.8 lb)
Restraint	3-point belt
Child Seat	Fisher Price Model 9100 - rear facing
Child's Major Injuries	Blunt impact injuries to rear of head

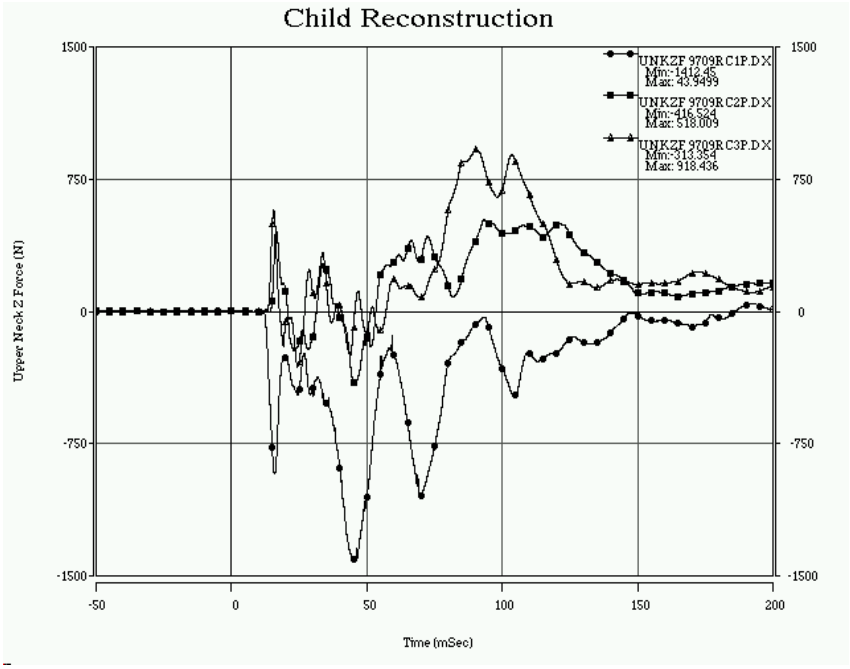

Figure 2. Reconstruction #1000 upper neck Z force.

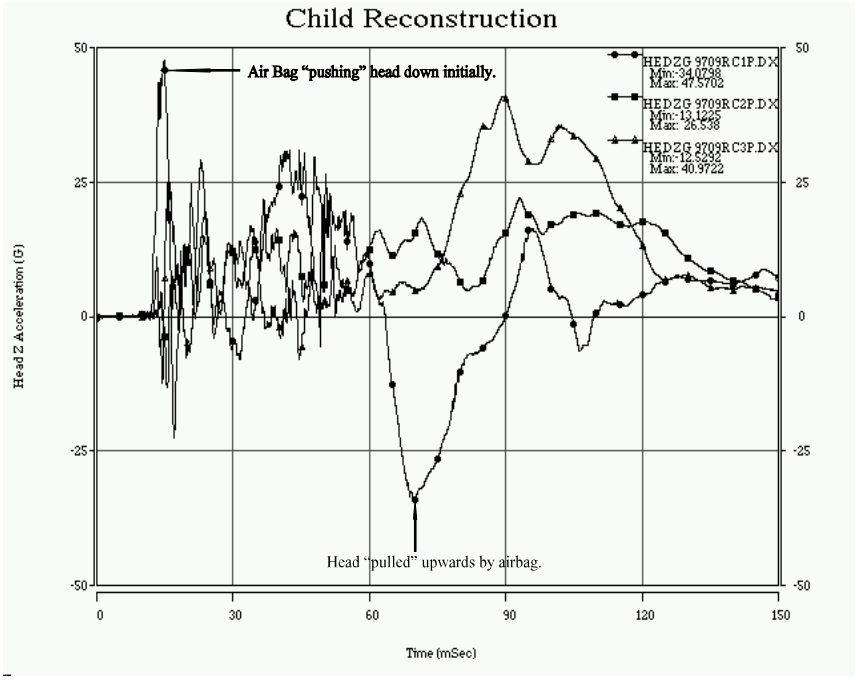

Figure 3. **Reconstruction #1000 head Z acceleration.**

Upon impact, the right front passenger mid-mounted air bag deployed, striking the rear of the child safety seat. There was no evidence of contact between the child safety seat and the air bag module cover. However, the force did crack the right rear side of the child seat vertically for 11 cm at the upper right rear corner of the seat. A second horizontal crack in the middle of the right rear side measured 19.5 cm. The force of the air bag propelled the child safety seat rearward and into the right front vehicle seat back. The child suffered fatal blunt impact head injuries as a result.

Injuries The fatal injuries (Table 6) to the 5-month-old infant consisted of blunt impact injuries of the head as a result of direct contact between the child's head and the back of the child seat as a consequence of air bag deployment. The injuries were greater on the posterior right side of the infant's head compared to the left side. A bruise was noted behind the right ear. The child's head appeared deformed from a scalp hemorrhage/edema and the right eye was swollen shut. There was a horizontal contusion 2" x ½" extending to the right side of the posterior midline, along with multiple fractures extending to the right side of the posterior midline of the head. The fractures on the right continued anteriorly to approximately the frontal bone where a vertically oriented fracture extended to the petrous temporal ridge with diagonal fractures extending anteriorly to the superior and inferior orbit. Anterior contusions were noted in the thymus, at the upper lobes bilaterally, as well as the right lower lobe.

Small contusions were noted at the base of the skull near the upper neck area. However, no significant neck injuries were identified.

Table 6.
Summary of Child's Injuries for Reconstruction Case #1200

Summary of Child's Injuries	
Fatal?	Yes
Head	Blunt impact injuries of head; greater on right than on left; bruise behind right ear; deformed head from scalp hemorrhage/edema; right eye swollen shut
Neck	Not significant
Thorax	Anterior contusions in thymus upper lobes bilaterally and right lower lobe
Spine	None

Reconstruction Tests This case was reconstructed using static air bag deployment tests in a representative vehicle and a Fisher Price Model 9100 child safety seat in the right front passenger position. Although the child was a 5-month-old, she was close in weight and size (9 kg, 66 cm) to a CRABI 12-month-old (10 kg, 74 cm), which was used in the reconstruction of the case.

Test Setup Four passenger side static air bag deployments were conducted in a vehicle of the same make and model as the crash, with the CRABI 12-month-old infant in a rear facing Fisher Price Model 9100 Car Seat with a T-shield configuration (Figure 4). The right front seat was positioned 3.8 cm rearward of the seat track midpoint. This position was selected since investigative evidence from the actual crash showed no interaction of the air bag module cover with the back of the child seat.

Results and Conclusions High speed film analysis indicates that the child seat is propelled into the back of the dummy's head by the air bag. This mechanism is consistent with the injuries seen in the actual child injury case since the injuries suffered by the child were primarily located on the back of the head.

Figure 4. Setup for Reconstruction Test #1200.

Injury criteria results for reconstruction series #1200 are shown in Table 7. In all four tests, the HIC (15 msec) exceeded the performance limit of 390. Head resultant accelerations ranged between 126 and 163 G (Figure 5). High head accelerations occur early in the event during the interaction of the air bag with the back of the child seat.

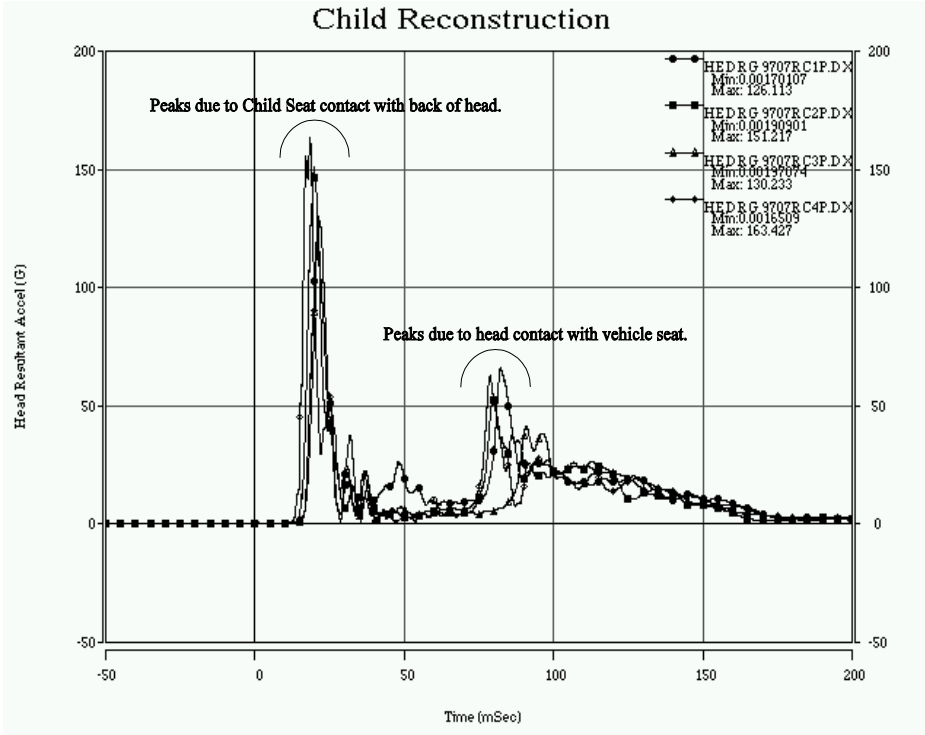

Figure 5. Resultant head accelerations from reconstruction series #1200.

Table 7.
Injury Values For Reconstruction Series #1200

Injury Crit	Performance Limit	Test 1	Test 2	Test 3	Test 4
HIC (15)	**390**	476	800	532	906
Nij	**1.0**	0.58	0.66	0.63	0.83
Peak Tens (N)	**780**	478	389	222	569
Peak Comp (N)	**960**	168	363	373	118
(Note: Table values are peaks occurring during air bag interaction interval which physical evidence suggests as the primary injury mechanism.)					

Neck injury values such as Nij were below the performance limit of 1.0 as expected since no significant neck injuries were present in this case.

Reconstruction Case #1100

Case Summary Case #1100 involved a 7 year-old female child (41 kg (90 lb), 127 cm (50")) who was fatally injured from an air bag deployment (Tables 8 and 9). The child was an unrestrained right side passenger in a vehicle in an intersection crash. Due to pre-impact braking of the case vehicle, the child initiated a forward trajectory, and as a result was in close proximity to the air bag when it deployed. The child's fatal neck injuries were attributed to involvement with the air bag flap and the air bag itself as evidenced by tissue transfer patterns on the flap and air bag fabric. The child suffered complete transection of the spinal cord as a result.

Injuries As a result of air bag membrane forces, the child suffered complete transection of the spinal cord at the level of the foramen magnum. Large tissue transfers were noted on the top panel and face of the right front air bag. A basilar skull fracture involving the left petrous and temporal bones was also attributed

to air bag membrane interaction. The module cover flap contacted the child's mandible resulting in a fracture of the left ramus of the mandible. Abrasions and contusions of the anterior neck were also noted. These extended vertically and laterally from ear-to-ear.

Table 8.
Reconstruction Case #1100 Summary

Age	7 year-old
Sex	Female
Height	127 cm (50")
Weight	41 kg (90 lb)
Restraint	Unrestrained
Child Seat	None
Child's Major Injuries	Atlanto-occipital dislocation resulting in complete spinal cord transection

Table 9.
Summary of Injuries for Reconstruction Case #1100

Summary of Child's Injuries - case #1100	
Fatal?	Yes
Head	basilar skull fracture; fractured left mandible; extensive abrasions of anterior chin (ear-to-ear); right occipital scalp contusion
Neck	atlanto-occipital dislocation (3 cm); complete transection of spinal cord at level of foramen magnum; extensive abrasions of anterior neck
Thorax	extensive abrasion of anterior chest to sternum level
Spine	complete transection of spinal cord at level of foramen magnum
Other	right metacarpal fracture and right hand abrasion

Reconstruction Tests This case was reconstructed using static air bag deployment tests in a representative vehicle. Although the child was a 7 year-old, she was larger (41 kg, 127 cm) than the Hybrid III 6-year-old dummy (23.4 kg, 114 cm). However, tests were still conducted using the Hybrid III 6-year-old dummy since this reconstruction involved a neck injury. Although the height and weight of the dummy was less than the actual occupant, the characteristics of the Hybrid III 6-year-old dummy neck should still be applicable to this occupant. In addition, the injury mechanism could be easily simulated statically, where height and weight are of lesser importance than in dynamic testing.

Three passenger side static air bag deployments were conducted in a vehicle of the same make and model as the crash, with the Hybrid III 6-year-old. The right front seat was positioned near the center of the track. The 6-year-old dummy was positioned leaning forward with chin resting on the air bag cover flap 1 3/4" above the flap tear seam (Figures 6 and 7). Tissue fragments from the case-child's chin were found at this location on the flap cover.

Figure 6. Setup for Hybrid III 6 year-old in reconstruction case #1100.

Figure 7. Setup for reconstruction #1100 showing head relative to air bag.

<u>Results and Conclusions</u> Film analysis and post test examination of the dummy revealed that the air bag deployed with the top flap contacting under the chin. The air bag then unfolded under the chin and along the anterior neck. The bag also wrapped around the chin along the jawline (Figure 8). Injuries sustained by the occupant, including a broken jaw and scrapes along the chin and neck are consistent with chalk displacement and abrasions on the Hybrid III 6 year-old dummy.

The neck load cell responses showed that the neck was forced into an extension-tension mode with peak loads well above 4000 N (Table 10)at the upper neck (Figure 9). The magnitude of these loads is consistent with the neck injuries received by the 7 year-old victim in this case who suffered transection of the spinal cord in the neck.

When evaluating the potential for neck injury in this reconstruction series, the Nij values (Table 10) are well above the 1.0 performance limit, as expected. HIC values are below the 700 level in all tests which suggests a low probability of serious head injuries. This is consistent with the minor head injuries of the case occupant, with the exception of the fractured left mandible. However, HIC is not expected to be a good predictor of mandibular injuries.

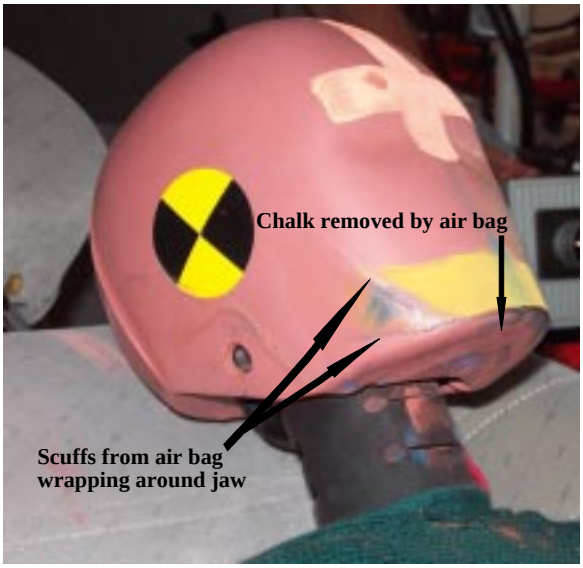

Figure 8. Evidence of air bag "wrapping" around chin on test dummy.

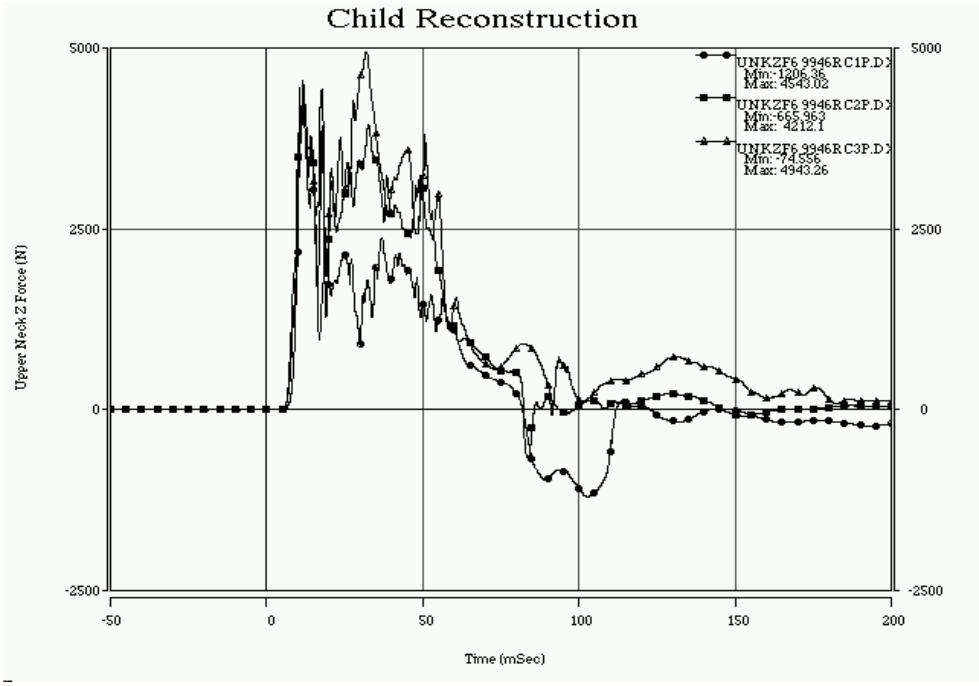

Figure 9. Upper neck Z force for reconstruction test #1100.

Table 10.
Injury Values for Reconstruction Series #1100

Inj Crit	Performance Limit	Test 1	Test 2	Test 3
HIC (15)	**700**	219	340	342
Nij	**1.0**	3.4	4.3	4.85
Peak Tension (N)**	**1490**	4543	4212	4943
**** Neck was only in tension during air bag event (Note: Table values are peaks occurring during air bag interaction interval which physical evidence suggests as the primary injury mechanism.)**				

CONCLUSIONS

The three reconstruction test series conducted in this study revealed that the injury criteria performance limits established for the CRABI 12 month-old and the Hybrid III 6-year-old were reasonable for the conditions tested. The reconstructions were capable of producing head and neck loading consistent with the physical evidence collected from the actual crash scenario and autopsy results. While the methodology appears to have potential, it is premature to conclude that it is a feasible method to establish performance limits and injury criteria in crashworthiness standards based on the few cases used in this study. Future testing may include additional case reconstructions for varying degrees of injury, rather than just fatalities, in order to further explore the ICPL's.

REFERENCES

1. Special Crash Investigations (SCI) cases, National Highway Traffic Safety Administration.