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Pediatric short-distance household falls: Biomechanics and associated injury severity

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ABSTRACT

Objectives: Short-distance household falls are a common occurrence in young children, but are also a common false history given by caretakers to conceal abusive trauma. The purpose of this study was to determine the severity of injuries that result from accidental short-distance household falls in children, and to investigate the association of fall environment and biomechanical measures with injury outcomes.
Methods: Children aged 0–4 years who presented to the Emergency Department with a history of a short furniture fall were included in the study. Detailed case-based biomechanical assessments were performed using data collected through medical records, interviews, and fall scene investigations. Injuries were rated using the Abbreviated Injury Scale (AIS). Each case was reviewed by a child abuse expert; cases with a vague or inconsistent history and cases being actively investigated for child abuse were excluded.
Results: 79 subjects were enrolled in the study; 15 had no injuries, 45 had minor (AIS 1) injuries, 17 had moderate (AIS 2) injuries, and 2 had serious (AIS 3) injuries. No subjects had injuries classified as AIS 4 or higher, and there were no fatalities. Children with moderate or serious injuries resulting from a short-distance household fall tended to have fallen from greater heights, have greater impact velocities, and have a lower body mass index than those with minor or no injuries.
Conclusion: Children aged 0–4 years involved in a short-distance household fall did not sustain severe or life-threatening injuries, and no children in this study had moderate or serious injuries to multiple body regions. Biomechanical measures were found to be associated with injury severity outcomes in short-distance household falls. Knowledge of relationships between biomechanical measures and injury outcomes can aid clinicians when assessing whether a child's injuries were the result of a short-distance fall or some other cause.

1. Introduction

Short falls in children, especially from beds or other furniture, are a common false history given by caretakers to conceal abusive trauma. In up to 70% of cases of children having abusive injuries, the initial explanation for the injuries given by the caretaker is a fall (Duhaime et al., 1992; Leventhal et al., 1993; Strait et al., 1995; Shaw et al., 1997; Scherl et al., 2000). However, short household falls are also a common occurrence in young children. A study of emergency department visits by children less than one year of age found that 61% of accidental cases were injuries due to falls (Macgregor, 2003). Clinicians are commonly asked to distinguish between abusive and accidental injuries by determining whether a child's injuries are consistent with the stated cause of the injuries. An improved understanding of biomechanical factors and injury severity in short household falls may aid clinicians in this decision. Early detection of abuse may lead to prevention of further escalating injuries and, in some cases, prevent the death of the child. Additionally, there is continuing controversy in the medico-legal community regarding whether short distance falls can lead to severe injuries or death (Hall et al., 1989; Joffe and Diamond, 1990; Chadwick et al., 1991; Plunkett, 2001; Spivack, 2001).

Several studies have investigated the types of injuries associated with bed falls and other short distance falls (Helfer et al., 1977; Nimityongskul and Anderson, 1987; Williams, 1991; Lyons and Oates, 1993; Tarantino et al., 1999; Macgregor, 2000; Belechri et al., 2002). However, few studies have investigated relationships between biomechanical factors and injury outcomes in short pediatric falls (Lyons and Oates, 1993; Prange et al., 2003; Bertocci

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Table 1
Type of data obtained from medical record reviews, caregiver interviews, and fall scene investigations.

Medical record review	Caregiver interview	Fall scene investigation
Subject age	Subject demographics	Subject height and anthropomorphic measures (if not obtained during interview)
Subject weight	Detailed fall description including pre-fall position, post-fall position, and dynamics	Furniture height
Detailed description of injuries	Approximate height of furniture child fell from Type of impact surface and underlying surface Subject height and other key anthropomorphic measurements	Type of impact surface and underlying subfloor construction Surface coefficient of restitution (COR)

et al., 2004; Thompson et al., 2009). The purpose of this study was to determine the types and severity of injuries that result from short-distance household falls in children, and to investigate the influence of fall environment and biomechanical measures on injury outcomes. This was accomplished through detailed case-based biomechanical assessments of short-distance household falls in children who presented to the Emergency Department (ED) of a regional children's hospital. Based on a review of prior studies, the authors hypothesized that serious injuries would make up less than 10% of cases.

2. Methods

2.1. Study design

This was a prospective, descriptive study approved by the University of Louisville Institutional Review Board (IRB #08.0011) using an informed consent process. To determine injury types and severities occurring in children in common household falls, the medical records of children ages 0–4 years who presented to the ED with a given history of a fall from a bed or other similar furniture were obtained. Interviews with the caregivers and in-depth scene investigations were conducted to obtain information regarding fall dynamics and to determine biomechanical measures associated with these falls.

2.2. Study setting and population

Children less than 4 years of age who presented to the ED of Kosair Childrens' Hospital (Louisville, KY) between May 2008 and July 2009 with a complaint of a household fall from a bed, sofa, or similar furniture were eligible for inclusion in the study. A research team was available 24 h/day, 7 days/week and was notified by triage of eligible patients in the ED. Any children being actively investigated for suspicion of abuse were excluded from the study. Additionally, all cases were reviewed by a study physician with expertise in pediatric emergency medicine and child abuse diagnoses (MCP). Each case was rated on a six-point scale as definite abuse, likely abuse, questionable abuse, questionable accident, likely accident, or definite accident using predefined criteria (Thomas et al., 1991; Leventhal et al., 1993). These criteria include: completeness and consistency of the given history, whether the injury was consistent with the history, whether there was a delay in seeking treatment, whether the fall was witnessed by someone other than the caregiver, and whether the child's behavior was consistent with the injury. Only cases meeting criteria for definite accident and likely accident were included in the data analysis. The parent/guardian could select one of three options for participation in this study:

Option 1: Review of their child's medical records.
Option 2: Caregiver interview and review of child's medical records.
Option 3: Investigation of the fall scene at their home, caregiver interview, and review of their child's medical records.

2.3. Study protocol

The type of data collected from the medical records, caregiver interviews, and fall scene investigations are shown in Table 1. For cases in which interviews and scene investigations were conducted, measurements obtained at the scene investigations were used in place of those obtained during interviews. Additionally, the reliability of the furniture height estimates provided by caregivers was evaluated to assess whether cases without fall scene investigations could be included in the biomechanical analysis.

At the fall scene investigations, surface coefficients of restitution (COR) were measured to quantify impact surface properties. COR is a measure of the elasticity of the surface. Surfaces with a higher COR, such as carpet, deform more upon impact leading to longer impact durations (the fall victim comes to a stop more slowly). This reduces the peak accelerations transferred to the victim. Conversely, surfaces with a lower COR, such as concrete, deform little and thus have shorter impact durations (the fall victim comes to a stop more rapidly) and greater peak accelerations (Thompson et al., 2009). Greater peak accelerations are generally associated with a greater injury risk. Therefore, injury risk tends to be greater on surfaces with low COR values than surfaces with high COR values. COR values were measured using a resiliency tester (IDM Instruments, Victoria, Australia). The resiliency tester drops a steel ball from a known height onto the impact surface (Fig. 1). The steel ball bounce

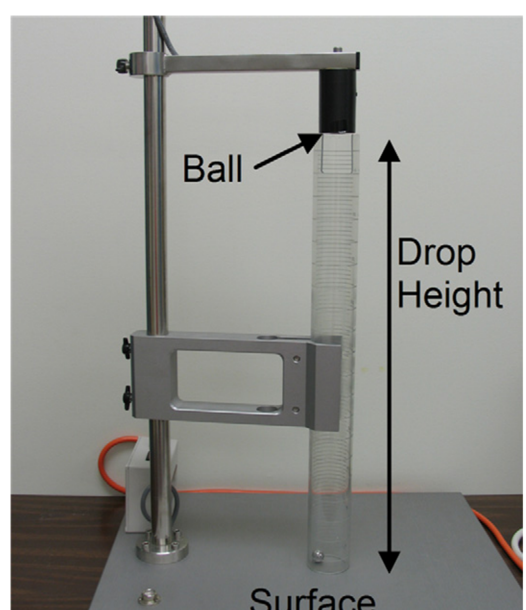

Fig. 1. Resiliency tester used to measure surface coefficients of restitution.

Table 2
Abbreviated Injury Scale code descriptions.

AIS code	Description
1	Minor injury
2	Moderate injury
3	Serious injury
4	Severe injury
5	Critical injury
6	Maximal (currently untreatable) injury

height is recorded, and the COR is calculated as the square root of the ratio of bounce height to drop height. Multiple measurements of COR were taken over the impact area to account for variations in floor properties.

Measurements of each child's height and weight were used to determine body mass index (BMI).

2.4. Data analysis

2.4.1. Injury assessment

Subject injuries were rated according to the Abbreviated Injury Scale (AIS). The AIS describes injury severity on a six-point scale (Table 2). Injuries are rated using predefined criteria based on location, type (e.g. skeletal injury, vascular injury, and muscular injury), and severity (Gennarelli and Wodzin, 2007). Each injury was assigned an AIS severity score, and the maximum AIS (MAIS) was determined for each subject.

2.4.2. Biomechanical assessment

To better characterize the fall event, several biomechanical measures were assessed. The impact velocity was determined using

$$V = \sqrt{2gh} \tag{1}$$

where g is the acceleration due to gravity (9.81 m/s^2), and h is the fall height. The fall height was defined as the distance from the child's center of mass at the start of the fall to the ground. The fall height was estimated based on the height of the furniture surface that the child fell from, the position of the child just prior to the fall, and anthropometric measures of the child. The potential energy was determined using

$$E = mgh \tag{2}$$

where m is the mass of the child, h is the height of the fall, and g is the acceleration due to gravity. Finally, the change in momentum during impact was determined using

$$M = mV(COR + 1) \tag{3}$$

where m, V, and COR are the mass of the child, impact velocity, and coefficient of restitution of the impact surface, respectively.

2.4.3. Statistical analysis

A power analysis was conducted using preliminary data to determine the sample size required to test the hypothesis that less than 10% of subjects would have serious injuries (MAIS 3 or greater). Using 85% power and alpha equal to 0.05, this analysis revealed a desired sample size of 76. To determine whether biomechanical variables were related to injury severity, subjects were divided into two injury severity groups: those with no or minor injuries (MAIS 0 and 1) and those with moderate or serious injuries (MAIS 2 or greater). For each of the continuous independent variables obtained (impact velocity, energy, change in momentum, fall height, impact surface COR, and child factors including mass, age, and body mass index), t-tests were performed to determine if there were significant differences between subjects with no/minor and moderate/serious injuries. In cases where the assumptions of normality were not met, the non-parametric equivalent test was used. For each of the categorical variables obtained (impact surface and subfloor types, pre-fall and post-fall positions of the child, general fall dynamics, and whether or not the child was in motion prior to the fall), chi-square tests were performed to determine if the variables were significantly associated with injury severity level (no/minor vs. moderate/serious injuries). Statistical analysis was performed using SPSS v12.0.1. Statistical significance was defined as $p < 0.05$.

3. Results

Fig. 2 provides details of study participation. Seventy-nine cases met the criteria for analysis. The subjects ranged in age from 1 to 47 months with a mean age of 18 months. Fifty-four percent (54%) of the subjects were male. Sixty-five percent (65%) of subjects were White, 29% were African American, and 6% were Hispanic.

3.1. Injury assessment

Fig. 3 shows the distribution of cases based upon MAIS injury level. No subjects had injuries classified as AIS 4 or higher. Injuries classified as AIS 1 included mostly lacerations and contusions and 2 cases with radial head subluxation (Nursemaid's elbow). AIS 2 injuries consisted of fractures (6 skull, 2 clavicle, 3 radius and ulna, 4 supracondylar humerus, 1 femur, and 1 metatarsal). There were two AIS 3 injuries which were both small isolated subdural hematomas. The first was a 3 mm subdural hematoma located in the left posterior frontal region. The second was a very thin right frontoparietal subdural hematoma accompanied by a right parietal minimally depressed skull fracture. Both children with subdural hematomas were clinically well-appearing and had no neurological abnormalities. No subjects had AIS 2 or greater injuries to more than one body region.

Six cases were excluded from the study because the history was inconsistent or vague. These cases did not meet criteria for definite or likely accidents. These subjects were not excluded on the basis of injury severity; the injuries of the excluded subjects were no more severe than those of subjects included in the study. Of the 6 excluded cases, 5 children had injuries that were classified as MAIS 1 and 1 child had injuries that were classified as MAIS 2 (clavicle fracture).

3.2. Reliability analysis

Impact velocity, potential energy, and change in momentum are dependent on measurements of furniture height and COR obtained at the fall scene investigations. Because only estimates of furniture height (from caregivers) were available for most cases ($n = 42$), the reliability of these estimates was evaluated. For 35 cases, both an estimate of the furniture height (obtained from caregiver during interview) and a measurement of the true furniture height (obtained during fall scene investigation) were available (Fig. 4). The intraclass correlation coefficient (ICC) between these two data sets was 0.76. In general, caregivers tended to overestimate the height. To account for this bias, the linear relationship between the height estimates and height measurements was determined. This resulted in the following equation which was used to predict furniture height (PFH) based on the caregiver-provided height estimate (CHE):

$$\text{PFH} \quad (\text{cm}) = 0.718 * \text{CHE} \quad (\text{cm}) + 11.736 \tag{4}$$

The coefficient of determination (R^2), a measure of the goodness of fit between the linear equation and height data, was

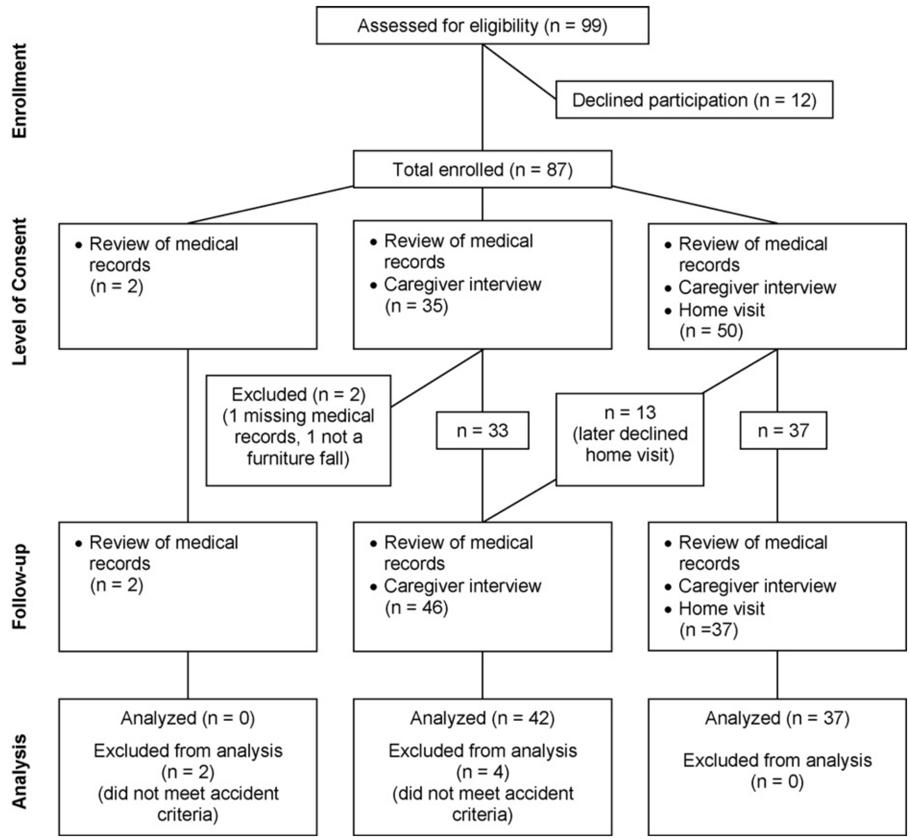

Fig. 2. Flow diagram of subject progression through study.

0.80. For each case without a scene investigation, the predicted height was calculated using the caregiver-estimated height collected during the interview. The predicted furniture heights were then used in the biomechanical analysis in place of the estimated heights.

3.3. Biomechanical assessment

Several fall, environment, and child characteristics were investigated to determine whether there were significant differences between subjects with no or minor injuries and subjects with moderate or serious injuries (Table 3).

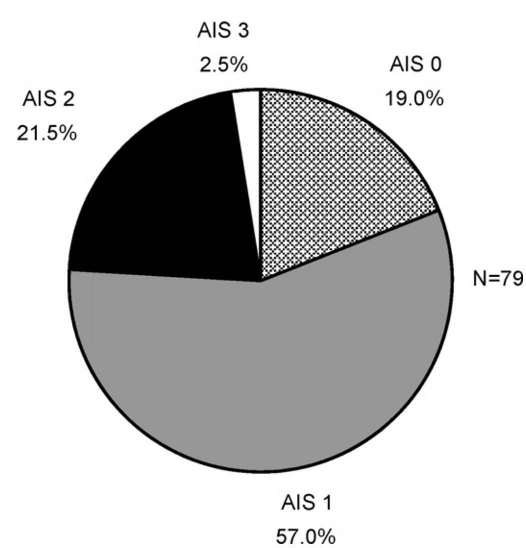

Fig. 3. Distribution of accidental cases by Maximum Abbreviated Injury Scale (MAIS).

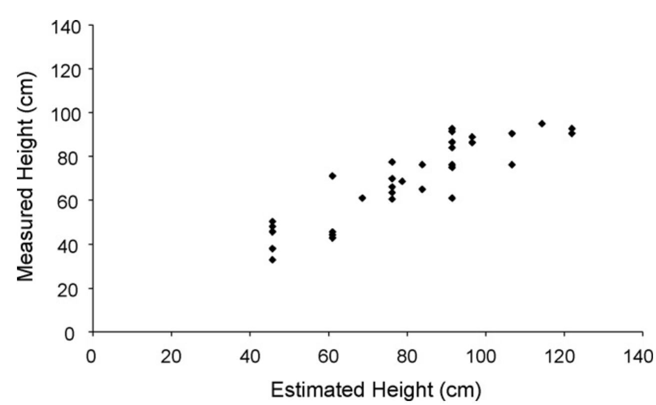

Fig. 4. Measured furniture height (from fall scene investigation) vs estimated furniture height (from caregiver interview) for 35 cases.

3.3.1. Fall environment

The frequency distributions of falls based upon type of furniture and impact surface are shown in Figs. 5 and 6. Twelve subjects were initially placed in a car-seat, bouncy seat, or adult's lap prior to the fall, but this factor was not found to be significantly associated with injury severity. Surface COR measurements were obtained for 37 cases. The mean COR for cases with similar surface/subfloor combinations is shown in Table 4. Neither surface, subfloor, nor COR were found to be significantly associated with injury severity.

Table 3
Subject, fall environment, and biomechanical measure mean values by injury category.

Measure	Subjects with no or minor injuries Mean (95% confidence interval)	Number of subjects	Subjects with moderate or serious injuries Mean (95% confidence interval)	Number of subjects
Subject age (months)	17 (14–20)	60	21 (13–28)	19
Subject mass (kg)	10.9 (10.0–11.7)	60	11.2 (9.4–13.0)	19
Subject body mass index[*,a]	17.7 (17.2–18.3)	58	16.4 (15.3–17.6)	17
Furniture height (cm)[*]	62.0 (57.3–66.7)	60	75.6 (68.1–83.0)	19
Fall height (cm)[*]	79.8 (73.6–86.0)	60	91.3 (83.9–98.8)	19
Impact velocity (m/s)[*]	4.0 (3.8–4.2)	60	4.3 (4.2–4.5)	19
Potential energy (Nm)	91.3 (79.6–103.0)	60	107.3 (85.7–128.9)	19
Change in momentum (kgm/s)[b]	56.2 (48.1–64.3)	26	57.8 (40.4–75.1)	11
Surface coefficient of restitution[b]	0.39 (0.35–0.43)	26	0.39 (0.30–0.48)	11

[a] Body mass index was not calculated for four subjects due to missing subject height data.
[b] Includes only cases in which a fall scene investigation was conducted.
[*] Statistically significant difference between subjects with no/minor injuries and subjects with moderate/serious injuries ($p < 0.05$).

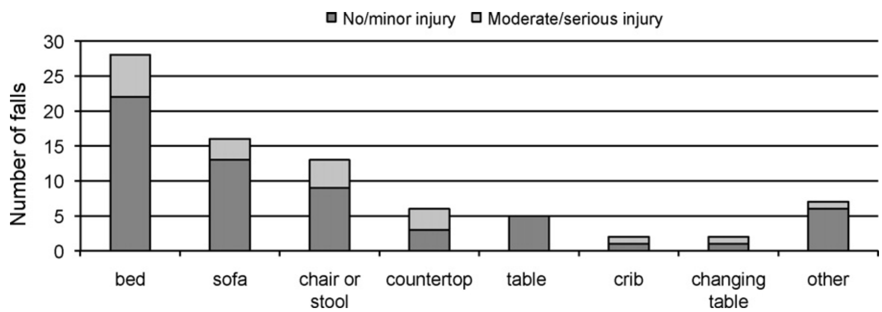

Fig. 5. Frequency distribution of falls for each injury severity category based upon furniture type ($N = 79$).

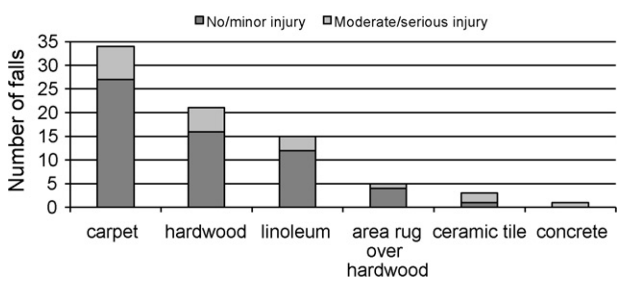

Fig. 6. Frequency distribution of falls for each injury severity category based upon impact surface type ($N = 79$).

3.3.2. *Fall characteristics*

Information regarding the child's position just prior to the fall was obtained in 69 cases, and information regarding the child's position immediately after the fall was obtained in 67 cases (Table 5). However, a description of the fall dynamics was obtained in only 40 cases (Table 5). This is because nearly half of the falls were not witnessed (44%). Pre-fall position, post-fall position, and description of fall dynamics were not significantly associated with injury severity. Additionally, 25 subjects were noted to have been in motion prior to the fall (e.g., jumping, crawling, or rolling). However, this factor was not significantly associated with injury severity.

Table 4
Mean coefficient of restitution (COR) measured for each impact surface–subfloor combination. Measurements were obtained for only 37 cases where fall scene visits were conducted.

Subfloor	Surface	Mean COR (standard deviation)	Number of falls
Wood	Carpet	0.49 (0.05)	12
	Area rug over hardwood	0.41 (0.02)	5
	Hardwood	0.33 (0.03)	9
	Linoleum	0.35 (0.08)	5
	Ceramic tile	0.44	1
Concrete	Carpet	0.51	1
	Hardwood	0.16	2
	Linoleum	0.17	1
	Ceramic tile	0.47	1

3.4. *Biomechanical assessment of MAIS 3 cases*

The fall that resulted in a 3 mm left posterior subdural hematoma was a fall from a sofa involving a 42-month-old female. The child was seated on the back of the sofa, approximately 1 m high, and fell backwards. She landed on her side and hit her head on the hardwood floor. This child had a mass of 11.8 kg and a BMI of 12.7. She was in the 45th percentile for her age by height, but only

Table 5
Frequency distribution of falls based upon pre-fall positions, descriptions of fall dynamics, and post-fall positions. Information not available for all cases.

Pre-fall position	Number of cases	Fall dynamics	Number of cases	Post-fall position	Number of cases
Lying prone	7	Head-first	16	Lying prone	26
Lying supine	18	Feet-first	2	Lying supine	18
Side-lying	1	Tumbling	14	Side-lying	13
Sitting	21	Other	8	Sitting	7
Standing	16			Other	3
Other	6				

the 5th percentile by mass. The estimated impact velocity, energy, and change in momentum for this fall were 4.7 m/s, 259 N m, and 74 kg m/s, respectively.

The subject whose fall resulted in a thin right frontoparietal subdural hematoma and skull fracture was 1-month-old male. In this case, the child was sleeping on his mother's chest while she was lying in bed. The mother fell asleep and rolled over causing the child to fall off the side of the bed. He struck his head on a humidifier that was adjacent to the bed and then landed supine on the carpeted floor. The fall scene investigation revealed a bed height of 86 cm and a COR of 0.56 for the carpet. These measurements produced impact velocity, energy, and change in momentum values of 4.6 m/s, 118 N m, and 40 kg m/s, respectively. The child had a mass of 5.5 kg and a BMI of 12.6. He was in the 95th percentile for his age by both height and mass.

4. Discussion

Serious injuries resulting from pediatric short household falls are rare. Less than 3% of the cases seen in this study were classified as a serious injury (MAIS 3), and no severe or life-threatening injuries were seen. Seventy-six percent (76%) of the cases in this study had no injuries or only minor injuries. These results are consistent with other studies of injuries resulting from short distance pediatric falls. Previous studies report no severe or life-threatening injuries and fracture rates ranging from 1% to 29% (mean 13%) (Helfer et al., 1977; Nimityongskul and Anderson, 1987; Lyons and Oates, 1993; Tarantino et al., 1999; Macgregor, 2000, 2003; Belechri et al., 2002; Dedoukou et al., 2004; Mack et al., 2007). The rate of fractures seen in our study (all AIS 2 injuries) was 21.5%. Very few studies have reported intracranial hemorrhages resulting from short distance falls (Hall et al., 1989; Plunkett, 2001). The two subdural hematomas seen in this study were small contact type injuries. The clinical presentation and course for each of these children was benign. Both subdural hematomas resulted from falls from heights over 1 m (distance from floor to center of mass of the child). The impact velocities in these cases were similar. The sofa fall involving the 42-month-old child was associated with much greater energy and change in momentum values than the bed fall involving the 1-month-old child. The child fell backwards off the sofa and likely landed directly on her head. Therefore, she was likely unable to have an active protective response to the fall. The 1-month-old child likely struck his head on the edge of the humidifier. The smaller contact area on the edge of the humidifier would have led to a greater, more concentrated impact force than if he had simply struck the floor.

Our study rated injury severity using the AIS scale. To the authors' knowledge, only two other studies have used the AIS scale to categorize pediatric fall injuries. Morrison et al. (2002) investigated furniture-related injuries in children 0–5 years of age, and found 8% of injuries were AIS 1, 75% were AIS 2, 10% were AIS 3, and 1% were AIS 4. However, Morrison et al. only included injuries that required hospital admission. Thus, the results are skewed towards more severe injuries. (Chiaviello et al., 1994) used a modified AIS scale referred to as the Modified Injury Severity Scale (MISS) to rate stair fall injuries in children 0–5 years of age. The MISS is determined by summing the squares of the AIS scores for the three most severely injured body regions. Therefore, an MISS 2 score represents a condition with only minor injuries (AIS 1) to two body regions. Only 4% of subjects in the Chiaviello study had an MISS > 2. In our study, all subjects with an MAIS 2 or MAIS 3 injury would translate to an MISS > 2. Therefore, we found a much lower incidence of moderate and serious injuries than Morrison et al., but a greater incidence of moderate/serious injuries than Chiaviello et al.

In this study, the MAIS was used as an overall injury score for each subject. Another commonly used overall injury scoring system is the Injury Severity Score (ISS) which is calculated by summing the squares of the AIS scores for the three most severely injured body regions. MAIS was chosen rather than ISS because few subjects had injuries to multiple body regions and no subjects had injuries greater than AIS 1 to multiple body regions.

Of the fall environment factors studied, only furniture height and fall height were found to be significantly different in subjects with no/minor injuries compared to subjects with moderate/serious injuries. The mean fall height for subjects in the no/minor injuries category was 80 cm compared to 91 cm in the moderate/serious injury category. This illustrates that small differences in height (11 cm in this case) can have a significant influence on injury severity outcomes. Other biomechanical studies have shown that increasing fall height leads to an increasing risk of injury (Prange et al., 2003; Bertocci et al., 2004).

Impact surface type was not found to be significantly associated with injury severity for the sample of pediatric falls evaluated in our study. Because there are many variations in surface type, surface COR was measured to quantify the resiliency of the surface–subfloor combinations. However, COR was not significantly different for the two injury severity categories. (We were only able to measure COR on a subset of cases; therefore the lack of significant differences may be due to an inadequate sample size.) Several biomechanical studies have shown impact surface to be associated with injury risk (Bertocci et al., 2003, 2004; Prange et al., 2003; Cory and Jones, 2006; Thompson et al., 2009). These studies investigated surface effects in a laboratory setting, where variations in fall dynamics and other environmental factors were controlled. In our study, there were many other factors that could contribute to injury (e.g., fall height, initial position of the child, fall dynamics, and child mass).

In addition to fall environment factors, our study investigated fall dynamics and biomechanical measures. A previous study of short feet-first falls found that fall dynamics played a significant role in measures of head injury risk (Thompson et al., 2009). However, initial position and fall dynamics were not found to be significantly associated with injury severity our current study. Impact velocity, energy, and change in momentum were determined for each case to further characterize the fall. Only impact velocity was found to be significantly different across the two injury severity categories. Fall energy and change in momentum were determined since they each account for a combination of child and fall characteristics, and it was predicted that these measures would be a better overall measure to compare with injury outcomes. In 25 cases, the subjects were said to have been in motion (jumping, rolling, etc.) prior to the fall. However, due to the unreliability of such initial velocity estimates, it was assumed that every child was at rest prior to the fall. If initial velocities had been accounted for, this would lead to an increase in the impact velocity, energy, and momentum values for these cases. A study by Lyons and Oates (1993) also assessed impact momentum for pediatric falls and found no significant difference in momentum between the injured and non-injured subjects. With a greater number of subjects and more accurate measures of fall height and surface COR, it is possible that significant differences in energy and change in momentum values between subjects with no/minor injuries and subjects with moderate/serious injures would emerge.

Child BMI was found to be significantly lower for subjects with moderate/serious injuries compared to subjects with no/minor injuries. Many studies have found a decreasing fracture risk with increasing BMI in adults (Robinovitch et al., 1995; Willig et al., 2003; De Laet et al., 2005; Beck et al., 2009). This is likely due to a protective effect of a greater soft tissue thickness in individuals with a higher BMI (Robinovitch et al., 1995). Additionally, studies have shown that bone mineral density increases with increasing mass (Beck et al., 2009). Higher bone mineral density suggests a greater bone strength which is often associated with a decreased fracture risk. A few studies have compared BMI and injury outcomes in children. Brown et al. (2006) compared injury outcomes in obese and non-obese children (aged 6–19 years) who were admitted to the intensive care unit and found obese patients suffered less severe (lower AIS) head injuries than non-obese patients, but no significant differences were found in chest, abdominal, and extremity injuries. Rana et al. (2009) found no significant differences in AIS scores between obese and non-obese children (aged 6–20 years) who suffered traumatic injuries but found a lower incidence of closed head injuries and abdominal injuries in the obese patients. Our study found that children with moderate and serious injuries had a lower mean BMI than children with no or only minor injuries. Studies of children have primarily focused on comparisons of obese to non-obese and did not investigate whether an underweight child may have a greater risk for injury. The relationship between BMI and injury severity outcomes in pediatric falls needs to be investigated further.

5. Limitations

Our study found 21.5% of pediatric falls resulted in moderate injury and 2.5% resulted in serious injury. This number is likely an overestimate of injury severity associated with household falls because only children who presented to the ED were included. Falls are a common occurrence in young children, and often result in no injuries or only minor injuries for which the parents do not seek care (Helfer et al., 1977; Warrington and Wright, 2001). The sample size was relatively small. With a greater sample size, differences in energy, change in momentum, surface COR, and other variables could emerge for different levels of injury severity. Additionally, due to the small sample size, each of the variables was analyzed independently for relationships with injury severity. A greater number of subjects would allow for a multifactor analysis in which interaction between variables could be investigated. In cases where scene investigations were not conducted ($n = 42$, 53%), furniture heights were predicted based on estimates provided by the caregiver and measurements obtained in cases involving scene investigations. Due to this transformation of the height data, the confidence interval presented is likely underestimated. The predicted furniture heights were further used to determine fall heights, impact velocities and potential energies which would introduce a source of error in these measures and their associated confidence intervals. Another limitation of this study is the possibility that cases of child abuse were misidentified and included in this study or true accidents were falsely excluded. Since this study sought to examine injury in short distance falls, any cases of abuse that were falsely included in the study could contaminate the findings. In an attempt to reduce this possibility, all cases were reviewed by a child abuse expert and judged to be accidental or abusive using predefined criteria (Leventhal et al., 1993). Any cases that did not meet criteria for a definite or likely accident were excluded from the data analysis. Six cases had vague or inconsistent histories and therefore, did not meet criteria for definite or likely accident. These cases were excluded from the study. It is worthwhile to note that the excluded cases were all classified as MAIS 1 (minor injuries only) except one which was MAIS 2 (clavicle fracture), and were not excluded on the basis of severe injury.

6. Conclusions

This study provides a comprehensive evaluation of the biomechanics of short-distance household falls and investigated the association of biomechanical and fall environment measures with injury severity. Children aged 0–4 years involved in a short-distance household fall did not sustain severe or life-threatening injuries. No children in this study had moderate or serious injuries to multiple body regions. Furniture height, impact velocity and child BMI were found to have the greatest influence on injury severity outcomes. Children with moderate or serious injuries tended to have fallen from greater heights, had greater impact velocities, and had a lower BMI than those with minor or no injuries. By identifying factors associated with injury outcomes, the results of this study provide first steps toward development of an injury prediction model for short-distance pediatric falls.

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