An improved method to calculate paediatric skull fracture threshold

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ABSTRACT

There is a need to better understand the threshold for paediatric skull fracture. Historically, drop tests of cadaver heads have been used to estimate thresholds. However, societal and ethical considerations prevent tests with child cadavers. Therefore, researchers have attempted to estimate the threshold by scaling adult tolerance data. Recent work suggests that mass and material scaling of adult tolerance data is insufficient to develop robust estimates of paediatric skull fracture tolerance. Researchers have also attempted to develop finite element models to estimate skull fracture tolerance. These models require that both geometry and material properties of the skull and brain be known, but, while detailed geometry is known, lack of experimental material test data prevents development of reliable finite element models. This paper describes development of a method to estimate skull fracture tolerance using fall data collected in emergency room. The method depends on the observation that width of force versus time pulse recorded in head drop tests onto a given surface does not vary with height of fall or the mass of head. This observation is supported by analyzing data from adult cadaver head drop tests onto 50mm thick 90 Shore D, and 40 Shore D rubber pads. Next, data from neonatal head drop tests are used to estimate pulse width when an infant head is dropped onto a steel plate. This pulse width is used together with child fall data collected at the Children’s Hospital, Milwaukee to estimate forces needed to cause a simple linear fracture in an infant head. This paper describes the procedures used to obtain anthropometric data and fall data such as height of fall and type of surface that the head contacted. This physics based method can be used to analyse child fall data relatively easily to obtain robust estimates of child skull fracture.

INTRODUCTION

Paediatric skull fracture threshold is an important variable needed to design a number of child protective devices such as helmets, child seats and children’s playground surfaces. Historically, skull fracture thresholds are estimated from drop tests of Post Mortem Human Subjects [PMHS] heads. Drop tests were the used to estimate adult skull fracture tolerance levels. However, societal and ethical considerations prevent testing with child PMHS. Therefore, researchers have attempted to use scaling laws to estimate paediatric skull fracture tolerance levels from adult skull fracture tolerance levels [Irwin and Mertz, 1997 , Melvin, 1995]. Initially, mass scaling was used but it was soon realized that differences in structure of the adult and child skull, and material properties would require that material properties also be scaled in the estimation of threshold [Thibault and Margulies, 1999].

Paediatric skull fracture threshold is also of interest to clinicians and in the field of forensic medicine. In many instances, physicians and law enforcement personnel are required to determine whether head injury is a result of an accident or abuse. Tarrantino et al [1999] reported that unintentional falls were the leading cause of non-fatal injury in infants less than a year old. Linear skull fractures are seen 58% of the time in accident cases [Reece and Sege, 2000] found that linear fractures were much more common than complex fractures in accident cases and occurred in 54% of the cases.

Prange, et al [2004] conducted head drop tests using 3 neonate heads. The heads were dropped from 15 and 30 cm heights and the objective of the tests were not to cause fracture. Weber [1984, 1985] conducted whole body child PMHS drop
tests in which child PMHS were dropped onto surfaces of varying stiffness such as tile, carpet, and softer surfaces. The drop height was standardized at 82 cm and he found that all drops onto stiff tile floor resulted in simple linear fractures. Weber did not describe the storage procedures for the PMHS specimens and the specimens were not instrumented.

Researchers have attempted to develop Finite Element [FE] models of varying degrees of sophistication to study the problem of skull fracture [Coats, 2007, Wagner, 2012, Klinich, 2002, Roth, 2010]. Development of reliable FE models requires that anthropometry and material properties of the skull and brain be known. Current developments in scanning technology make it possible to obtain fairly accurate information about geometry of the paediatric skull but inability to conduct tests with paediatric specimens make it difficult, if not impossible to accurately prescribe material properties in FE models. Because of these problems, FE models can at best be used as a trend predicting tool. Reliable FE models generally require powerful computers to exercise them and considerable time may have to be devoted to develop input data sets and to analyse the output. This can be time consuming and expensive.

The aim of this paper is to develop a simple, physics based method to estimate paediatric skull fracture tolerance. Our aim was to develop a method that could be installed in the form of spreadsheet programme on PCs, and, which would yield estimates for skull fracture tolerance in terms of peak loads. We feel that this method can be used to analyse fall data as they are obtained and to form robust initial estimates of skull fracture tolerance.

The proposed method depends on the observation that width of force-time pulse in head drop tests does not vary significantly with changes in contact velocity [drop height] or mass. Therefore, it is possible to use currently available data from a limited set of child PMHS tests [Prange, et al. 2002] in conjunction with impulse-momentum theorem to develop reliable estimates of paediatric skull fracture thresholds.

The work described in this paper is split into 4 parts listed below:

1. Confirmation of invariance of pulse width for adult PMHS tests for head drop tests onto Shore 40D and 90D pads from various drop heights. Data used in this confirmation process will be described in the METHODOLOGY section. Results will be discussed in the RESULTS section.

This paper assumes that the Impact force – Time waveform in a head drop test is tri-angular in shape. With this assumption, the impulse-momentum theorem will be invoked to estimate peak impact force for a given change in momentum of the head. Estimated peak force will be compared with measured peak force for each PMHS test. Comparisons will be presented in the RESULTS section.

2. Collection of prospective data in the Emergency Room [ER] from paediatric patients reporting with linear skull fractures. Procedures used to collect data will be discussed in the METHODOLOGY section.

3. Once the invariance of pulse width is confirmed, we will assume that this will hold for child PMHS head drop tests onto steel plates. Data from tests conducted by Prange, et al [2004] will be analysed in the METHODOLOGY section to reconfirm this principle for infant PMHS head drop tests. An estimate of pulse width will be obtained from Prange [2004].

4. ER data collected includes one case of a 4-month old child who fell onto concrete floor resulting in a simple linear fracture. It is assumed that the pulse width obtained from neonate head drop tests onto to steel plates is applicable to this fall. Impact force resulting from the fall will be calculated invoking the Impulse-Momentum theorem for the known fall height, fall surface, and anthropometry of the infant, once again assuming that the Force-Time curve has a tri-angular shape. This process will be discussed in the RESULTS section.

METHODOLOGY

This section will describe procedures used to confirm the hypothesis of invariant pulse width and to collect child fall data in the Emergency Room [ER].
Confirmation of Hypothesis Regarding Pulse Width - Analysis of Adult Head Drop Test Data

The first objective of this study was to confirm the observation that pulse width of the force vs time curve in head drop tests does not vary appreciably with reasonably large changes in drop height [impact velocity] and mass of the head as long as the head is dropped onto the same contact surface. Lateral head drop tests conducted by Yoganandan et al [2004] were analysed to confirm this hypothesis. In Yoganandan [2004], isolated heads of Post Mortem Human Subject [PMHS] were freely dropped onto 50.8 mm thick rubber pads. PMHS skulls were dropped onto their lateral aspect. Rubber pads with Shore durometer values of 40D and 90D were used. Drop heights were varied in steps from 305 mm to 2134 mm. In this study data from tests where no fracture was observed were used. We provide a brief description of the test methodology, for a fuller description of the PMHS preparation and test methodology, please see Yoganandan [2004].

PMHS heads were isolated at the level of the occipital condyles and further prepared by the replacement of the intracranial content by Sylgard gel that closely mimics the density and mechanical properties of the human brain. Pretest radiographs and computed tomography (CT) scans ([Somatome Plus, Siemens Inc., Germany) were taken of each skull. Tri-axial accelerometers were mechanically fixed to the skull and after each test, the mounting of all instrumentation was checked to assure it remained rigidly attached. Each skull was measured and weighed before and after instrumentation was attached. The skulls were dropped onto a six-axis load cell padded with flat elastomeric 40- and 90-durometer material (50 mm thickness). The mid-sagittal plane of the specimen was aligned at an angle of approximately 10 degrees with respect to the horizontal plane such that the impact occurred to the left tempro-parietal region. Each specimen was dropped from successively increasing heights until either fracture or the limits of the load cell was reached. The heights were 305, 610, 914, 1219, 1524 and 2438 millimetres. After each drop the specimen was radiographed and examined for evidence of skull fracture. Biomechanical response data were gathered using a digital data acquisition system according to SAE J 211 specifications at a sampling frequency of 12.5 kHz.

<table>
<thead>
<tr>
<th>ID</th>
<th>Age, Years</th>
<th>Height, cm</th>
<th>Weight, kg</th>
<th>Head Weight, kg</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500</td>
<td>56</td>
<td>178</td>
<td>96</td>
<td>4.37</td>
<td>M</td>
</tr>
<tr>
<td>1600</td>
<td>30</td>
<td>163</td>
<td>41</td>
<td>3.52</td>
<td>F</td>
</tr>
<tr>
<td>1700</td>
<td>71</td>
<td>169</td>
<td>81</td>
<td>3.72</td>
<td>M</td>
</tr>
<tr>
<td>1800</td>
<td>44</td>
<td>178</td>
<td>91</td>
<td>4.48</td>
<td>M</td>
</tr>
<tr>
<td>1900</td>
<td>59</td>
<td>182</td>
<td>100</td>
<td>4.52</td>
<td>M</td>
</tr>
<tr>
<td>2200</td>
<td>74</td>
<td>178</td>
<td>51</td>
<td>3.8</td>
<td>M</td>
</tr>
<tr>
<td>2300</td>
<td>81</td>
<td>157</td>
<td>60</td>
<td>3.24</td>
<td>F</td>
</tr>
<tr>
<td>2400</td>
<td>67</td>
<td>168</td>
<td>87</td>
<td>3.66</td>
<td>F</td>
</tr>
</tbody>
</table>

Peak vertical force, Fz and pulse width for each PMHS test were obtained by analysing data from the load cell. The pulse width was calculated as the time between a threshold of 5% of peak values.

The following data were abstracted from test results:
1. PMHS ID number
2. PMHS head mass
3. PMHS gender

All data were entered into a Excel spreadsheet for further analysis.

Collection of Child Fall Data

This Section will describe the procedure used to collect child fall data in the ER.

Overview

This was a case-control study. We recruited children ages 0 to 3 years old (36 months) who present to Children's Hospital of Wisconsin’s Emergency Department/Trauma Center (EDTC) within 48 hours of witnessed blunt head injury. Details of the fall such as the circumstances, estimated height, and nature of surface contacted were obtained from an adult witness for eligible subjects. In addition, anthropomorphic data (height, weight, and head circumference) were also obtained. All data for eligible participants were recorded in standardised data sheets in the Emergency Department and Trauma Center [EDTC] database.
Participants

Participants were recruited from the Children’s Hospital of Wisconsin Emergency Department and Trauma Center [EDTC]. All eligible patients with witnessed head injury due to a fall were evaluated within 48 hours in the EDTC during the study period. Screening occurred based on the availability of physician co-investigator. In order to ensure that no patients were missed during screening, all patients with an injury to the head (direct force or transmitted force) were identified by related chief complaints noted on the EDTC tracking board and were screened for eligibility by the EDTC research assistants. Chief complaints included any description of an injury to the head or an associated mechanism with the potential to have sustained direct force to the head (e.g., “concussion,” “head injury,” “laceration,” or “fall”). If screened patients met inclusion/exclusion criteria based on medical record and discussion with the treating medical team, they were recruited for participation in a study on pediatric head injury. If the patient agreed to study participation, the research assistants then contacted the physician co-investigator to complete the Structured Assessment of Injury. Additionally, anthropomorphic data not already collected (height and head circumference) per usual EDTC processes was collected.

Inclusion criteria

EDTC patients ranging in age from 0 to 3 years were eligible who presented to the EDTC within 48 hours of a reported injury involving the head secondary to a fall were eligible to participate in the study.

Exclusion criteria

These included conditions that would alter the dynamics of the injury (e.g. helmet use, metabolic bone disease, known intracranial disease or injury), mechanisms that were not fall related or prevented a valid assessment of injury details (unwitnessed event, inability to verbally contact adult who witnessed event, physician concerned for inflicted trauma, or non-English speaking patient/family).

Patients were recruited in two groups: children with linear skull fractures confirmed on imaging and children without skull fracture (either scalp hematoma but no skull fractures seen on imaging or children with scalp lacerations and no suspected fracture). For this preliminary report, we recruited 4 patients in 6 months.

Setting

The study took place at the Children’s Hospital of Wisconsin Emergency Department/Trauma Center (EDTC). The EDTC is certified by the American College of Surgeons as a Level I Pediatric Trauma Center. It is the only freestanding Level 1 pediatric trauma center in Wisconsin. The primary catchment area for the Trauma Center includes Milwaukee County and six other counties in southeastern Wisconsin. The total population of the seven-county area is 1,960,289 people, of which 505,279 are children under 22 years of age. Of this total, 48% live within Milwaukee County. The total area is 2,622 square miles (including 242 square miles in Milwaukee County). The secondary catchment area includes 12 additional counties in Wisconsin and northern Illinois. The EDTC has 60,979 visits annually, with a patient age range of 0–22 years old, 54% male, and a racial distribution of 37% Caucasian, 42% African American (AA), and 15% Hispanic non-AA.

From 2002-2008, there were a total of 419 skull fractures in children under the age of three years at CHW, an average of 60 per year (range 45 to 77, with no obvious trend over time). In 2008, there were a total of 1354 blunt head injuries without skull fracture (1075 scalp lacerations and 279 blunt head injuries without skull fracture or intracranial injury) in children under the age of three. Racial and gender distributions were similar to the general EDTC population. Falls predominate as a cause of injury in these patients, regardless of race and gender. EDTC research assistants staff the department 15 hours a day, 5 days a week, during peak census hours. Our physician co-investigator was available for a total of 4 calendar months distributed over the study period. Our experience is that most patients younger than 3 with blunt head injury present to the ED during peak census hours.

ER Data Collection Methods

Structured Assessment of Injury (SAI): Witnesses to the injury were asked to complete an injury survey. The survey was administered as a structured interview by the physician investigator. The assessment collected anthropomorphic data including height, weight, head circumference, and points of impact or injury. Points of impact were documented via body map and, when permitted, digital photographs. Witness’ detailing of the fall were documented including, but not limited to, height of the fall, position of the body during the fall, objects struck while falling, and position of the body after

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the child came to rest. In addition, a researcher went to the location of the fall and collected data such as fall height, full surface material, etc. Measurements of relevant objects (i.e. height of furniture from which the patient fell) were taken using a standard measuring tape. As in the case of patients who fell from a caretaker’s arms, the caretaker assumed the approximate position they were in when the patient fell, and relevant measurements (i.e. height of arm) were taken. When applicable, drawings were used on the SAI to accurately demonstrate the mechanism of the fall. When visiting the site of the fall, photographs were taken to corroborate the witness’ description of the fall. Data related to immediate injury outcomes was obtained from the patients’ medical record. These data included digital imaging, when applicable. Any available imaging data was collected and converted for use in the project.

**Data collected in ER-Study subject**

4 patients were eligible for inclusion in the study. Out of these, only 1 fell onto a stiff surface. This patient was a 4-month old, male, 0.66 m tall, and weighing 7.4 kg. He fell from his father’s arm onto a ceramic tile floor. Fall height as reported in the ER was 1.21m, which was revised to 1.28m during home visit. The infant sustained a nondisplace linear fracture through parietal bones, right longer and more distracted than left with a moderate sized right parietal scalp haematoma.

**RESULTS**

In this section, we will discuss the following:

1. Variation of pulse width with drop height for adult PMHS tests.
2. Dependence of pulse width on contact surface for adult PMHS tests.
3. Goodness of estimated peak forces for adult PMHS tests.
4. Estimate of pulse width for neonate head drop tests.
5. Estimate of peak forces for test case collected in the ER.

**Figure 1: PMHS Head Drop Test Setup**

Figure 1 illustrates the drop test setup. Figure 2 is a plot of vertical impact forces \( F_z \) recorded by the load cell on the platform under the rubber pad. In the drop tests under consideration, forces in the Y and X direction were negligible and only \( F_z \) was used in further calculations.

**Figure 2. Vertical Force for various drop heights for one PMHS**

Figure 2 shows the variation in \( F_z \) as a function of drop height, and therefore, velocity at contact with the rubber pad. It is seen that pulse shapes are similar and that pulse width is essentially the same for all drop tests. Note that the drop height has increased by a factor of 3.5 and so has the potential energy of the head. Higher contact
velocities resulted in higher forces. Data for these tests were obtained from drop tests of a disarticulated male head weighing 3.72kg onto a 61mm thick Shore durometer 40D rubber mat. Similar results were obtained in other tests.

Pulse widths for drop of a 4.48 kg [ID 1700] head onto Shore 40D durometer pad are tabulated in Table 2. It is seen that pulse width is more or less constant with a small standard deviation.

Table 2. Variation of pulse width with drop height.

<table>
<thead>
<tr>
<th>Drop Ht, m</th>
<th>Contact Velocity, m/s</th>
<th>Pulse Width, ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.61</td>
<td>3.46</td>
<td>7.60</td>
</tr>
<tr>
<td>0.91</td>
<td>4.24</td>
<td>7.2</td>
</tr>
<tr>
<td>1.22</td>
<td>4.89</td>
<td>6.88</td>
</tr>
<tr>
<td>1.52</td>
<td>5.47</td>
<td>6.72</td>
</tr>
<tr>
<td>1.83</td>
<td>5.99</td>
<td>6.8</td>
</tr>
<tr>
<td>2.11</td>
<td>6.47</td>
<td>7.04</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>7.04</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td></td>
<td>0.32</td>
</tr>
</tbody>
</table>

Table 2 indicates that there is very little variation in pulse width with increase in drop height.

Variation in pulse width between specimens for the same drop height is tabulated in Table 3. It indicates that even though the mass of the specimens vary, pulse width remains essentially the same.

Table 3. Variation of pulse width with mass

<table>
<thead>
<tr>
<th>ID</th>
<th>Pulse width, ms</th>
<th>Peak Fz, N</th>
<th>Mass, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500</td>
<td>6.48</td>
<td>9103</td>
<td>4.37</td>
</tr>
<tr>
<td>1600</td>
<td>6.8</td>
<td>8020</td>
<td>3.52</td>
</tr>
<tr>
<td>1700</td>
<td>6.8</td>
<td>8759</td>
<td>3.72</td>
</tr>
<tr>
<td>1800</td>
<td>7.36</td>
<td>9352</td>
<td>4.48</td>
</tr>
<tr>
<td>1900</td>
<td>7.52</td>
<td>9277</td>
<td>4.52</td>
</tr>
<tr>
<td>Mean</td>
<td>6.99</td>
<td>8902</td>
<td>4.12</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td></td>
<td>0.433</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Dependence of pulse width on contact surface

Shore D stiffness can be used to calculate the Young’s modulus of the rubber pad using the formula given below.

\[
\log (E) = 0.023(\text{SD}+50) - 0.6403 - 1
\]

This formula indicates that the Young’s modulus of the 40D and 90D pads, are, 4.18 MPa and 13.19 MPa respectively. The increase in stiffness of the pads is reflected in the higher \( F_z \) and shorter pulse widths seen in drops onto 90D pads as compared to drops onto 40D pads.

Difference in pulse width for 2 specimens of approximately the same mass when dropped from the same height onto to Shore 40D and 90D rubber pads is tabulated below. As expected, pulse width is narrower when the head is dropped onto a stiffer surface.

Table 4. Pulse width and contact surface stiffness

<table>
<thead>
<tr>
<th>Drop Ht, m</th>
<th>ID 2200, Mass 3.8kg</th>
<th>ID 1701, Mass 3.72 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak Fz, N</td>
<td>Pulse Width, ms</td>
</tr>
<tr>
<td>0.61</td>
<td>4.24</td>
<td>7.2</td>
</tr>
<tr>
<td>0.91</td>
<td>4.89</td>
<td>6.88</td>
</tr>
<tr>
<td>1.21</td>
<td>5.47</td>
<td>6.72</td>
</tr>
</tbody>
</table>

Goodness of estimates of peak \( F_z \)

Peak \( F_z \) for each drop test was estimated using the impulse-momentum theorem. It was assumed for the sake of simplicity that the force-time waveform had a triangular shape. With this assumption, impulse-momentum theorem can be written as:

\[
0.5 \cdot F_z \cdot \text{pulse width} = \text{mass} \cdot \text{contact vel} - 2
\]

Knowing drop height, mass, and pulse width, peak \( F_z \) was calculated for each PMHS test. Measured and estimated peak \( F_z \) are tabulated in Table 5 for PMHS ID 1700 with a head mass of 3.72kg for a number of drop heights onto Shore 40D pad.
Table 5.
Comparison of estimated and measured peak forces

<table>
<thead>
<tr>
<th>Drop Ht, m</th>
<th>Contact vel., m/s</th>
<th>Measured force, N</th>
<th>Estimated force, N</th>
<th>Diff, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.61</td>
<td>3.46</td>
<td>3654</td>
<td>3511</td>
<td>19</td>
</tr>
<tr>
<td>0.91</td>
<td>4.24</td>
<td>4476</td>
<td>4349</td>
<td>19</td>
</tr>
<tr>
<td>1.22</td>
<td>4.89</td>
<td>5168</td>
<td>5022</td>
<td>26</td>
</tr>
<tr>
<td>1.52</td>
<td>5.47</td>
<td>5778</td>
<td>5615</td>
<td>27</td>
</tr>
<tr>
<td>1.83</td>
<td>5.99</td>
<td>6330</td>
<td>6151</td>
<td>30</td>
</tr>
<tr>
<td>2.13</td>
<td>6.47</td>
<td>6837</td>
<td>6644</td>
<td>25</td>
</tr>
</tbody>
</table>

Similar results were obtained for all other PMHS drop tests for drops onto Shore 40D and 90D pads. Differences varied from about 1% to 30% and there was no seeming correlation of the differences to subject mass, contact velocity and stiffness of contacting surface.

This study assumed that the waveforms were triangular in shape and the area under the curve forms the left hand side of Equation 1. An examination of Fig.1 indicates that the area under the F-T curve will be higher than one obtained with a tri-angular approximation. Preliminary geometric experiments indicate that the area under the measured $F_z$ – time curve might be approximately 20% higher than the value obtained with the tri-angular approximation. We propose to evaluate this more fully in future work.

Estimates peak $F_z$ for case patient

Prange et al. [2004] conducted drop tests with 3 neonate heads dropped onto a steel plate from 15 and 30 cm heights. The authors indicate in their discussion that the average pulse duration was 18 ms. Using this information and anthropometric data collected in the ER, peak $F_z$ for the case patient can be calculated using Formula 2. Relevant data are tabulated below.

Table 6.
Estimated contact force calculation

<table>
<thead>
<tr>
<th>Weight, Kg</th>
<th>Est. Hd Wt, Kg</th>
<th>Est. Contact Vel, m/s</th>
<th>Est. Pulse width, ms</th>
<th>Est. Peak $F_z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.4</td>
<td>2.5</td>
<td>5</td>
<td>18</td>
<td>1392</td>
</tr>
</tbody>
</table>

The head mass can be used to estimate a head acceleration of 57G.

DISCUSSION AND CONCLUSIONS

This paper presents a simple, physics method to estimate impact loads on head in head drop tests. Estimates for forces exerted by the impacting surface on the adult PMHS heads have been compared with measured forces for 2 drop surfaces.

1. Maximum difference between estimated and measured head impact forces is in the range of 30% for head impacts into 90 and 40 Shore D pads with a majority of the estimates being in the 20% range.
2. Differences between measured and estimated forces does not depend on mass of the head or velocity at contact [or drop height].
3. This paper assumes that the head loading pulse is tri-angular in shape. In future work, we will consider the effect of pulse shape on the goodness of estimated force. Since most of the estimated forces are lower than measured forces by about 20%, it is likely that the estimates will be closer to the measured values if the area under the F-T curve was about 20% higher. In other words, the F-T pulse is not tri-angular in shape as assumed in this paper. Figure 1 illustrates that the Force-Time pulse is not triangular.
4. Our aim was to develop a simple robust method to estimate head impact loads that can be coded onto a spreadsheet and supplied to ER personnel. Assumption that the force-time waveform is tri-angular is justified by this requirement.
5. Proposed procedure underestimates impact forces. Therefore, any thresholds based on estimated forces are likely to be a conservative estimate.
6. The posture of the case patient will affect the peak contact loads and is unknown in this case.
7. Pulse duration for neonatal head drops may be different from that estimated for the case patient because of the interaction of body segments with the floor. However, it is reasonable to assume that since the child is so young, its reflexes may not be developed enough for it to take defensive action to prevent or modulate head injury.
8. Head mass of the case patient has been estimated to be 1/3 of the total weight. We propose to use geometry and scans in
future work to more correctly estimate the child’s head mass.

REFERENCES