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Author(s):	Gina E. Bertocci, Ph.D., P.E.
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PD/PI Name, Title and Contact Information (e-mail address and phone number):

Gina E. Bertocci, PhD, PE

Professor, Bioengineering

Endowed Chair of Biomechanics

University of Louisville

Ph: 502-852-0296

g.bertocci@louisville.edu

Name of Submitting Official, Title, and Contact Information (e-mail address and phone number), if other than PD/PI:

Barbara Sells, Associate Director, Sponsored Programs Administration – Grants Division

bfsell01@louisville.edu , Ph: 502-852-8362

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Development of a Computer Simulation Model to Describe Potential Bruising Patterns Associated with Common Childhood Falls

Office of Investigative and Forensic Sciences, National Institute of Justice Award # 2014-DN-BX-K006

PI: G. Bertocci– University of Louisville

Final Report – Nov 2017

Project Purpose

Child abuse is a leading cause of fatality in children aged 0-3 years, with approximately 1,649 fatalities annually[1]. Infants (younger than 1 year) are at greatest risk. Most infants and children have earlier, non-life threatening injuries prior to a fatal assault. These earlier injuries, termed sentinel injuries, are often misinterpreted as accidental trauma due to false histories provided by caregivers.[2] The ability to detect child abuse in its earliest stages has proven to be critical in the prevention of escalating injury severity and even death. Bruising is the earliest sign of physical abuse, and previous studies have shown differences in the number of bruises and their location on the body when comparing accidental vs. abusive trauma.[3-18] Differentiation between accident and abuse based upon bruising patterns presents an opportunity for early diagnosis/detection of abuse, as well as a means to exonerate innocent families in cases where accidental trauma has occurred. Bruising patterns (the constellation of individual bruises throughout the body) provide a "roadmap" documenting a child's exposure to impact; information that can be critical in forensic analysis. Currently there are limited means to predict potential bruising patterns associated with common household falls or abusive events, and they do not include the ability to investigate the influence of fall environment- and child-specific parameters. Moreover, knowledge of potential bruising patterns and corresponding injury events does not exist. Instead, clinicians, child protective services, law enforcement personnel and judicial officials are left to rely upon disparate and sparse clinical observational reports to determine whether a child's bruising pattern is compatible with the stated cause.

The purpose of this study was to develop and use a 3D computer simulation model representing a 12-month old child to predict potential bruising patterns associated with common household falls often falsely reported as the cause of injury in abuse. By using computer modeling to develop a virtual bruising detection system (VBDS) it will enable investigation of the influence of fall victim characteristics and fall environment parameters on potential bruising patterns. Our proposed unique approach is innovative and provides an objective tool to facilitate early recognition of physical abuse and will aid in forensic analysis of pediatric injuries. In addition to protecting abused children, innocent families wrongly accused of abuse will also benefit from the application of our scientific, objective-based tool. Our long-term goal is to improve early detection of physical child abuse so as to prevent further exposure to abusive trauma and to improve the accuracy of forensic analysis.

Project Subjects

No human subjects were used in this study.

Methods

The goals of our project were to develop a virtual bruising detection system implemented through 3D computer simulation model to predict potential bruising patterns associated with common household falls that can be falsely reported as injury causing scenarios in child abuse, and to understand the influence of child and fall environment parameters on bruising patterns. We achieved our project goals through the following aims:

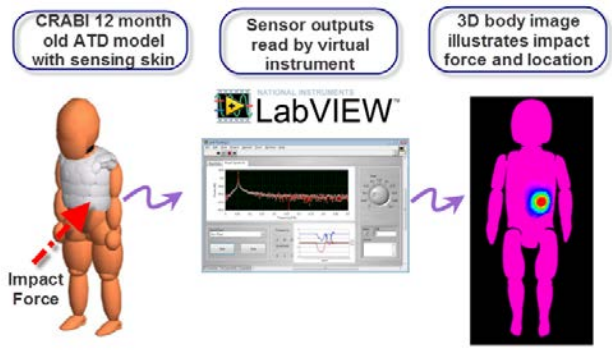
<u>Specific Aim 1</u>: Develop a 3D child surrogate computer model capable of capturing, recording and displaying impact locations and force when used in simulated injurious events.

Objective 1a: *Develop a virtual sensing skin, adapted to a child surrogate computer model that will identify impact locations and measure forces resulting from impact(s) during simulated fall events.* A 3D computer model of an existing pediatric anthropomorphic test device (ATD) (CRABI 12 month old) available within MADYMO (MAthematic DYnamic MOdeling) software (MADYMO software is a multi-physics simulation engine that is used for the design and analysis of complex dynamic systems) was modified, overlaying a force sensing skin on the ATD surface. This force sensing skin allows for the measurement of impact forces and locations of impact experienced when using the ATD in fall simulations. Facet-based modeling was used to create a meshed skin that interfaces with the individual rigid body segments of the ATD. Mesh resolution corresponded with the number of sensors per segment.

Objective 1b: *Design and develop a virtual instrument that will read and compile output data from the virtual sensing skin adapted to the child surrogate computer model.* A custom Labview (National Instruments) Virtual Instrument (VI) was developed to acquire, analyze, store and display force and location data from the MADYMO model. Each sensor has a unique identifier to mapping its output to the corresponding sensor on the model.

Objective 1c: *Develop a computerized visual body mapping system capable of displaying impact force and corresponding location patterns of potential bruising during simulated events.* A 3D body map image paralleling the MADYMO ATD virtual sensing skin was developed in Labview and used to display sensor force and location data. Data collected from each sensor in MADYMO is mapped to corresponding sensors on the 3D body map image.

Objective 1d: *Integrate and test the bruising detection system consisting of the virtual sensing skin adapted to the surrogate computer model, the virtual data acquisition system and computerized body mapping image system.* Function of the complete virtual bruising detection system was verified through application of known forces to each segment of the ATD model.



Specific Aim 2: Describe potential bruising patterns in children associated with bed falls.

Objective 2a: *Utilize the developed virtual bruising detection model (Specific Aim 1), to simulate bed falls to determine corresponding impact locations.* The virtual bruising detection system will measure impact data from bed falls at 20" and 36" heights, and will characterize impact locations (activated sensors) and force applied to the ATD upon contact with the carpeted floor.

Objective 2b: *Conduct bed fall experiments replicating the model fall parameters using our (physical) surrogate bruising detection system to assess impact locations.* Our previously developed surrogate bruising detection system[19] consisting of a (physical) 12-month-old CRABI ATD equipped with a custom force sensing skin, data acquisition system, and data processing/analysis software was used to perform a series of bed fall scenarios replicating those simulated *in silico* (Objective 2a).

Objective 2c: *Evaluate computer simulation model's predictive capability by comparing potential bruising patterns predicted by computer model to those predicted using surrogate* *experiments.* Computer model predicted potential bruising patterns (Obj 2a) will be compared to surrogate fall experiment-predicted potential bruising locations (Obj 2b).

Objective 2d: *Conduct a parametric sensitivity analysis using the model to investigate relationships between model parameters (surrogate and fall environment) and outcome measures related to potential bruising patterns.* Relationships between model parameters and outcome measures associated with fall dynamics and potential bruising patterns (body regions, body planes, number of body planes, and total number of potential bruises) will be investigated.

Data Analysis

No data analysis was necessary for Specific Aim 1, since it consisted of only design and development activities. For Specific Aim 2 - Objective 2b (bed fall experiments), a two-way analysis of variance (ANOVA) test was used to determine if changes in initial position and impact surface characteristics led to significant differences in impact forces applied to body regions. Additionally, post-hoc tests were conducted to further examine where significant differences existed ($p \leq 0.05$). Data was evaluated for normal distribution. Individual sensors were grouped by body region. Body regions were defined as head, anterior torso, posterior torso, left and right upper arm, left and right lower arm, left and right upper leg, and left and right lower leg.

Findings

Specific Aim 1: The virtual bruising detection system (Fig 1) that integrates: 1) a 3D pediatric computer model equipped with a virtual sensing skin having the capability of measuring impact force and locations of impact, 2) a data acquisition system that reads individual sensor output and corresponding sensor location from the computer model, and 3) a 3D body mapping system that displays force and location data from activated sensors during simulated events, was developed and validated (Fig 2). The VBDS is capable of simulating falls or other injurious events *in silico*, while measuring and recording force imparted to the body during the event. The VBDS is equipped with 132 virtual sensors capable of detecting the application of force applied to the 3D model representing a 12-month-old child.

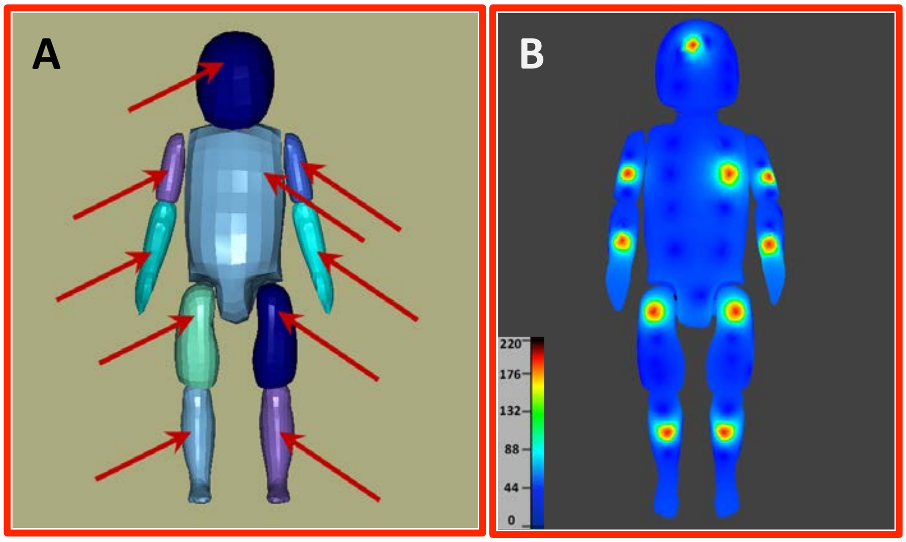


Figure 2. Virtual bruising detection system (VBDS) validation process illustrating application of force to each body region in MADYMO model equipped with the sensing skin (A; arrows depict force application) and associated output indicating regions of potential bruising and level of force in custom Labview body map (B). The application of force and assessment of corresponding output was repeated for each of the 132 sensors as part of the system validation process.

Specific Aim 2: While this work is still on going and scheduled to be complete by Dec 31, 2018, bed fall experiments using our surrogate bruising detection system (SBDS) have been conducted (Obj. 2b). Our SBDS adapted to an ATD representing a 12-month-old was used to investigate potential bruising locations (contact during impact) associated with bed falls from varying heights and initial positions. Across all trials, primary contact occurred on one plane of the ATD body, with secondary contact occurring only on adjoining planes (Fig 3 & 4; representative results); no contact was recorded on planes opposite the primary contact plane. This finding is important to forensic investigations given that this feature alone can support or reject whether the provided fall description is biomechanically compatible with a child's presenting injuries. The number of planes where bruising is present should be the first characteristic of injuries that is evaluated when attempting to determine biomechanical compatibility between history and injuries. Regions of contact were found to differ with varying fall heights and initial positions, but number of planes having evidence of impact and their orientation to each other (i.e. adjacent) remained the same. While many extrinsic and intrinsic factors determine whether bruising will occur on impact, documentation of potential bruising locations based upon recorded contact to individual body regions is a first step towards understanding bruising patterns that may result from a bed fall. This knowledge can potentially aid in delineating bruising patterns associated with an accidental bed fall versus that of a falsely reported bed fall.

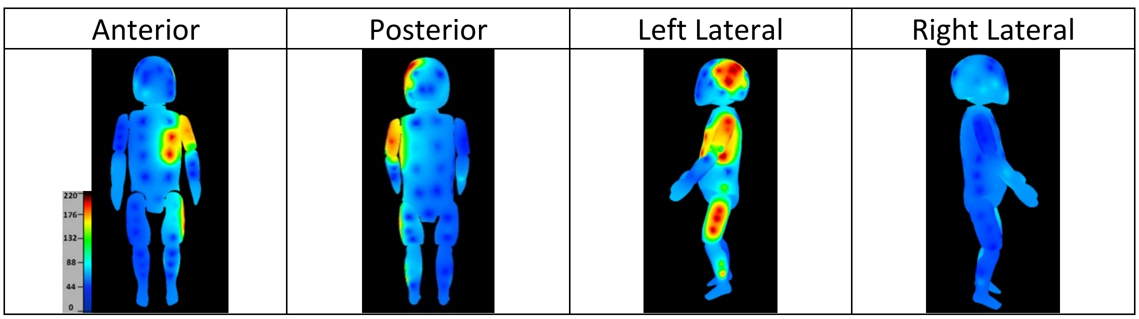


Figure 3. Cumulative contact regions across 5 trials as recorded by the SBDS for the forward facing initial position, 61 cm height fall scenario during physical experiments. Body map images show the anterior, posterior, left lateral and right lateral aspects of the ATD. The colors and intensities vary dependent on level of force (N) imparted to specific regions during the fall event.

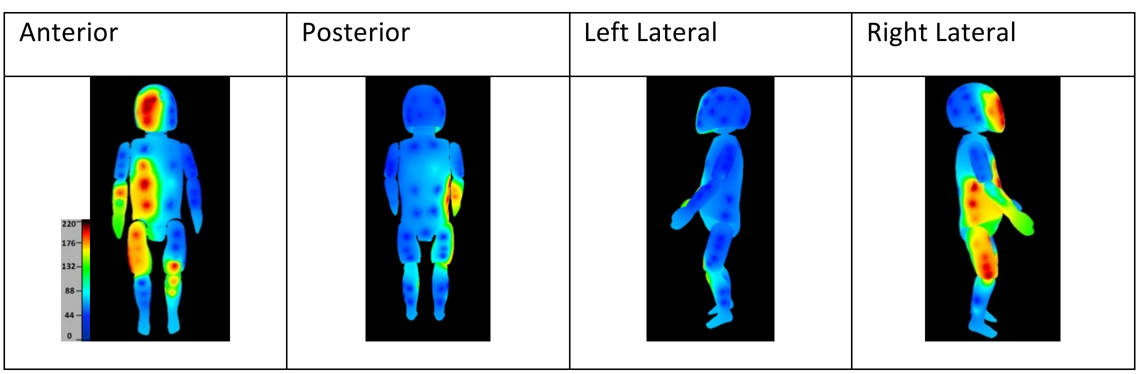


Figure 4. Cumulative contact regions across 5 trials as recorded by the SBDS for the rearward facing initial position, 61 cm height fall scenario during physical experiments. Body map images show the anterior, posterior, left lateral and right lateral aspects of the ATD. The colors and intensities vary dependent on level of force (N) imparted to specific regions during the fall event.

Scholarly products

1. Dsouza R, Bertocci G. Impact Sites Representing Potential Bruising Locations Associated with Bed Falls in Children, Forensic Science International (in review), Oct 2017.

2. Dsouza R, Bertocci G. Design, Development and Use of a Surrogate Bruising Detection System to Describe Impact Sites (Potential Bruising Patterns) Associated with Falls in Children, *Shaken Baby Syndrome/Abusive Head Trauma Symposium*, Montreal, Canada, Sept 2016.

Implications for criminal justice policy and practice in the United States

This *in silico* virtual bruising detection system provides an objective method to describe bruising patterns that can occur in abuse and accidental events. Oftentimes expert witnesses overlook a child's bruises given their non-life threatening nature. However, bruising patterns are a "roadmap" to a child's exposure to impact, whether due to accident or abuse. Bruising patterns represent critical evidence that enable reconstruction of an alleged fall to determine biomechanical compatibility between presenting bruises and those expected based upon fall dynamics associated with the described fall event. The virtual bruising detection system developed in this study enables prediction of potential bruising patterns (constellation of bruises across the body) in alleged events such as falls. Our virtual bruising detection system can provide objective data for pediatric forensic analyses conducted by child abuse physicians, law enforcement and legal personnel, and judicial officials as to potential bruising patterns that can be expected in common household falls often provided as false histories in an effort to conceal child abuse. Conversely, use of our VBDS in its ability to provide objective data regarding bruising patterns can also aid in the exoneration of those who are innocent of alleged abuse. In summary, our *in silico* virtual bruising detection system provides an objective method to elucidate differences in bruising patterns that can occur in abuse vs. accidents as a source of evidentiary data in the diagnosis and medico-legal investigation of child abuse.

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