Accident Analysis and Prevention 72 (2014) 219–229

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

The response of the adult and ATD heads to impacts onto a rigid surface

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ARTICLE INFO

Article history:
Received 2 September 2013
Received in revised form 24 June 2014
Accepted 30 June 2014
Available online 31 July 2014

Keywords:
ATD
Head impact
Hybrid III
Head injury
Traumatic brain injury
Q3

ABSTRACT

Given the high incidence of TBI, head injury has been studied extensively using both cadavers and anthropomorphic test devices (ATDs). However, few studies have benchmarked the response of ATD heads against human data. Hence, the objective of this study is to investigate the response of adult and ATD heads in impact, and to compare adult Hybrid III head responses to the adult head responses.

In this study, six adult human heads and seven ATD heads were used to obtain impact properties. The heads were dropped from both 15 cm and 30 cm onto five impact locations: right and left parietal, forehead, occiput and vertex. One set of drops were performed on the human heads and up to four sets were carried out on the ATD heads. For each drop, the head was placed into a fine net and positioned to achieve the desired drop height and impact location. The head was then released to allow free fall without rotation onto a flat aluminum $\frac{3}{4}$ -inch thick platen. The platen was attached to a three-axis piezoelectric load cell to measure the impact force. The peak resultant acceleration, head impact criterion (HIC) and impact stiffness were calculated using the force/time curve and drop mass.

No statistical differences were found between the adult human heads and the adult Hybrid III head for 15 cm and 30 cm impacts ($p > 0.05$). For the human heads, the mid-sagittal impact locations produced the highest HIC and peak acceleration values. The parietal impacts produced HICs and peak accelerations that were 26–48% lower than those from the mid-sagittal impacts. For the ATD heads, the acceleration and HIC values generally increased with represented age, except for the Q3, which produced HIC values up to higher than the other ATD heads.

The impact responses of the adult Hybrid III onto different impact locations were found to adequately represent the impact stiffness of human adult head impacts from 30 cm and below onto a rigid surface. The Q3 dummy consistently produced the highest HIC values of the ATD heads, and produced higher acceleration and HIC values than the adult human heads as well, which is contrary to neonatal data demonstrating that the head acceleration increases with age.

1. Introduction

One of the main tools used to study head injury are anthropomorphic testing devices (ATDs). ATDs simulate the human head geometry and impact response. One ATD widely used in automotive impact testing is the 50th percentile Hybrid III adult male, henceforth referred to as adult Hybrid III (Mertz, 1985). It has been in use since the 1970s and is currently used in standards for evaluating the safety of cars (Foster et al., 1977; FMVSS, 1998). Other ATDs have been developed to evaluate the safety of child restraint systems and cars, including ATDs representing an average anthropometry for pediatric ages from age newborn to 10-year-old (Irwin and Mertz, 1997; Van-Ratingen et al., 1997). The adult Hybrid III was benchmarked against forehead skull fracture data; however, the other child ATD heads and the other locations on the adult Hybrid III head have not been compared against human data (Hubbard and Mcleod, 1973,1974; Foster et al., 1977).

Most TBIs occur from direct head impacts onto other objects usually in the form of motor vehicle crashes, sports collisions or falls (Faul et al., 2010). Drop tests, with prescribed impact

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http://dx.doi.org/10.1016/j.aap.2014.06.022
0001-4575/

Table 1
Adult heads used in the head impact tests.

Specimen ID	Age	Sex	Race	Cause of death	Head drop mass (kg)	Head length (mm)	Head width (mm)	Head circum. (mm)
A01M	61-year-old	M	Caucasian	Unknown	3.16	185	163	565
A02M	53-year-old	M	Caucasian	Respiratory failure	3.27	195	143	565
A04M	59-year-old	M	Hispanic	Septic shock	3.21	195	163	583
A05M	58-year-old	M	Caucasian	Chronic obstructive pulmonary disease	3.08	187	147	615
A06M	67-year-old	M	Caucasian	Respiratory failure	3.41	203	150	611
A07M	67-year-old	M	Caucasian	Unknown	3.45	210	155	599

momentum and location, are a controlled way of mimicking these impacts and are the current method for validating the response of ATDs (Foster et al., 1977; Mertz, 1985). From drop tests, the response of the heads can be analyzed to understand impact properties of the head. To correctly characterize the impact properties of the adult and ATD heads, this study will evaluate the impact response of the human adult head and seven different ATD heads. The results will characterize the impact response of the adult head for five different impact locations, and quantify the changes in response of the ATD head with represented age. In addition, the Hybrid III will be directly evaluated against the adult head for multiple impact locations.

2. Methods

Two sets of heads were tested: six adult cadaver and seven ATD heads (Tables 1 and 2). The cadaver drop tests were performed following a neck testing series and prior to a head compression test series (Dibb et al., 2009). The cadaver heads were dissected from the neck. The mandibles of all specimens had been removed during the prior neck testing and remained detached for all head drop tests. The head circumferences, lengths and widths were measured. The circumference was measured around the gabella and the most posterior portion of the head and above the ears. The head width was measured from most lateral locations of the cranial cap. The head length was measured from the gabella to the most posterior portion of the head. Both external auditory meatuses (EAMs), infraorbital foramen (IOF) and Frankfort plane were marked (Walker et al., 1973). Each head was filled with saline (0.9% NaCl solution) to remove all air voids. Then the heads were sealed at the occipital condyles with polymethylmethacrylate (PMMA). Finally, each head was weighed to determine head drop mass.

The drop tests were performed using two drop heights, 15 cm then at 30 cm, and onto five impact locations in this order: forehead, occiput, vertex, right parietal and left parietal. All the 15 cm drops were done first. The drop heights were selected to ensure that no fractures would occur during the impacts and to make the test "non-destructive" (Hodgson and Thomas, 1971; Prange et al., 2004). There were no randomizations done. One set of drops was performed on the post mortem human subject (PMHS) heads. After each human head drop, the head was palpated for fractures and the force-time plots were checked for fractures. For the ATD heads up to four sets of drops were done. The repeated drops for each ATD head were done using the same ATD, and there was at least an hour of wait time between impacts onto the same impact location for each ATD. Only one set of tests were conducted on the 6-month CRABI due to time constraints. For each drop, the head was placed into a fine net that was attached to a pulley using nylon line (Fig. 1). The head was positioned inside the net to set the desired impact location. The head was then adjusted to the desired drop height and released by burning the nylon line. The head then impacted a smooth, flat aluminum platen that was $\frac{3}{4}$ -in. thick and attached to a Kistler three-axis piezoelectric load cell (Kistler, France) (Fig. 1). Force–time data were recorded using LabVIEW (National Instruments, Austin, TX) at a sample rate of 100,000 Hz. A Phantom high-speed digital video camera (Vision Research, Inc., Wayne, NJ) recorded all of the head drops. All human heads were dissected and inspected for fractures after testing.

For analysis, all data were filtered using the SAE J211b Class 1000 filter specifications for head impact (Saej222-1, 1995). Peak resultant acceleration, head injury criterion (HIC) and impact stiffness were calculated for each head drop. The acceleration time history for each head was estimated by normalizing the force–time history by the drop mass. This acceleration–time history was used to calculate peak resultant acceleration and HIC (Kleinberger et al., 1998).

Force–displacement curves were obtained by integrating the acceleration–time histories. The displacement was calculated by double integrating the acceleration–time pulse using MatLAB (Figs. 2 and 4). The force was taken from force–time curves of

Table 2
ATD heads used in the head impact tests.

Specimen ID	ATD head	Head drop mass (kg)	Number of tests
D01D	50th percentile adult male Hybrid III	4.32	4
D02D	12-month CRABI	2.65	3
D03D	3-year Hybrid III	2.50	3
D04D	6-year Hybrid III	3.30	3
D05D	10-year Hybrid III	3.74	3
D06D	3-year-old Q3	2.81	3
D07D	6-month CRABI	2.10	1

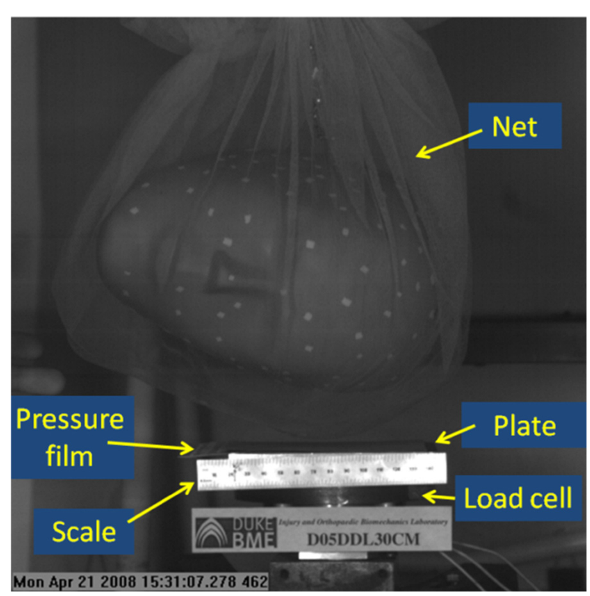

Fig. 1. The head drop setup during a head impact. The head in this figure is the 10-year-old Hybrid III.