A Novel Approach to Assessing Head Injury Severity in Pediatric Patient Falls

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ABSTRACT

Introduction: Pediatric patient falls with head-to-floor impact have the greatest potential for injury.
Methods: An objective measure of head injury severity, the Head Injury Criterion (HIC_{15}), was calculated from anthropometric and biomechanical components of patient falls. A secondary aim was to compare HIC_{15} levels with the hospital's subjective assignment of level of harm (1-9 scale) used for regulatory reports.
Results: Adverse event reports yielded a sample of 49 falls from heights of 72.5 to 1793.0 cm by children ages 11 months through 17 years. Contact velocity from beginning to end was 2.81 to 6.16 ms. Mean acceleration was 19.5 to 95.3*g*. HIC_{15} levels of impact ranged from 26.4 to 1,330.0, and mean force upon contact was 2.0 to 9.8 N/kg body mass. Seven (14.3%) children's HIC_{15} levels exceeded age-specific thresholds, with no follow-up scheduled. Hospital-assigned levels of harm were not correlated with HIC_{15} levels (r = .23, R^2 = .05, p = .12).
Discussion: A point-of-care computerized HIC_{15} algorithm would be useful for diagnostic and follow-up decisions. J Pediatr Health Care. (2017) ■■, ■■-■■.

KEY WORDS

Biomechanics, concussion, falls, traumatic brain injury

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Conflicts of interest: None to report.

This study was partially supported by the President's Faculty Opportunity Award (#221-272-76MH), University of Nevada, Las Vegas, and the American Nurses Foundation (#2350-257-736T).

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0891-5245/$36.00

https://doi.org/10.1016/j.pedhc.2017.09.012

Falls are the leading cause of nonfatal unintentional injury for children from birth through 14 years and the second leading cause in 15- to 24-year-olds (Centers for Disease Control and Prevention, 2015). Even more concerning is that falls were the most common cause of traumatic brain injury in children ages less than 1 year through 14 years during 2006 through 2010 (U.S. Department of Health and Human Services, 2014). Children's falls occur at home, at school, and in the community; thus, it is not unexpected that children may fall during hospitalization. A fall is defined as "An event which results in a person coming to rest inadvertently on the ground or floor or other lower level" (World Health Organization, 2016, para. 1). Based on data from 26 children's hospitals in the United States over a 6-month period, the rate of pediatric inpatient falls (N = 782) was estimated at 0.88 falls per 1,000 patient-days (Jamerson et al., 2014). Overall, 39% of the children (age range = birth through 18 years) fell from a bed, crib, or stretcher; 43% were ambulating; and 14% fell in the bathroom. Fall-related injuries were observed in 32% of the falls; however, the types of injury were not reported.

Most hospitalized infants and toddlers who fall from their cribs, beds, chairs, or examination tables contact the floor head first because of cephalocaudal growth patterns in which the head is the center of gravity (Loyd et al., 2010; Santos & Noggle, 2011). In cases for which a skull fracture or intracerebral intracranial hematoma are suspected, the most common diagnostic procedure is computed tomography (CT) imaging to assess the level of traumatic brain injury and need for subsequent follow-up care. It is beyond the scope of this study to describe the management of head injury from a fall; however, a review of the literature on the diagnosis, recovery assessment, and management of acute concussion in young children indicated a lack of standardization across institutions (Davis & Purcell, 2014). Some hospitalized children who fall and make head contact with the floor may not be evaluated for potential head injury nor receive important follow-up care. However, CT scans should not be used without a high index of suspicion of head injury.

CT IMAGING

Approximately 5 to 9 million CT scans are performed on children annually, and their use has increased rapidly since 1980 (Blackwell, Gorelick, Holmes, Bandyopadhyay, & Kuppermann, 2007; National Cancer Institute, 2012). Routine use of CT as a diagnostic tool for children is questionable from perspectives of cost and patient safety (Shiomi, Echigo, Hino, Hashimoto, & Yamaki, 2016). The National Cancer Institute (2012) has cautioned against excessive use of CT as a diagnostic tool for vulnerable populations, including children. In response to growing concern about radiation exposure due to medical imaging, the U.S. Food and Drug Administration introduced the Initiative to Reduce Unnecessary Radiation Exposure from Medical Imaging. The initiative focused on safe use of medical devices, patient awareness of radiation exposure, and informed decision-making about when to use radiation-producing medical imaging. Although more emphasis was on pediatric exposure to radiation, the initiative also championed the need to require radiation exposure record-keeping for all medical imaging procedures (Neumann & Bluemke, 2010).

A single CT scan for adults has been deemed safe (National Cancer Institute, 2012); however, this may not be the case for children. Cumulative effects from various diagnostic procedures, more prevalent in older adults, may also be of concern for children if they are repeatedly exposed to diagnostic imaging. This is addressed explicitly in the U.S. Food and Drug Administration's initiative to improve radiation exposure record-keeping (Neumann & Bluemke, 2010). One possible means to reduce the cumulative and potentially deleterious effects of radiation exposure for children who fall is to develop noninvasive methods of evaluating head injury and to follow up with CT scans only for children who are more likely to have brain injury.

MECHANISMS OF BRAIN INJURY AND BIOMECHANICS

Exact determination of the mechanisms of brain injury may be difficult to establish because of the inability to measure the events directly. Use of animal, human cadaver, and computer models have resulted in a contemporary understanding of four possible mechanisms of brain injury. Although these mechanisms may not all induce concussions singularly, they are likely to be involved, in some capacity, during chronic or acute concussive episodes. These mechanisms include contusions resulting from skull deformation and brain motion, intracranial pressure gradients produced from impact, rotation causing relative motion between the skull and brain, and combined linear and rotational acceleration from impact (Post & Hoshizaki, 2012). However, it has also been documented that all injuries to the brain are linked to some amount of brain tissue deformation, which results from an impact where the head is subjected to acceleration (Post & Hoshizaki, 2012).

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Head injuries typically result from a directly impacted force to the head (impact loading) or from an indirect impact (impulsive loading) that is applied to the head and neck when the rest of the body moves differently. In the case of pediatric patient falls examined in the current study, impact loading was the primary exposure for each child. By definition, impact loading is governed predominantly by linear acceleration and primarily results in focal brain injuries, that is, a contusion or skull fracture, and a transmission and reflection of pressure waves through the brain tissue (Goldsmith & Plunkett, 2004; King, Yang, Zhang, Hardy, & Viano, 2003). This has led to a fifth mechanism of head injury that occurs through a combination of skull deformation, positive and negative pressures, and brain lag, all of which result from linear and/or angular accelerations (Bandak & Eppinger, 1994; Gurdjian, 1975; Zhou, Khalil, & King, 1995). Thus, it is important to develop tools that account for both linear and angular head motion.

It must also be stressed that the mechanical characteristics of the brain are dynamic throughout the lifespan. The material and structural properties of skull and brain depend on age (Huelke, 1998). The infant skull is soft and consists of loosely associated bony plates with soft membranes interspersed throughout