TITLE PAGE

THE ROLE OF SKELETAL SURVEY IN IDENTIFYING NON-ACCIDENTAL TRAUMA IN PEDIATRIC TRAUMA PATIENTS

A Thesis Presented

By

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SIGNATURE PAGE

THE ROLE OF SKELETAL SURVEY IN IDENTIFYING NON-ACCIDENTAL TRAUMA IN PEDIATRIC TRAUMA PATIENTS

A Masters Thesis Presented

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The signatures of the Master's Thesis Committee signify completion and approval as to style and content of the Thesis

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ABSTRACT

Background: Non-accidental Trauma (NAT) is a major cause of morbidity and mortality in children. Children less than 2 years old are at greater risk of NAT than older children. A skeletal survey is a series of X-rays of all the bones in the body, or at least the axial skeleton and the large cortical bones used to identify NAT in children. In this observational study, we examined the association between a child's age, frequency of positive skeletal surveys, and the types of injuries discovered in pediatric patients undergoing a trauma work-up.

Methods: The study sample consisted of all pediatric trauma patients ≤3 years old who had skeletal surveys performed at a single tertiary care center in Central Massachusetts between 2005 and 2015. Patients were divided into two age groups: ≤6months old (n=98) and >6months old (n=86). The utilization of a skeletal survey, frequency of confirmed NAT, and injuries were compared between these 2 age groups.

Results: The average age of the sample was 8.4 months, 56.0% were boys, and 62.5% were Caucasian. A positive skeletal survey was found in 14.3% of patients ≤6months old and 18.6% of patients >6months old (p=0.43). The most common fractures identified were long bone (50.0%), torso (30.4%), and skull (13.0%). Similar frequencies of NAT were observed between those less than and older than 6 months (58.2% vs. 57.0%). Head computed tomography (CT) scans were performed in the majority (95.9%) of patients ≤6 months old while in only 66.3% of patients > 6 months old ($p < 0.01$).

Conclusions: Skeletal surveys identify injuries at comparable rates in pediatric trauma patients regardless of age. Advanced imaging differs in younger and older pediatric trauma patients undergoing skeletal survey.

Categorization: Outcomes research; Pediatric Non-Accidental Trauma; Skeletal Survey

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PREFACE

Other accomplished works that will not be presented as a part of this thesis:

Green J, Friedrich A, Schlieve C, Barrata K, Ma D, May M, Patel K, Stein BS, Cave D, Litwin D, Cahan M. Approach to Diagnostic Workup and Management of Small Bowel Lesions at a Tertiary Care Center. Journal of Surgical Endoscopy- In Review

Green J, Damle RN, Kasper RE, Borer E, Manno M, Nazarey PP, Aidlen JT, Hirsh MP. Goods For Guns is Good for the Community: A 2015 Update of a Community Gun Buyback. Journal of Trauma in publication

Kasper RE, **Green J**, Damle RN, Aidlen JT, Nazarey PP, Manno M, Borer E, Hirsh MP. And the survey said.... evaluating rationale for participation in gun buybacks as a tool to encourage higher yields. Journal of Pediatric Surgery 2016 Journal of Pediatric 2017, 52; 354-9.

Green J, Schlieve CR, Nazarey P, Hirsh MP, Aidlen JT. Application of Mitomycin C After Dilation of an Anastomotic Stricture in a Newborn with Necrotizing Enterocolitis. Journal of Ped Sur Case Reports 2016, 4; 49-51

CHAPTER I: INTRODUCTION

In 2014, the rate of child abuse or neglect was 9.4 per 1,000 American children and approximately 3.2 million children were subjects of at least one report from Child Protective Services and nearly 1,600 children die from maltreatment each year[1]. Younger children are at the greatest risk of non-accidental trauma and are more likely to be harmed by their primary caretakers[2].

Non-accidental trauma (NAT) is a major cause of childhood traumatic injury which commonly results in skeletal fractures[3-5]. Although not as common as contusions, skeletal fractures have also been associated with serious intracranial injuries in pediatric NAT victims [3, 5]. According to the American Academy of Pediatrics, a skeletal survey is the gold standard for identifying fractures in children that are too young to communicate[6]. A skeletal survey is a series of X-rays of all the bones in the body, or at least the axial skeleton and the large cortical bones[6].

In addition, skeletal surveys are recommended for young children with findings suspicious for NAT and in older children who cannot communicate the location of their pain [7]. Skeletal surveys diagnose obscure, new, and healing fractures. They not only have significant clinical impact, but also help to identify victims of NAT and so they may be removed from dangerous environments [8, 9].

Previous studies have demonstrated the importance of skeletal surveys in the identification of NAT in pediatric patients with a frequency of fracture detection ranging from 11% to 33%[6, 10-12]. While these studies have failed to show an association

between race and gender with the risk of NAT[13-16], earlier studies indicated that children younger than 2 years of age are more likely to be victims of NAT [13, 17-19]. In a retrospective cohort study of more than 700 pediatric patients undergoing a skeletal survey, children less than 6 months of age had more than two fold higher rates of a positive skeletal survey compared with children older than 6 months (16.4% vs 6.8%)[11]. However, a more recent retrospective cohort study of over 2600 pediatric NAT patients <60 months of age from the Examining Siblings to Recognize Abuse (ExSTRA) research database demonstrated that a positive skeletal survey could have a similar diagnostic yield among patients as old as 36 months compared with younger children [20]. Inasmuch, further investigation into the role of the skeletal survey in identifying NAT in pediatric trauma patients is warranted.

Among pediatric patients, children under the age of 6 months are potentially the most vulnerable for NAT due to their high level of dependence on their caregivers. Therefore, we hypothesized that among pediatric patients undergoing a trauma work-up for NAT, younger children (≤6 months of old) would have a higher positive yield (fractures identified) of skeletal survey and higher rates of NAT compared with older children (>6 months to 3 years old).

Specific Aims:

In this descriptive observational study, we examined injuries and diagnoses related to NAT in pediatric trauma patients who underwent skeletal surveys at a major tertiary care center in Central Massachusetts over a decade long period (2005-2015). The

primary aim of this study was to explore the yield of the skeletal survey and rate of NAT among pediatric trauma patients undergoing a trauma work up for NAT based on the child's age. Secondary study aims included investigation into patient characteristics, injury patterns, and disposition of pediatric patients undergoing a skeletal survey in relation to the child's age.

CHAPTER II: STUDY METHODOLOGY

Patient Population

All trauma evaluations were performed at the University of Massachusetts Medical Center from January 2005 to December 2015. Using the Trauma Registry database records, we identified all pediatric patients (≤3 years old) who underwent a skeletal survey during this period. This age cutoff was chosen based on previous clinical studies [20]. A medical chart review was employed to abstract data on patient demographic characteristics, 51A (initiation of a formal investigation for abuse or neglect in Massachusetts) status, skeletal survey results, additional imaging results, specific injuries, and patient's hospital course, outcomes, disposition (e.g., home, into custody), and an injury severity score. The Injury Severity Score (ISS) is an anatomical scoring system that provides an overall score for patients with multiple injuries. Each injury is assigned an Abbreviated Injury Scale (AIS) score and is allocated to one of six body regions (Head, Face, Chest, Abdomen, Extremities (including Pelvis), External). Only the highest AIS score in each body region is used. The 3 most severely injured body regions have their score squared and added together to produce the ISS score[21].

Confirmed NAT was defined as patients who satisfied all of the following criteria: 51-A filed, injuries inconsistent with history or mechanism of injury and child was removed from parental custody/legal guardianship as per institutional child protective

service. In cases of confirmed NAT, the perpetrator was also identified in the medical record. Institutional review approval was obtained for this study.

Data Collection

All study data were managed using REDCap electronic data capture tools hosted at the University of Massachusetts Medical School[22]. REDCap (Research Electronic Data Capture) is a secure, web-based application designed to support data capture for research studies, providing 1) an intuitive interface for validated data entry; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for importing data from external sources.

Data Analysis

Patients were divided into 2 groups for purposes of analysis: ≤6months old and > 6months old. Comparisons between these 2 study groups were performed using Chi-square tests for categorical variables and the Student's-*t* test for continuous variables. Statistical analysis was performed using *Stata Statistical Software: Release 13* (College Station, TX).

CHAPTER III: STUDY RESULTS

Study Population Characteristics

Our study identified 184 eligible patients out of a total of 5,937 total pediatric trauma patients at our institution during the years under study (2005-2015). Of these, 98 (53.2%) were ≤6 months old. Overall, the mean age of the children studied was 8.4 months, slightly more than half were male (56.0%), and almost two-thirds (62.5%) were Caucasian. Children in the ≤6-month-old group were on average 12 months younger than the older group. There were no significant differences in either sex or race between the 2 study groups **(Table 1)**.

Characteristics of Presenting Injury

Most of the children presented to our institution with falls/assault related injuries (75.5%), over half of which occurred at home **(Table 2)**. More than one half of the study sample were transported to the hospital via ambulance, with over three-quarters (77.2%) of the injuries occurring between the hours of 4pm and 4am. There were no differences in the mechanism of injury between the younger and older children, severity of injury(ISS), Glasgow Coma Scale (GCS) on arrival, length of the total hospital or intensive care unit stay. However, more children in the >6-month-3-year-old group were intubated upon arrival **(Table 2)**.

Diagnostic Imaging

The majority (71.7%) of the skeletal surveys were performed on the pediatric wards. There was an increase in the frequency of skeletal surveys during the most recent study years, with one-third of all skeletal surveys performed in the 2 most recent study years of 2014 and 2015 **(Figure 1)**. A positive skeletal survey was found in 16.3% of all patients. Long bone (50.0%), torso (30.4%), and skull (6.7%) fractures were the most common findings on skeletal surveys with no between group differences **(Table 3)**.

Patients underwent a variety of additional imaging studies with Head CT scans performed in most patients (82.1%). Additional extremity X-rays (22.8%), CT Abdomen/Pelvis (12.5%), MRI of the Head (11.4%), and focused assessment with sonography for trauma [FAST] (10.3%) were the next most common imaging modalities performed **(Table 4)**. Head CT scans were performed in almost all children ≤6 months old compared with approximately two-thirds of patients > 6 months old ($p < 0.01$). On the other hand, three times as many children >6months to 3 years old had a CT of the Abdomen and Pelvis performed compared with children less than 6months old ($p<0.01$).

Injury Diagnoses and Final Disposition

The most frequent locations of the final injuries (fractures, bruising, soft tissue damage were Head (63.6%), Extremity (47.3%), and Abdomen and Pelvis (11.4%) with no differences between our 2 study groups **(Figure 2)**. In over half of the patients, NAT was confirmed based on the review of data contained in hospital medical records.

Mothers were the most common perpetrator of NAT. Children were removed from the custody of at least one parent in 57.6% of all patients. In addition, 42.0% of all children with confirmed NAT were taken into state custody with no differences between groups **(Table 5)**. All of the patients were alive at the end of the study.

TABLE 3.1. Patient Demographic Characteristics According to Child's Age			
	0-6 months old (n = 98)	**>6 months old (n = 86)**	**p-value**
Child Age (months)	2.9 (1.7)	15 (7.7)	<0.01
Male	53 (54.1)	50 (58.1)	0.58
Race			0.73
Asian	1 (1.0)	3 (3.5)	
African-American	10 (10.2)	7 (8.0)	
Hispanic	21 (21.4)	19 (22.1)	
Native American	1 (1.0)	0 (0.0)	
White/Caucasian	61 (62.2)	54 (62.7)	
Other	4 (4.1)	2 (3.5)	
Values are N (%) or mean (standard deviation) unless otherwise specified			

TABLE 3.2. Characteristics of Presenting Injury According to Child's Age			
	0-6 months old (n = 98)	**>6 months old (n = 86)**	**p-value**
Initial Stated Mechanism of Injury			0.28
Fall	40 (40.8)	29 (33.7)	
Assault	41 (41.8)	29 (33.7)	
Accident	3 (3.1)	6 (7.0)	
Burn	1 (1.0)	5 (5.8)	
Not Specified	11 (11.2)	14 (16.3)	
Neglect	1 (1.0)	3 (3.5)	
Location			0.06
Home	62 (63.3)	44 (51.1)	
Public Building	1 (1.0)	6 (7.0)	
Residential area	2 (2.0)	0 (0.0)	
Street	2 (2.0)	0 (0.0)	
Not Specified	31 (31.6)	36 (41.8)	
Transportation			0.046
Ambulance	61 (62.2)	38 (44.2)	
Helicopter	3 (3.1)	5 (5.8)	
Parent/Guardian	34 (34.7)	43 (50.0)	
Trauma			0.09
Level 1	2 (2.0)	8 (9.3)	
Level 2	11 (11.2)	8 (9.3)	
Level 3	51 (52.0)	35 (40.7)	
Level 4	34 (35)	35 (40.7)	
Injury Severity Score	8.8 (7.7)	9.7 (8.8)	0.47
GCS on arrival	14 (2.5)	13 (3.8)	0.25
Intubated on arrival	3 (3.1)	9 (10.5)	0.04
Cervical collar present on arrival	7 (7.1)	10 (11.6)	0.30
Length of Stay (days)	3.4 (4.7)	3.8 (5.1)	0.51
Intensive care unit stay(days)	1.0 (3.4)	1.6 (4.6)	0.35
Values are N (%) or mean (standard deviation) unless otherwise specified			

TABLE 3.3. Characteristics of Skeletal Survey According to Child's Age			
	0-6 Months Old (n = 98)	**>6 months old (n = 86)**	**p-value**
Patient Location at time of Skeletal Survey			0.85
Emergency department	3 (3.1)	4 (4.7)	
Intensive care unit	24 (24.5)	21 (24.4)	
General Inpatient Unit	71 (72.4)	61 (70.9)	
Positive Skeletal Survey	14 (14.3)	16 (18.6)	0.43
Fractures on Skeletal Survey	**n=23**	**n=23**	**1.00**
Skull fracture	2 (8.7)	4 (17.4)	0.38
Facial fracture	0	2 (8.7)	-----
CTL spine fracture	0	1 (4.3)	-----
Torso fracture (rib/scapula/clavicle)	8 (34.8)	6 (26.1)	0.52
Upper extremity fracture	6 (26.1)	5 (21.7)	0.73
Lower extremity fracture	7 (30.4)	5 (21.7)	0.50
Values are N (%) or mean (standard deviation) unless otherwise specified			

TABLE 3.4. Non-Skeletal Survey Imaging According to Child's Age			
	0-6 months old (n = 98)	**>6 months old (n = 86)**	**p-value**
Additional imaging			
CT head	94 (95.9)	57 (66.3)	<0.001
MRI head	11 (11.2)	10 (11.6)	0.93
CT/MRI of Spine	7 (7.1)	10 (11.6)	0.30
CT chest	2 (2.0)	4 (4.7)	0.32
CT abdomen/pelvis	6 (6.1)	17 (19.8)	0.005
Extremity x-ray	20 (20.4)	22 (25.6)	0.44
Pelvis x-ray	4 (4.1)	7 (8.1)	0.24
Chest x-ray	6 (6.1)	9 (10.5)	0.28
Abdominal x-ray	1 (1.0)	1 (1.2)	0.93
Focused Assessment with Sonography of Trauma	14 (14.3)	5 (5.8)	0.06
Abdominal ultrasound	4 (4.1)	2 (2.3)	0.50
Electroencephalogram	5 (5.1)	5 (5.8)	0.83
Values are N (%) or mean (standard deviation) unless otherwise specified *not exclusive, so % may add to more than 100%			

TABLE 3.5. Characteristics of NAT According to Child's Age			
	0-6 months old (n = 98)	**>6 months old (n = 86)**	**p-value**
Non-accidental Trauma Confirmed	57 (58.2)	49 (56.9)	0.87
Relationship of Perpetrator			0.13
Mother	13 (22.8)	7 (14.3)	
Father	5 (8.8)	3 (6.1)	
Both parents	6 (10.5)	4 (8.2)	
Mother's significant other	1 (1.2)	8 (16.3)	
Foster Parent	0 (0.0)	1 (2.0)	
Daycare/Babysitter	2 (3.5)	2 (4.1)	
Not specified	30 (52.6)	24 (49.0)	
Disposition			
Home with both parents	41 (41.8)	36(41.9)	
Family member other than parents	7 (7.1)	4 (4.7)	
Taken into custody	43 (43.9)	38 (44.2)	
Taken out of custody of 1 parent	7 (7.1)	6 (7.0)	
Rehab	0 (0.0)	2* (2.3)	

Values are N (%) or mean (standard deviation) unless otherwise specified
*One of the rehab patients was taken out of parental custody

Figure 3.1. Annual Skeletal Survey Frequency at a Trauma Center According to Child's Age

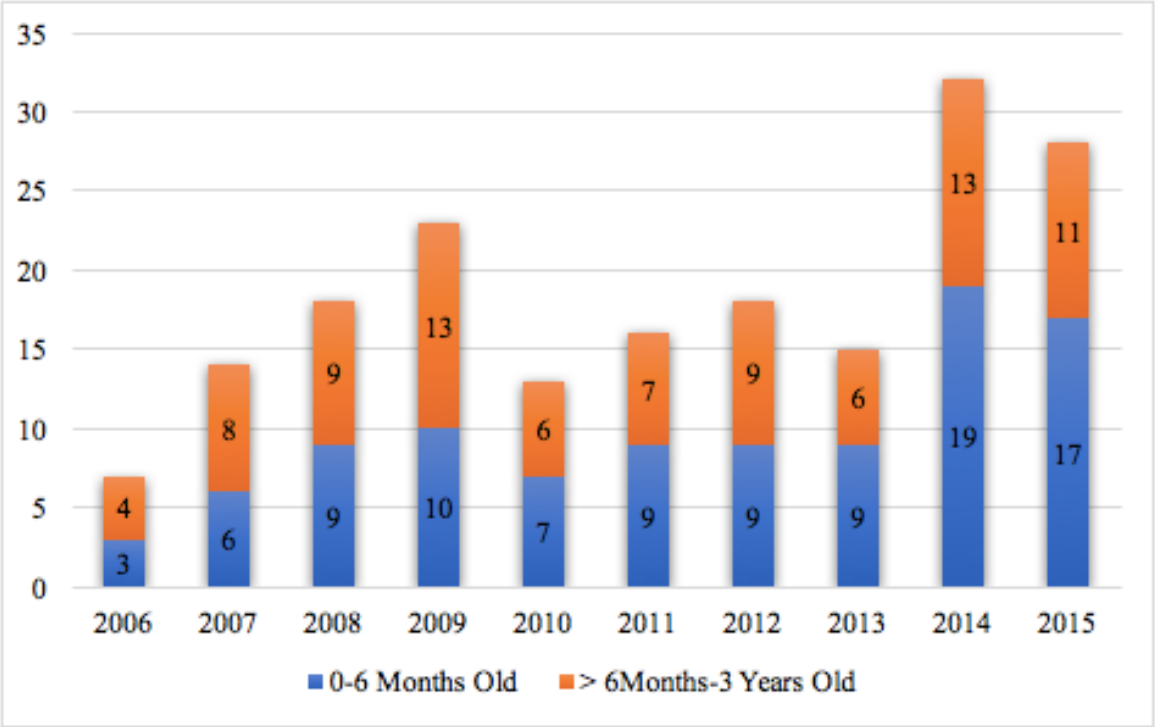
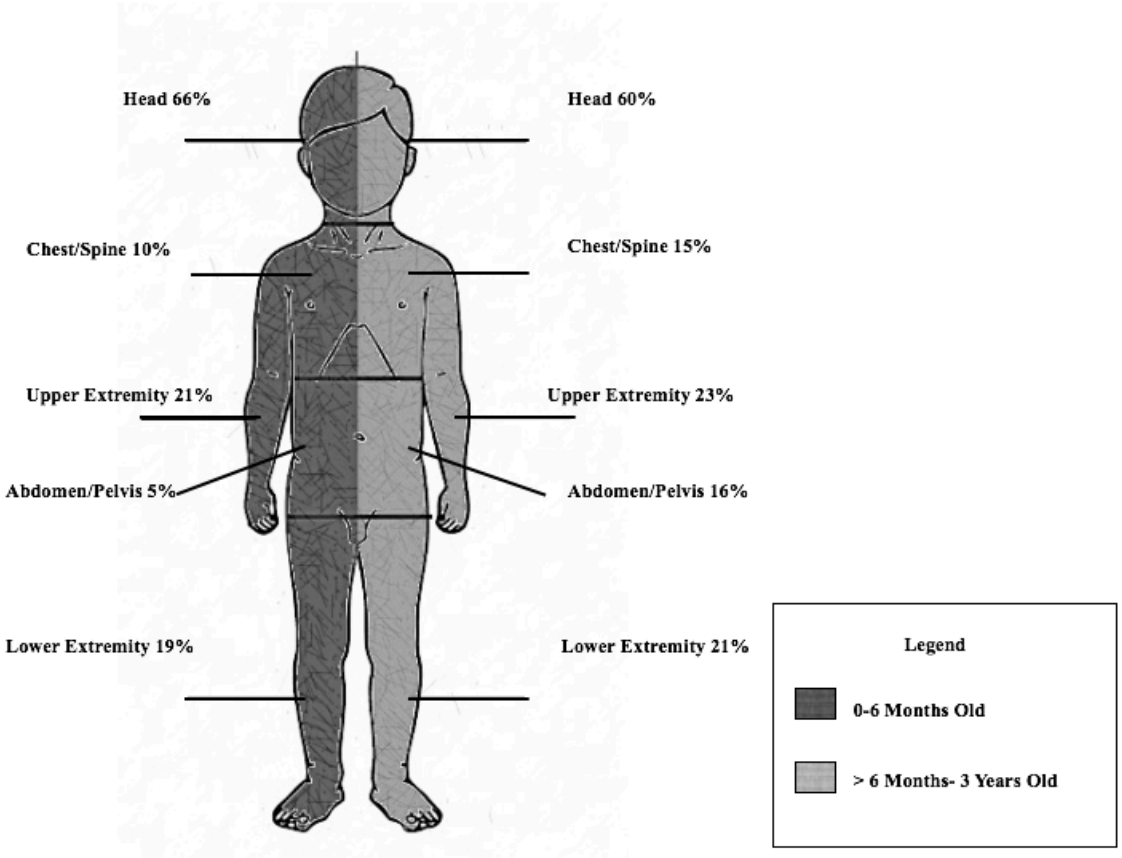


Figure 3.2. Pattern of Injuries According to Child's Age



CHAPTER IV: DISCUSSION

We examined the hospital medical records of pediatric patients who had skeletal surveys performed over a recent decade long period at our tertiary care, level one pediatric trauma center. Our study identified 184 patients who had a skeletal survey for suspicion for NAT out of a total of 5,937 total pediatric trauma patients. The majority of patients were less than 1 year old, white, and were male.

Utility and Findings of Skeletal Surveys

A positive skeletal survey was found in one sixth of all patients: 14% of patients ≤6 months old and 19% of patients >6 months to 3 years old, falling within the range of detection rates found in prior studies[10-12, 20]. We found no significant differences in the rates of positive findings of skeletal survey between children ≤ 6months old compared with children >6 months- 3years old. This was contrary to our initial hypothesis, as well as the results of earlier retrospective studies which showed that children under the age of 6 months had the highest rates of positive findings on skeletal survey[3, 11, 12].

In the largest and most recent retrospective study of more than 2,500 children investigated by child abuse specialists for suspicion of NAT, patients were selected from the Examining Siblings to Recognize Abuse (ExSTRA) research database. This database utilizes information from participating children's hospitals throughout the United States who have child abuse specialists. Investigators studied at children who were under 60

months old to determine if skeletal survey was diagnostic in children older than 24 months of age. They found that the skeletal survey identified fractures in 23% of all patients and this diagnostic yield was similar between children 12-24 and 24-36 months old[20].

Our study did not demonstrate a significant difference in rates of positive skeletal survey between patients in our 2 age strata, suggesting equal utility of skeletal survey in children ≤ 6months and those > 6months to 3 years of age. Currently, the American Academy of Pediatrics and American College of Radiology state that skeletal surveys are mandatory in children under the age of 24 months[6, 23]. However, the findings of the aforementioned retrospective cohort utilizing the ExSTRA database[20] demonstrate that skeletal survey might be beneficial in detecting NAT in children older than 24 months as well. Therefore, our study results along with those in the ExSTRA study convey that skeletal survey has utility in detecting NAT in children as old as 3 years of age, although future investigation is necessary to confirm this.

The most common fractures identified on the skeletal surveys were those of the long bone (50%), torso (30%), and skull (13%), with no differences noted between age groups. This pattern of injury follows similar trends previously reported [24-26]. For example, in a retrospective study reviewing all patients with NAT at a Pediatric Trauma Center in Texas over the period between 2007 and 2011, investigators identified 267 patients who presented with over 473 injuries. The median age of these patients was 7 months old and over half (61%) were males. Among patients presenting with isolated

injuries, extremity (49%), torso (20%) and skull fractures (13%) were the most common, consistent with our findings [25]. These injuries continue to be more prevalent in victims of NAT and the skeletal survey identifies them consistently, demonstrating its utility in the pediatric trauma population.

Institutional Trends in the Use of Skeletal Survey

Skeletal surveys were performed with the greatest frequency during the 2 most recent study years at our institution. The number of skeletal surveys has nearly tripled within a 5-year time frame, with 23 skeletal surveys performed in 2015. Skeletal surveys have been recommended for the detection of injuries suspicious for NAT as far back as the early 1990's [27]. However, in 2009, our institutional policy was modified so that all patients with traumatic injuries who are preverbal or unable to explain what happened are referred to the Child Protection Program (CPP, consisting of pediatricians who are fellowship trained in NAT). Although a skeletal survey is not automatically done when a CPP referral is placed, CPP will recommend skeletal surveys after their review if indicated. Our increasing use of the skeletal survey in suspected pediatric NAT victims may reflect not only our general hospital policy, but also heightened clinical awareness and knowledge of NAT.

Additional Imaging Studies

The most common additional imaging performed was a Head CT. These scans were performed in nearly all patients ≤6 months old and in two thirds of patients >6 months old. Although the rate of CT head scan utilization in NAT varies between 19-

66% depending on institutional neurologic imaging protocols [28], we found that the youngest patients were significantly more likely to have a head CT scan performed. This trend is similar to the rate of head CT scans for all cause minor head injuries in children presenting to the emergency department which has been between 32-38% for children <1 year and between 25 and -30% for children ages 1-5 years [29].This finding may be related to the inability of children ≤ 6months to communicate injury locations and symptoms or that these children experience the more severe head injuries.

On the other hand, we found that almost three times as many children > 6months to 3 years old had an Abdomen/Pelvis CT compared with younger children. A recent (2015) retrospective study performed in 2015 at a Pediatric Trauma Center in Houston Texas evaluated 404 patients admitted for suspected NAT over an 8-year period. Patient ages ranged from 11 days to 17 years old with over half (60%) males and 72% of all injuries occurring in patients less than 12 months of age. They found that abdominal injuries were more common in children older than 12 months compared with those under 12 months of age (25% vs 7%)[30]. These differences may represent how children of different ages suffer distinct mechanisms of injury. For instance, children under the age of 6 months might be more likely to experience NAT by shaking compared with striking in older children. Therefore, children in these different age groups have dissimilar diagnostic work ups.

Injury Presentation, Diagnosis, and Disposition

Most children presented to our institution with fall/assault injuries that occurred at home. Almost all children were transported to the hospital via ambulance or parent/guardian, with a majority of the injuries occurring between the hours of 4pm and 4am. Injury severity scores were comparable between our 2 age-specific comparison groups. These findings are similar to the results of a previous study carried out in 180 cases of suspected NAT that occurred between 2008 and 2012 at a single institution, which had a median injury severity score of 9 [26]. More children in the older group were intubated upon arrival compared with the ≤6-month-old group, which when used as a measure of injury severity, is contrary to prior findings where younger victims of NAT had more severe injuries [31]. These differences in results could be attributed to the power of the study, since the aforementioned investigation included more than 2,500 patients. Therefore, we could have potentially seen a similar trend in a larger study population.

The most prevalent locations of final injuries were the head, extremity, and abdomen/pelvis, results which are similar to prior studies [26, 32]. A prior study identified 265 pediatric NAT patients at a regional Trauma Center in Denver, Colorado over a 7-year period. The mean age of patients was 11 months old, 60% were males. Investigators found that patients most often suffered head injuries (71%), followed by extremity injuries (23%), which is consistent with our findings[32].

In over one half of the patients, there was suspicion of NAT, and a child was taken out of custody of at least one parent. In fact, 42% of children with confirmed NAT were taken into state custody. A prior study showed that 40% of children who were victims of abuse excluding non-accidental head trauma were placed into foster care [33]. Our study did not show a difference in the frequency of confirmed NAT after receiving a skeletal survey between younger (≤6 months old) and older (>6 months- 3 years old) trauma patients, suggesting that clinicians must remain vigilant in diagnosing NAT in pediatric patients regardless of age.

Study Strengths and Limitations

This study offers insights into the workup for NAT in pediatric trauma patients. In addition, it highlights the utility of the skeletal survey in pediatric patients under the age of 3 years old, who are already receiving an extremely comprehensive workup. We identified differences in the utilization of head and abdomen and pelvis CT scans among children ≤ 6 months old and >6 months old. On the other hand, this study has several limitations that need be kept in mind in interpreting our study results. Our study reviewed pediatric trauma patients who came to our institution over a 10-year period. This may have excluded other patients who had skeletal surveys performed due to suspicion of NAT but were not trauma patients. Finally, the power of our study may not have been sufficient to detect differences between the two principal study groups.

Conclusions

Pediatric patients represent a vulnerable population that is at risk for NAT with severe injuries. Knowledge of patterns and mechanisms of injury, in conjunction with clinical data, may provide guidance in the management of these patients. In our study, advanced imaging modalities differed between the 2 age groups. Neurologic imaging (CT Scan) was more frequently performed in patients ≤ 6 months old, whereas abdominal CT scans were performed more often in children > 6 months old. Head and extremity injuries were most often identified, with a similar detection rate between patients in both age groups. Skeletal survey is a valuable tool in assessing for injuries of NAT in pediatric trauma patients undergoing extensive workup, regardless of the child's age.

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