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INJURIES RESULTING FROM FALLS

David L. Chadwick, MD, Gina Bertocci, PhD, and Elisabeth Guenther, MD, MPH

INTRODUCTION

Short falls causing minor injury occur very frequently in infants and children. Long falls causing more serious injury are not rare. Serious inflicted injuries are often falsely attributed to short falls by the persons who inflicted them.[1]

Bipedality is the quintessential characteristic of humans,[2] and the bumps and bruises from the falls of infants and young children are part of the evolutionary price paid for this advantage. Falling is universal among children who are learning to walk. In addition, young children often climb to and fall from elevated surfaces. However, if such falls were often fatal, the human race would not have survived.

In the 1960s Kravitz[3] studied infant falls by asking mothers about their children's falls. In one study, he asked the parents of infants attending a clinic to recall the falls of their children aged 10 months to 2 years some months after the falls occurred. The other focused on 336 infants under 1 year of age, asking parents to describe falls soon after they happened. Both studies were of falls from elevated surfaces rather than ground level falls. Both groups demonstrated "peaks" of fall incidence around 6 to 8 months, but both found falls at all ages including at 1 month of age. During this study, 536 infants experienced 328 falls, and about half of all infants fell at least once. Eighteen infants were hospitalized and none died. Three infants had skull fractures, two had concussion, and one had a subdural hematoma. There were no extremity fractures. Kravitz stated that child abuse was not found in any of these cases, but he did not explain how it was excluded. The most frequent circumstance leading to a fall was climbing out of a crib, and Kravitz concluded that crib design was the most important correctible factor.

Warrington and Wright[4] used the ongoing Avon Longitudinal Study of Parents and Children (ALSPAC) that had enrolled 14,000 newborn babies and their parents for prospective determination of their illnesses and injuries and associated risk factors. A questionnaire administered to all parents when the infants were 6 months of age inquired about falls and resultant injuries. Data were available for 11,466 infants; 2554 of them generated 3357 falls from "elevated places." Falls from beds or settees comprised 53% of the falls, and 10% of the infants fell from someone's arms. The rest fell from chairs, changing tables, prams, bouncers, and tables, and 5.6% "fell over" (a term not defined). An injury was sustained in 437 cases. Serious injury, defined as concussion or fracture, occurred in 21 cases (<1% of falls). Eighteen were admitted to hospital. No deaths or life-threatening injuries were reported, and the authors concluded that although falls in infants less than 6 months of age are "surprisingly common," injuries were "… infrequent, generally trivial, and almost entirely confined to the head."

Figure 59-1 captures sequential snapshots of a toddler's fall recorded in a childcare center and demonstrates why the vast majority of ground level falls in this age group are benign. Short falls have been shown to result in minor trauma such as bruising, linear parietal skull fractures, and clavicle or extremity fractures, but fatal injuries from short falls are extremely rare.[5]

A rational discussion of injury mechanisms requires the use of standard definitions. Definitions have been provided by the work of Christoffel,[6] the ICD-9,[7] ICD-10,[8] and other sources. The definitions used are found in Table 59-1.

TYPES OF FALL INJURIES

Head Injuries with Fall Histories

Most children with life-threatening head injuries present with impaired consciousness and sometimes altered breathing or full arrest. In some cases, the child is dead at the scene or on arrival at the hospital. This chapter applies to those children who survive long enough to reach a setting in which a thorough medical evaluation is possible. Many children with head injury from falls have obvious head bruising, but many do not. Certain patterns of bruising, however, would be unlikely to have been caused by a fall and should alert the clinician to the possibility of abuse. Figure 59-2 (found in Chapter 59 Supplemental Resources online at www.expertconsult.com) shows such an injury.

Complex and diastatic skull fractures (see Figure 59-3 online) have not been reported in association with short falls in observed settings such as hospitals. Their presence indicates that a major force was involved in the injury event.[9] Initial presentation with obvious severe injury and a minimal event history is typical of inflicted head injury.[10]

One type of serious cranial injury that is well known to be caused by short falls is the epidural hematoma (see Figure 59-4 online). A laceration of an artery can cause bleeding between the dura and the skull, leading to the rapid accumulation of a large, space-occupying hematoma. This can cause life-threatening increased intracranial pressure and deep coma or death. Epidural hematomas are easily recognized on CT scans and can be successfully treated if surgery is performed quickly after diagnosis.[11] In some cases,

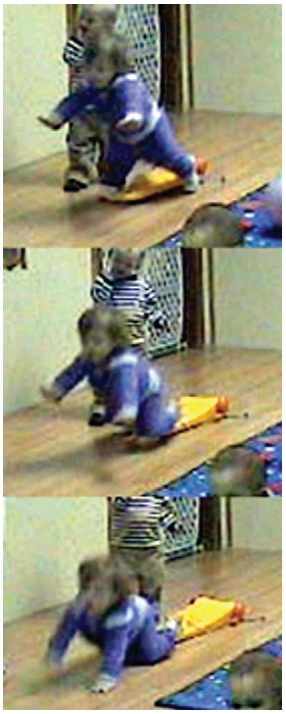

FIGURE 59-1 Illustration of a toddler's fall. These three images illustrate the use of video to study the common falls of toddlers. The toddler crumples forward, absorbing energy at multiple points on her body including her knees and hands. No damage occurs.

the epidural hematoma will communicate through a skull fracture with a subgaleal hematoma.

Abdominal Injuries with Fall Histories

Life-threatening abdominal injuries, usually present in one of two ways: (1) hypovolemic shock, which can occur shortly after injury, or (2) sepsis and peritonitis, which occur hours or days after an injury perforating a hollow viscus. There may or may not be bruising present on the abdominal skin. Sometimes bruising on the back over spinous processes provides a clue that the child was injured by deep indenting blunt trauma to the abdomen while lying on the back on a firm surface (see Figure 59-5 online).

Recognition of abdominal injury as a cause of otherwise unexplained hypovolemic shock requires experience and a high index of suspicion on the part of the physician. In these cases, shock results from blood loss into the peritoneal cavity from damaged viscera or blood vessels. Clinicians might be misled by short fall histories that do not predict life-threatening injury, and the abdomen can be soft. Children with serious intraabdominal bleeding can look fairly normal for a time and then deteriorate very quickly. Several useful articles discuss evaluating possibly inflicted abdominal injuries.[12-21] Short falls of previously healthy infants and young children are extremely unlikely to cause life-threatening abdominal injuries.[15]

Chest Injuries with Fall Histories

Unexplained healing rib fractures are sometimes found on skeletal surveys obtained in infants and toddlers who are being evaluated for possible child abuse (see Figure 59-6 online). Posterior and lateral rib fractures, pulmonary contusions, and hemothoraces are more likely to be caused by child abuse rather than falls, although complex falls and falls from heights can also cause these conditions.[22] Rarely, infants and children present with cardiac injuries such as hemopericardium, again a finding not likely to occur in a household fall and more often found in inflicted injuries.[23] There is a single case report of ventricular fibrillation (commotio cordis) following a fall.[24] The condition is difficult to diagnose in living children and almost impossible after death in the absence of an accurate history.[25]

Table 59-1 Definitions Used in this Chapter

Elevated surface	A surface above ground or floor level
Fall	To come down by force of gravity suddenly (noun or verb).
Fall height	The change in height of the center of gravity of the falling object from the starting point to the ending point of the fall (In practice, usually the height of an elevated surface from the floor or the ground)
Ground level fall	A fall beginning and ending at ground level usually from standing to prone, supine, or sitting position
Infants	Persons at ages between birth and the first birthday
Injury	1. An event resulting in damage to a body part; 2. The damage or pathology resulting from an event
Intentional injury	Injuries that were intended to injure a person (i.e., assaults, homicides, self-inflicted injuries, and suicides)
Long fall	A fall of >1.5 meters
Nonaccidental injury	An injury inflicted by other than accidental means often without clear intent to cause injury
Outcome	The status of a case at an advanced or ultimate point
Point of recognition	The point in a case at which a health professional has a "reasonable suspicion" that the child with an injury and a fall history might be injured by "other than accidental means"
Short fall	A fall of <1.5 meters (includes falls from all household furniture items except bunk beds)
Young children	Persons between birth and the fifth birthday

Less Serious Injuries

Fractures of the extremities and linear parietal skull fractures occur infrequently (in about 1%) in the short falls that have been witnessed by multiple people in hospitals.[26-29] Other minor and moderate injuries, including concussion,[3,4] are often associated with less reliable short fall histories. Pierce et al[30] has provided an algorithm for the analysis of femur fractures occurring in association with short fall histories. It focuses the criteria suggested by Leventhal et al.[31] The algorithm points out that "… differences exist in 4 key categories: (1) history quality and detail; (2) biomechanical compatibility of the fracture morphologic features; (3) time line for seeking medical care; and, (4) presence of other injuries."[30]

The widespread use of definitions of abusive injury, which require that the injuries be severe in relationship to their explanations, has created an epidemiological anomaly. It has resulted in an apparent high case fatality rate for abusive as compared with unintentional injury. It is important to improve the recognition of minor and moderate inflicted physical injuries, because the affected children are likely to be at risk for future, more serious, injury.

Recognition and Reporting

The "point of recognition" is that point in the case at which a health professional has a reasonable suspicion that the child with an injury and a fall history might be injured by "other than accidental means." At this point a report is usually made to a child protection agency. From that point forward the process of medical assessment requires confirming or excluding that diagnosis. The point can occur as early as the first health care contact or as late as at autopsy or during an even later review by a child fatality review team. In most cases, the parents or guardians of the child should be informed that a report has been made and that an investigation will probably follow. Reporting suspected abuse is mandatory in all states, although details may vary.[32] There can be criminal sanctions and civil liability for failure to report suspected abuse.

"Points of recognition" are not unique to inflicted or abusive injuries. They occur in any medical condition, when the physician becomes aware that the facts in the case require one or more serious conditions to be diagnosed or excluded as soon as possible. However, in cases of suspected abuse when a report is made to an agency, the caretakers who are providing histories of the events leading up to the child's change of condition may adopt attitudes aimed at protecting themselves and alter the histories that they provide.

IS IT A FALL OR IS IT ABUSE? ASSESSING THE CHILD

The initial clinical assessment of the child presenting to the emergency department with the history of a fall begins by rapidly assessing the injury and medically stabilizing the child before further evaluation is undertaken. Once the child is stabilized and assessed, the process of differentiating among nonintentional trauma, abuse, or neglect begins. A complete description of the appropriate medical workup for a child presenting with the history of a fall when possible child physical abuse or neglect is being considered can be found in Chapter 59 Supplemental Resources online at www.expertconsult.com.

Radiological Imaging

Radiological imaging, including CT, is helpful in determining the types and severity of injury and is warranted in cases in which the physical examination is unreliable because of patient age, presence of other injuries that may obfuscate the physical examination, or the presence of nonspecific signs or symptoms that could be indicative of head injury.[33,34] (See Chapter 46, "Biochemical Markers of Head Trauma in Children"; Chapter 33, "Imaging of Skeletal Trauma in Abused Children"; Chapter 34, "The Role of Cross-Sectional Imaging in Evaluating Pediatric Skeletal Trauma"; and Chapter 35, "Long Bone Fracture Biomechanics.")

CONSULTATIONS

Consultations and involvement of pediatric subspecialists in the diagnostic workup, medical management, and appropriate documentation of these cases vary significantly depending on several factors including the severity of the injury, the type of injury, the age of the child, and the examination findings. Many institutions now have multidisciplinary medical/surgical teams to efficiently manage these potentially complex cases with the associated medical, psychological, social, and legal implications.

Differential Diagnosis

When considering whether an injury is caused by a fall or by abuse, several characteristics of the injury and the event will give the clinician important information. Table 59-2 outlines these characteristics of injuries.

Biomechanical Assessment of Stated Fall Scenarios

A biomechanical assessment of a fall scenario presented as the cause of a child's injuries can provide additional objective information when attempting to distinguish abusive and nonabusive trauma. A biomechanical assessment can be best undertaken by a multidisciplinary team of clinicians and engineers; however, in the absence of an engineer, clinicians can follow some of the same basic principles in their assessment that would be used by an engineer. In particular, scene investigations and the approach outlined in the biodynamic compatibility section can be followed by clinicians when challenged to distinguish between abusive and nonabusive trauma. In contrast, biomechanical analyses must be conducted only by an engineer with the appropriate training and expertise.

Scene Investigation for Biomechanical Assessment

When conducting scene investigations, it is imperative that characteristics of the fall environment be carefully documented. Documentation should include photographs of the scene, including photographs documenting the orientation of any objects (bed, sofa, etc.) involved in the event.

Table 59-2 Differential Diagnosis of Physical Examination Findings Presenting in Cases of Alleged Falls that Can Be Associated with Abusive Injury

Body Region/Injury Type	Relationship to Abuse	Differential Diagnosis
Head Subdural hematoma (SDH) Subarachnoid hemorrhages (SAHs) Cerebral edema Skull fractures Parietal fractures Multiple or bilateral skull fractures	20% of abused children suffer CNS trauma. It is fatal in 7-30%. 30-50% sustain permanent deficits. Injuries to the brain and spinal cord account for 75% of the deaths caused by abuse. 50% of abuse fatalities have SDH. SDH is the most common injury in shaken baby syndrome. Cerebral edema is found in 66% of abuse fatalities. Depressed, diastatic, nonparietal and complex skull fractures are more common in abuse. 80-90% of abusive skull fractures are parietal fractures.[31,35] Multiple or bilateral skull fractures are more likely caused by abuse in the absence of major accidental trauma.	Glutaric aciduria type 1 (characteristics: macrocranium, SDH, sparse intraretinal and preretinal hemorrhages, frontotemporal atrophy) and hemorrhagic disease of the newborn (risk factors: home birth, no vitamin K prophylaxis, breastfeeding). Simple linear skull fractures can result from short falls of less than 3 ft, are usually associated with scalp bruising and/or swelling. Simple linear parietal fractures can occur by toddlers falling from standing.
Skin Bruises on protected areas (neck, face, ears, trunk, buttocks, and hands)	High-velocity injuries (e.g., slap or cord mark) leave a petechial image or outline of the object.[36] Low velocity or severe forces leave a "positive" bruise image in children 0-8 months old. Bruises in protected areas are more likely caused by abuse.[36-39]	Less than 1% of bruises in infants under 6 months old have accidental bruises. Less than 3% of children who are not yet cruising have accidental bruises.[37] Other causes of bruises include accidents, coagulopathies (idiopathic thrombocytopenic purpura, vitamin K deficiency, hemophilia, von Willebrand disease), and vaculitis (Henoch-Schönlein purpura).
Head, Eyes, Ears, Nose Throat Scalp Eyes Nose Ears Mouth Neck	50% of documented abuse cases include orofacial trauma. Bald areas on the scalp can be caused by traction alopecia. Severe malnutrition causes thinning of hair. Extensive, multilayer retinal hemorrhages extending from the posterior pole to the ora serrata are often caused by acceleration/deceleration forces.[40] These types of hemorrhages are not likely to be found in impact injuries.[41] Bleeding from the nose and mouth occurring with apparent life-threatening events are associated with suffocation.[42] Pinna bruising associated with SDH, retinal hemorrhages, and cerebral edema has been called "tin ear syndrome."[43] Hemotympanum is associated with basilar or temporal bone fractures. Frenulum tears can occur with blows to the mouth or from forcing objects into the mouth. Extensive caries may indicate dental neglect. Ligature marks or finger marks can occur with strangulation.	Bald spots can be causes by tinea capitis, alopecia areata, and occipital bald spots because of the recommended supine positioning of young infants. Birth retinal hemorrhages can be extensive and multilayer, and usually clear within a few weeks. Hemotypanum can occur with leukemia. Frenulum tears of the upper lip can occur in toddler falls.
Chest Ribs	Chest injuries are more common in child abuse cases than in accidental injury cases.[44] Rib fractures in children under the age of 3 are commonly caused by abuse.[45,46]	Cardiopulmonary resuscitation was not known to cause rib fractures in the past. AP resuscitation might cause fractures.[47] More fractures are seen if the periosteum is stripped.

Continued

Table 59-2 Differential Diagnosis of Physical Examination Findings Presenting in Cases of Alleged Falls that Can Be Associated with Abusive Injury—cont'd

Body Region/Injury Type	Relationship to Abuse	Differential Diagnosis
Abdomen Liver Duodenum Pancreas	Abdominal injury is found in 1-10% of abuse cases, but mortality in these cases is 40-50%. Bilious vomiting can be seen in abdominal injuries. Suspect liver injury if AST >450, ALT >250.[48] Liver is the most common solid organ injury in abuse. Left lobe is more commonly injured in abuse. Abused children are more likely to have a hollow viscous injury than children injured accidentally.[49] Abused children are younger and more likely to have a delayed presentation and a higher mortality rate. Pancreatic injury without a clear trauma history is suspicious for abuse.[50] Pancreatic pseudocyst can result from pancreatic injury.	Right lobe injuries are more common in accidental injuries.
Genitals/Anus	Unexplained bruises, tears, and lacerations can be caused by abuse.[51] Pregnancy and STD can be from abuse.	Straddle injuries can mimic abuse.
Extremities Classic metaphyseal lesions (CML) Diaphyseal fractures Humerus fractures Supracondylar fractures Clavicular fractures Spinous process fractures Sternal fractures Scapular fractures Vertebral body fractures and subluxations Fractures of the digits Multiple fractures of different ages	11-55% of abused children have extremity fractures. 80% of fractures caused by abuse are in children under 18 months old.[52] 2% of accidental fractures are in children under 19 months old. In immature bones, planar fractures occur through the zone of provisional calcification at the metaphysis (CML).[54] On x-ray, CML can appear as "bucket handles" or "corner fractures." Humerus fractures are suggestive of abuse in infants less than 15 months old.[55] Clavicular fractures are uncommon in abuse cases.[56] Spinous process fractures are highly specific for abuse. They can be caused by hyperflexion and hyperextension of the spine. Sternal fractures are unusual and highly specific for abuse. Scapular fractures are unusual and highly specific for abuse. Vertebral body fractures are moderately specific for abuse. They can be caused by hyperflexion and hyperextension of the spine and by vertical loading. Fractures of the digits are moderately specific for abuse. Multiple fractures of different ages are highly suspicious for abuse in the absence of bone disease.	Accidental leg fractures in infants have been associated with the use of "exersaucers."[3] Recently ambulatory toddlers can experience accidental spiral or oblique fractures of the tibia. Accidental spiral femur fractures can occur in older children who fall when running. Metabolic and genetic bone disease should be considered when abuse is suspected. Diaphyseal fractures are not specific for abuse. Supracondylar fractures can occur with falls on outstretched arms. Clavicular fractures can be caused by falls on an outstretched arm.
Other Concerning Conditions Seizures in infants Apnea or respiratory arrest Sudden infant death syndrome (SIDS)	These conditions frequently occur in abusive head trauma. Apnea/ALTE event at age > 8 months are high risk for abuse. Up to 10% of SIDS cases may actually be abuse fatalities.[57]	

Photographs should be taken from a number of vantage points or perspectives to allow for full view of the scene. Photographs of all objects that might have been involved with the injury should be obtained and movable objects should be identified as such.

A sketch of the scene, providing a plan (top) view and any necessary additional views to describe movable objects and fixed structures, along with their relative orientation to each other, should be made. Structures and objects that are a part of the scene should be measured and these measurements should be documented on a sketch. Dimensions should include height, width, and length of each object or structure. A second copy of the dimensioned sketch should be used to overlay the initial position (pre-fall) of the child as well as the resting or final position (post-fall) of the child. These positions should not only identify height of the child's feet above the impact surface, but also the child's posture (i.e., standing, sitting). Fall information should also describe final, post-fall orientation of the child (anterior, posterior, or lateral) relative to objects or structures at the scene as stated by witnesses.

In addition, samples of the impacted surfaces should be obtained when possible. For example, if the child fell onto a padded carpeted floor, samples of the carpet and padding should be obtained so that characteristics of the flooring can be determined. Similarly, if the child impacted an object during her descent, the material used to construct this object should be accurately described and documented. Information related to impact surface properties is key to a biomechanical analysis since these properties have been shown to affect biomechanical outcome measures such as resulting accelerations and force experienced by the body on impact.[58-61]

Biodynamic Compatibility of Stated Cause and Injuries

The objective of a biodynamic compatibility assessment is to determine whether the constellation of injuries is compatible with the biodynamics of the stated event.[30] In other words, as described, can the fall dynamics (how a child's body moves or falls from their initial pre-fall position to their final post-fall resting position) account for all of the presenting acute injuries? In fatal cases, *one must not only account for the underlying specific fatal injury, but also each and every acute impact injury associated with the event.* This includes all bruises, contusions, and lacerations even though they might not affect the child's overall health outcome. (Obviously, soft tissue injuries associated with medical interventions must be excluded from the biodynamic compatibility assessment.) Each of these soft tissue injuries associated with the fall will likely represent an impact or point of contact that must be accounted for in the fall dynamics. These markings provide a "roadmap" to the child's exposure. For example, a single free fall from standing on a 12-inch high chair onto a padded carpeted floor without impacting any objects during the descent cannot account for the combination of a subdural hematoma; bruising to the lateral, posterior, and anterior aspects of the head; and bruising to the buttocks and lacerations to the anterior thorax. Such a fall would lead to markings or injuries associated with impact to *one* plane of the body. If a child fell rearward from a chair, one would expect to find evidence of impact on the posterior aspect of the body, but no markings or evidence of impact on the anterior portion of the body. Using an approach that accounts for the entire "roadmap" of injuries provides an objective means of determining biodynamic compatibility of presenting injuries and their stated cause.

Biomechanical Analyses of Stated Falls

In addition to a qualitative biodynamic compatibility assessment, in some cases that proceed to litigation, a more extensive biomechanical analysis is sometimes desired. A biomechanical analysis typically strives to approximate accelerations, velocities, or forces associated with the stated impact event. These biomechanical measures, which are known to be related to injury risk, can be estimated for a particular body region or for the entire body. For example, estimated angular head acceleration can be compared with published injury thresholds to predict the risk of a subdural hemorrhage.[62-65] To estimate biomechanical measures such as acceleration or velocity, additional information must be obtained related to the child and fall event, and assumptions may need to be made. Information such as the child's mass, overall height, anthropometrics, and percentiles of growth are needed, and can influence the estimation of biomechanical measures.

In an unwitnessed fall event, assumptions regarding the fall dynamics (i.e. how the child's body moved during descent and their position upon impact with a surface), initial position and final position must be adopted for the analysis. Knowledge or assumption regarding the child's position just prior to impact is key to the analysis. For example, if a child impacts the ground head first, as opposed to feet first, this has a substantial influence on estimated head acceleration.

Biomechanical analysis is possible using a variety of methodologies, but it is critical that methods are based on the principles of physics. Such techniques can include manual calculations, use of surrogates (anthropomorphic test devices or "dummies") representing the child in fall experiments, or computer simulation modeling.[66] In each approach the goal is to determine key outcome measures associated with a given fall, which is then compared with injury thresholds to determine likelihood of injury. The advantages and disadvantages of the three methodologies are described in Table 59-3.

Manual calculations, based upon theories or laws of physics (conservation of energy, conservation of momentum, etc.), often represent the fall victim as a simplified lumped mass or rigid body with a specified mass and height (in the case of a rigid body) representative of the child. A commonly used rigid body representation is that of an inverted pendulum that consists of a rod representing the torso and lower extremities and a mass representing the pendulum or head of the fall victim. Assumptions or known facts regarding initial position, fall dynamics, and impact surface characteristics are incorporated, and physics-based computations are performed to estimated key outcome measures such as accelerations or velocities.

Surrogates have also been used in the estimation of biomechanical outcome measures associated with a fall.[67-69] These surrogates could be customized representations of the fall victim or commercially available anthropomorphic test devices. Biofidelity of surrogates (how human-like they are) relates directly to their ability to accurately predict the exposure of a child in a given circumstance. For example, when assessing head injury, the design and construction of the surrogate neck must be biofidelic in its response to exposure of force application. The surrogate must be biofidelic in all of its joint responses, as well as body segment anthropometrics and inertial properties (mass distribution). Surrogates are typically equipped with instrumentation such as accelerometers, and load cells to determine key outcome measures from various body regions. Mock fall experiments are then conducted to recreate the stated fall during which data are collected from the onboard instrumentation. Mock

Table 59-3 Some Key Advantages and Disadvantages of Various Biomechanical Analyses Methodologies

Method	Advantages	Disadvantages
Manual physics-based calculations	Requires relatively limited time to perform Basic level engineering knowledge sufficient to perform	Greatly simplifies representation of child Greatly simplifies fall dynamics Theories or laws forming basis of calculations incorporate assumptions
Surrogate experiments	Physical device can be instrumented to assess outcomes of multiple body regions Provides visual representation of fall dynamics Ability to evaluate variations of given fall	High cost and lack of availability of surrogates Limitations in biofidelity Requires auxiliary data acquisition equipment to capture data from instrumentation
Computer simulation models	Ability to conduct parametric sensitivity (what-if) analyses Provides graphical output of fall dynamics Ability to evaluate variations of given fall	Time consuming and costly Difficult to validate Costly software needed to develop models Requires specialized expertise to develop and validate models Digitized version of child and environment Limitations in biofidelity of child surrogate

experiments again require knowledge of the initial position and fall dynamics of the child so that the surrogate can be appropriately positioned and so that the surrogate fall dynamics can be verified.

Computer simulation modeling has been used to study factors affecting injury risk associated with falls and shaken baby syndrome.[70-72] A computer simulation model of a pediatric fall consists of a discrete digital representation of the child and the fall environment. Physics-based equations of motion represented through numerical computations are used by specialized software to prescribe the child's path of motion during a fall. Outcome measures such as acceleration, velocity, and force applied to body segments can be determined by most computer simulation software programs. It is important to note that physics-based simulation software operates differently than animation software, and thus will provide different outcomes. When using animation software, the programmer has the ability to prescribe object motion of his or her choice. Therefore, when viewing visual graphics illustrating fall dynamics of a child, one must first question whether the software used to develop the graphics are physics based or animation based. *Animation-based outcomes and findings are not scientifically based and should not be considered a valid biomechanical analysis*. Although physics-based computer simulation models can provide reasonable prediction of injury risk, models must first be experimentally validated.[70-72] Experimental validation requires that the developed model be "tuned" to match data from an experiment representing the simulation. For example, to validate a computer simulation model of a pediatric bed fall, bed fall experiments using a physical surrogate that represents the model-based child surrogate must be conducted and key outcome measures from the model must match those of the experiments.[70] Only after model validation has been proved should it be used in the prediction of injury risk. Even then, one must critically assess the biofidelity of the model-based surrogate given that it is likely a representation of a commercially available surrogate that may have limited biofidelity.

It is important to note that biomechanical analyses, especially of hypothesized unwitnessed falls, inherently have assumptions incorporated into their findings. An incorrect assumption regarding fall dynamics can greatly overestimate or underestimate biomechanical measures (acceleration, velocity, etc.) leading to erroneous conclusions regarding likelihood of injury. In addition, each method described above uses a simplification of the child, the fall dynamics, and the fall environment. Engineers performing these analyses must clearly identify the limitations associated with their analysis, along with the effects that assumptions and limitations have on their findings. At a minimum, expert reports provided by engineers should provide a list of assumptions used in conducting their analysis. Although the intent of a biomechanical analysis is to provide additional objectivity, it must be cautioned that this objectivity can be compromised in the shadow of assumptions and limitations. Therefore, the findings of biomechanical analyses should be interpreted with caution and should constitute only one component of a more comprehensive assessment.

THE LIKELIHOOD OF DEATH OR SERIOUS INJURY FROM A SHORT FALL

Medicine in general, and epidemiology in particular, have used statistical analyses to assist in making quantitative probability statements comparable over time or between populations. Still, in most child abuse cases in which medical expert testimony is provided, the experts use only semi-quantitative statements such as, "Death from a short fall of a toddler is rare." Quantitative expressions of probability allow comparisons of the likelihood of different events (e.g., the comparison of deaths resulting from lightning strikes or cancer to deaths resulting from short falls).

Recently we have used an epidemiological mortality rate calculation to estimate the maximum possible likelihood of death from a short fall affecting a young child.[5] The short fall mortality rate for infants and children from birth to age 5 is less than 0.48/million young children/year. Quantitative probability expressions should be used wherever possible in litigation.

The publication of data from fall cases that lack valid observations has been a problem.[73-75] Authors have concluded that short falls resulting in fatal injuries are "possible." Some authors conclude that they are "unlikely," but they do not attempt to make quantitative or even semi-quantitative estimates. The manner in which injury events are witnessed must always be carefully described and critically analyzed. Cases of falls occurring in hospital settings can usually be considered to be valid observations.[26-28] Cases that are multiply witnessed in childcare settings are also more likely to be valid, especially if systematically and prospectively observed, recorded, and analyzed biomechanically. Such studies are badly needed and feasible with modest support.

Observations made by persons who are also suspects for possible child abuse should not be relied upon as accurate data for research purposes or for drawing general conclusions. Confessions are very useful for many purposes[76] but may not be valid in every instance. Assessing their validity can be difficult.[77]

RESPONSIBLE TESTIMONY IN CASES OF DEATH/SEVERE INJURY FROM SHORT FALLS

Responsible testimony follows the guidelines set out by the American Medical Association (AMA).[78-80] The most common form of irresponsible testimony is testimony that goes beyond the "recent and substantive experience" of the person providing the testimony, but "unique causal theory" is also common and can lead to blatant lies. Expertise requires hands-on experience as well as "book-learning" and knowledge of the literature. For child abuse cases, different types of expertise can be acquired at the bedside with patient contacts, in the laboratory, or through clinical research. Different specialists acquire expertise in different ways. Clinicians learn from patient contacts; pathologists from autopsies. Prior court appearances only confer expertise in court presentation.

The House of Delegates of the AMA has ruled that expert testimony is a part of the practice of medicine, and like any other aspect of practice, may be subject to peer review and to regulation by medical societies or governmental entities. However, review of expert testimony is a very challenging process requiring significant investments of time and knowledge. It is not generally in place at this time. A recent misguided attempt at regulation of expert testimony by the medical licensing agency of the United Kingdom has had the unintended effect of serious disruption of child protection in that country.[81]

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