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Applications of Biomechanics Aiding in the Diagnosis of Child Abuse

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Injury biomechanics is the field of study focusing on the biomechanical behavior of the human body under injury-producing conditions. One of the unique challenges faced by pediatric emergency medicine clinicians is distinguishing between inflicted and non-inflicted injuries in children. Biomechanics is one tool that can aid in determining the compatibility between a child's injury and the reported mechanism of injury. An overview and examples of various biomechanical approaches used to distinguish between inflicted and noninflicted injuries in children are described.
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Injury biomechanics is the field of study focusing on the biomechanical behavior of the human body under injury-producing conditions at both the macroscopic and microscopic levels. It is a multidisciplinary field bringing together engineering and medicine. Injury of the human body occurs by deformation of anatomic structures beyond their failure limits, resulting in damage of tissue or alterations in normal function. Injury biomechanics uses the principles of engineering mechanics to study the behavior of biologic tissue exposed to injurious conditions. Injury biomechanics research relies upon analytical, experimental, and numerical simulation techniques to answer questions such as how an injury has occurred (injury mechanism), how tissue responds to specific injurious conditions, and what levels of exposure to force, acceleration, and so on are injurious to the body (injury tolerance).

One of the unique challenges faced by pediatric emergency medicine clinicians is distinguishing between inflicted and noninflicted injuries in children. Biomechanics is a tool that can aid in determining the compatibility between a child's injury and the reported mechanism of injury. Most of the current biomechanical research working toward distinguishing inflicted versus noninflicted injuries in children can be classified into 4 primary categories: (1) case-based investigation or assessment, (2) test dummy or human surrogate experiments, (3) computer modeling or simulation, and (4) animal injury models (Figure 1). A brief description of these categories of biomechanical research, as well as examples of studies using these various biomechanical approaches in the area of pediatric injury and child abuse, is provided below.

Case-Based Investigations or Assessments

A better understanding of injuries that can result from a specific event can be achieved through detailed investigations and dynamic reconstructions of how noninflicted injuries occur. Knowing the types of injuries that can result from a specific event type (eg, stair fall, bed fall) and understanding the dynamics of the event that led to a child's injuries can be important to those attempting to determine whether a stated cause and resulting injuries are compatible. For example, it would be useful for clinicians to know the possible types of injury that could be expected from a stair fall. Furthermore, an understanding of the dynamics of a fall event and associated

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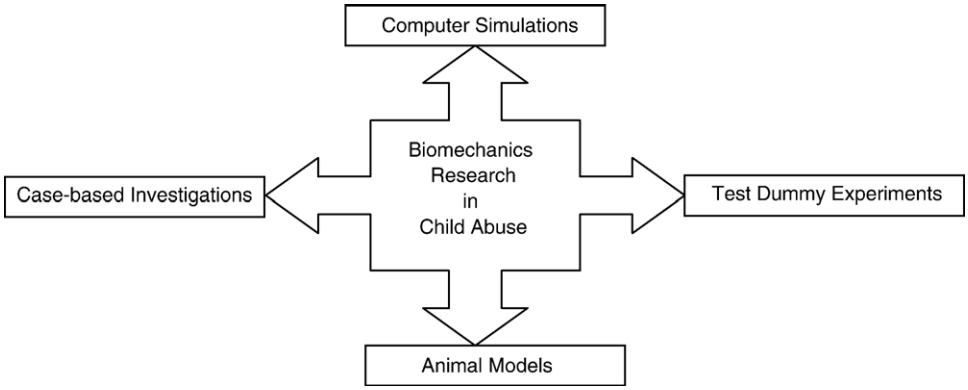

Figure 1 Classifications of biomechanics research contributing to the field of child abuse detection.

body contact points could aid in determining whether a child's injuries could have been produced from the history provided by the child's caregiver.

Characteristics of a fall such as the initial position, fall height, impact surface, and landing position are also important in understanding resulting injuries because these factors have been shown to be related to injury risk [1-5]. Furthermore, calculated biodynamic outcome measures of a fall, such as the child's energy, impact velocity, and momentum, can also provide insight into an event's relative injury-producing potential. These measures can be useful when attempting to make overall comparisons of fall events.

Examples of Studies Using Case-Based Investigations or Assessment

A 1977 study conducted by Snyder et al [6] investigated impact tolerances of the head and lower extremities in free-fall events occurring in children, female adults, and the elderly. This study used a combination of techniques and investigative strategies to create a database, analyze injury patterns, and define an association between biomechanical measures and injury severity. These researchers relied upon scene investigations, medical record assessment, theoretical biodynamic calculations, experimental free falls using anthropometric test devices (ATDs, commonly referred to as "test dummies"), and 2-dimensional computer simulation models to predict key biomechanical impact measures that have previously been correlated with injury risk. It was found that for given fall conditions, children were generally injured less severely than adults exposed to the same conditions. Whole-body energy, impact velocity, and momentum were calculated for each fall case. Correlations between injury severity level and whole-body biomechanical measures were observed only for headfirst type falls. For children 18 months and younger, a fall distance of 4 to 10 ft was determined to be the threshold for skull fracture. Headfirst falls from greater than 10 ft onto a rigid surface were predicted to result in skull fracture or concussion, and at least an Abbreviated Injury Scale (AIS) severity 2 score of AIS-2 (moderate) injuries for adults and children.

Pierce et al [7] used case-based assessment to gain a better understanding of femur fractures resulting from stair falls and to develop an injury plausibility model. Twenty-nine children and infants, 2 to 36 months old, who presented to the emergency department with a femur fracture from a reported stair fall, underwent a detailed history assessment, physical examination, and fracture characterization. Injury scene investigations and a biomechanical assessment of the event were conducted. A number of key factors, including the biomechanical compatibility of the injuries and event, were used in the injury model to distinguish between plausible and nonplausible scenarios. This study demonstrated the important role that biomechanical compatibility assessment plays when developing a predictive model. The study also determined key biomechanical measures such as energy, momentum, and impact velocity associated with each stair fall case. Among those cases determined plausible, momentum was found to be 10 times higher in transverse fractures as compared with buckle or spiral fractures. This type of biomechanical characterization can aid in the understanding of the conditions necessary to produce specific types of injuries.

Test Dummy or Human Surrogate Experiments

ATDs are human surrogates that have been used for many years in automotive crash studies to represent motor vehicle occupants. ATDs are a mechanical analogue of a human and provide opportunities to measure mechanical quantities such forces, strains, and accelerations during exposure to impact, accelerations, or other potentially injurious conditions using onboard instrumentation (eg, accelerometers, force sensors). These measurements can then be compared with established injury thresholds to

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