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Impact sites representing potential bruising locations associated with rearward falls in children

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ABSTRACT

Children presenting multiple unexplained bruises can be an early sign of physical abuse. Bruising locations on the body can be an effective indicator of abusive versus accidental trauma. Additionally, childhood falls are often used as falsely reported events in child abuse, however, characterization of potential bruising locations associated with these falls does not exist. In our study we used a 12-month old pediatric anthropomorphic test device (ATD) adapted with a custom developed force sensing skin to predict potential bruising locations during rearward falls from standing. The surrogate bruising detection system measured and displayed recorded force data on a computerized body image mapping system when sensors were activated. Simulated rearward fall experiments were performed onto two different impact surfaces (padded carpet and linoleum tile over concrete) with two different initial positions (standing upright and posteriorly inclined) so that the ATD would fall rearward upon release. Findings indicated impact locations, and thus the potential for bruising in the posterior plane primarily within the occipital head and posterior torso regions.

1. Introduction

The United States has one of the worst records among developed nations in deaths related to child abuse and neglect [1]. On average between four and seven child fatalities occur daily because of child abuse and neglect in the U.S. [2]. Child abuse is a leading cause of fatality in children up to 4 years of age; an estimated 1520 children are fatally injured annually as a result of child abuse [2]. Infants (less than 1 year in age) are the most vulnerable to abuse and have the highest rate of fatalities of all age groups [2].

Bruising in children is often visually apparent and is frequently an early manifestation of a child's abusive environment. Accidental bruising is infrequently observed in infants, due to their low degree of independent mobility [3]. Bruising locations and bruising patterns (constellation of individual bruise locations throughout the body) provide a "roadmap" documenting a child's exposure to impact. Health care professionals and law enforcement officials often have to address the question of likelihood that a child's presenting injuries are compatible with history provided by the care giver. If injuries were distinguishable between accidental and abusive trauma, presenting abused children could be diverted from being reintroduced into their abusive environments which often result in further harm or death [4].

Previous studies have retrospectively highlighted differences in bruising patterns observed clinically, to provide a better understanding of skin findings in children that maybe at a high risk of abuse in their current environment [3,5–11]. However, the ability to predict potential bruising locations associated with falsely reported events (e.g. short distance falls) in child abuse does not exist and could prove useful in the distinction between abusive and accidental injuries. Rearward falls could be experienced by children who are in the early development stage of independent mobility. This type of fall (falling rearwards and impacting the head occipital region) may represent greater potential for injury because there is no protective or righting reflex in a rearward fall as in a sideways or forwards fall [12].

In our study we used a bruising detection system to identify potential bruising patterns in simulated rearward falls from standing using a child surrogate representative of a 12-month old child (stage of early independent mobility). The bruising detection system consists of a pediatric anthropomorphic test device (ATD) adapted with a custom developed force sensing skin

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that is linked to display recorded force data on a computerized body mapping image system when the force sensors are activated [13]. Simulated rearward fall experiments were performed onto two different impact surfaces with two different initial positions, while recording ATD impact sites so as to predict potential bruising locations.

The purpose of this study is to provide a "roadmap" of the child surrogate's contact exposure during specific fall events and to identify whether variations in the fall parameters (impact surface, initial position) lead to differences in impact locations. Our goal was to characterize potential bruising locations or patterns associated with a common childhood fall.

2. Methods

The surrogate bruising detection system (SBDS), consisting of the 12 month old CRABI ATD (10 kg mass) fitted with a force sensing skin and associated data acquisition hardware and analysis software, was used to predict potential bruising patterns in simulated fall scenarios. The CRABI ATD head weight is 2.6 kg (5.8 lbs), and body weight is 10 kg (22 lbs), thus the head represents ~26% of the overall body weight. The sensing skin of the SBDS consists of 132 force sensing resistive sensors (the head had a total of 32 sensors) enveloping the surface of the ATD that is divided into seven regions including the head, anterior torso, posterior torso, upper arm (arm), lower arm (forearm), upper leg (thigh), and lower leg (shank). Each body region was covered with an individualized custom sensor array/pattern. The resistive sensors in the sensing skin were connected to the data acquisition system through a voltage divider circuit. Additional details of the SBDS and its individual components are described in earlier publications [13,14].

The SBDS was used to assess potential bruising locations on the ATD body during a series of rearward fall experiments simulating falls.

2.1. Test setup

The ATD was placed in an upright standing (orthostatic) position on ground level using a suspension system supported by a tripod with a manually operated release mechanism to allow the ATD to fall under the effect of gravity. The ATD has a standing height of 74.7 cm (29.4 in.). Fall experiments were conducted using two different initial conditions. The ATD was suspended such that the ATD was positioned at an angle of 20 degrees (scenario 1 – upright initial condition) and 30° (scenario 2 – posteriorly inclined initial position) (two different initial positions) to the vertical so that the ATD would fall rearward upon release (Fig. 1, scenario 1). The ATD's CG height above ground level differed for each fall scenario (Table 1). In both fall scenarios the ATD's feet were in contact with the ground at the start of the fall. To initiate a fall, the release mechanism was activated which released the ATD allowing it to fall rearward.

Prior to each fall, ATD joint angles were adjusted using a goniometer to ensure repeated positioning in all tests. Additionally, joint stiffness was calibrated to manufacturer specifications whereby the joints were tightened until the friction was just sufficient to support the weight of the limb against gravity. Two impact surfaces were evaluated for each fall scenario: (1) padded carpet over a wood subfloor and (2) linoleum tile over a concrete subfloor. The carpet surface consisted of a 1.3 cm (1/2 in.) thick open loop carpet placed over 1.0 cm (3/8 in.) thick foam padding. The carpet and padding were placed over a 1.9 cm (3/4 in.) thick plywood platform 183 cm × 91.5 cm (6 ft × 3 ft) built to standard building codes with 5.1 cm × 10.2 cm (2 in. × 4 in.) joists, spaced 40.6 cm (16 in.) on center. 0.32 cm (1/8 in.) linoleum tile was adhered to a concrete subfloor for the second impact surface used in the fall experiments.

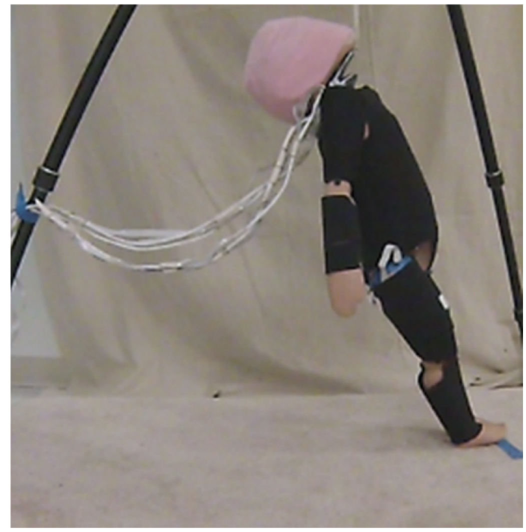

Fig. 1. ATD in an upright initial position (scenario 1) for simulated rearward fall experiments.

2.2. Data acquisition and analysis

The SBDS's sensors consist of force sensing resistors whose outputs were fed to the data acquisition system through a voltage divider circuit to convert resistance to voltage. Data acquisition hardware (National Instruments, Austin, TX) was used to capture and convert the analog sensor output. Multifunctional input/output data acquisition cards (PCI-6225; National Instruments) acquired, conditioned and digitized the sensor output signals. The National Instruments PCI-6225 data acquisition card is capable of measuring 80 single ended analog channels at a 16 bit resolution and a sample rate of 250 kS/s. A personal computer served as the platform for the data acquisition hardware. Graphical programming software (Labview 2010; National Instruments, Austin, TX) was used to acquire and display sensor output in a manner that relates sensor location to body region. A Virtual Instrument (VI) was developed to accomplish this objective. An active 3D (3-dimensional) body map image representing the ATD served as a graphical interface and was developed using Labview (National Instruments) software. The body image was discretely mapped to the sensors on the ATD such that active sensor outputs (those which have been impacted) and their locations were displayed on the computerized body map image. Sensor outputs in terms of force magnitude were color-coded, designating a pre-determined force range so as to aid in the quick overview of locations with high intensities of impact. A personal computer served as the platform for the data acquisition hardware. A threshold force of 4.5 N (≈1 lb or 5% of ATD body weight) was used to establish the onset of contact between the ATD and impact surface.

Table 1
Evaluated fall scenarios, ATD center of gravity (CG) position and impact surfaces.

Fall type and initial position	CG height (cm/in)	Surface type
Rearward – upright	46 (18)	Padded carpet on wood Linoleum tile on concrete
Rearward – posteriorly inclined	38 (15)	Padded carpet on wood Linoleum tile on concrete