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Infant car safety seats and risk of head injury

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ABSTRACT

Background/Purpose: We observed a high incidence of traumatic brain injuries (TBI) in properly restrained infants involved in higher speed motor vehicle crashes (MVCs). We hypothesized that car safety seats are inadequately protecting infants from TBI.
Methods: We retrospectively queried scene crash data from our State Department of Transportation (2007–2011) and State Department of Public Health data (2000–2011) regarding infants who presented to a trauma center after MVC.
Results: Department of Transportation data revealed 94% of infants in MVCs were properly restrained (782/833) with average speed of 44.6 miles/h when there was concern for injury. Department of Public Health data showed only 67/119 (56.3%) of infants who presented to a trauma center after MVC were properly restrained. Properly restrained infants were 12.7 times less likely to present to a trauma center after an MVC (OR = 12.7, CI 95% 5.6–28.8, $p < 0.001$). TBI was diagnosed in 73/119 (61.3%) infants; 42/73 (57.5%) properly restrained, and 31/73 (42.5%) improperly/unrestrained ($p = 0.34$). Average head abbreviated injury scale was similar for properly restrained (3.2 ± 0.2) and improperly/unrestrained infants (3.5 ± 0.2, $p = 0.37$).
Conclusion: Car safety seats prevent injuries. However, TBI is similar among properly restrained and improperly/unrestrained infants involved in higher speed MVCs who present to a trauma center.
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There are 1.3 million children involved in MVCs each year [1]. MVCs are a leading cause of death and injury among children <1 year of age, accounting for 3% of emergency department visits [2], and the cause of >70,000 injuries over the last decade [3]. The majority of these injuries are to the head, accounting for 70% of significant injuries acquired by infant motor vehicle passengers [4]. In our state, federal law mandates that infants are restrained in a rear-facing car safety seat positioned in the back of the vehicle [5]. This is because infants have relatively large heads compared to older children and have several structural features of their neck and spine that place them at particularly high risk of head and spine injuries in MVCs [6]. It is theorized that rear-facing car safety seats provide optimal support to the head and spine in the event of a crash [6,7] because forces are transferred from the back of the car safety seat to the infant's back, which is the infant's strongest body surface [7]. It is known, however, that shaking an infant without the head impacting a surface is enough to cause tearing of bridging veins, resulting in subdural hemorrhage [8]. Infant head injuries related to MVCs have been attributed to head movement without substantial head contact to any structure or another occupant. This is significantly different from older children in forward-facing restraints, in which head injuries are associated with more skull fractures and with additional head contact points within the vehicle [9]. We have observed that infants involved in moderate to high-speed MVCs often sustain significant head injuries, despite being properly restrained. This observation along with the differences between infants and older children in anatomy and restraint type prompted our investigation. Here we examine TBI rates and severity in properly restrained and improperly/unrestrained infants who presented to trauma centers after being injured in an MVC. There are no previous studies evaluating this specific question.

1. Methods

Two data sets were retrospectively reviewed. The first, from our state Department of Transportation, includes the police records of all reported MVCs in the state. From this data set we abstracted data on infant passengers <1 year old involved in a MVC between 2007 and 2011. We calculated frequencies for proper use of car safety seats and infant position in the vehicle, as well as the mean speed ± standard error of the mean of involved vehicles. The second data set is from the state Department of Public Health. It includes records of all infants <1 year old in the state, who presented to a level I, II, or III trauma center with injuries resulting from an MVC from 2000 to 2011. From this data set, we also calculated frequencies for proper use of car safety seats, presence of TBI and other injuries, and severity of injuries using the injury severity score (ISS) and abbreviated injury scale (AIS). Student's t-test and odds ratio with 95% confidence intervals

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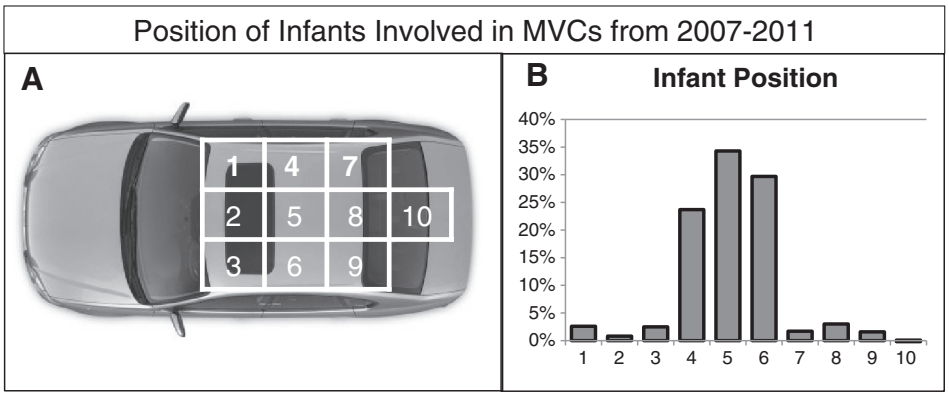

Fig. 1. Position of infants involved in an MVC from 2007 to 2011. (A) Position entered by recording officer on scene. (B) Percentage of infants located at each position. Proper positions include 4–9.

were used for statistical analysis. Statistical significance was set at a p-value <0.05. All data sets were complete unless otherwise stated. This study was IRB reviewed, and considered not human subjects research.

2. Results

2.1. Department of Transportation data

To establish a baseline for the number of infants involved in MVCs in our state, we reviewed records from the Department of Transportation from 2007 to 2011. There were 833 infants involved in MVCs during this 5-year period. According to the recording officer on the scene, 782/833 (93.9%) of infants were properly located in a rear passenger seat of the vehicle, and 788/833 (94.5%) were properly restrained in a car safety seat (Fig. 1). Restraint status was unknown for 11/833 (1.3%) children. The average speed of all vehicles was 25.1 ± 0.8 miles/h. This increased to 34.2 ± 0.8 miles/h when excluding non-moving vehicles, and increased to 44.6 ± 4.2 miles/h for vehicles in which the officer recorded possible infant injury.

2.2. Department of Public Health data

To determine rates of injury, injury types, and severity of injuries for infants involved in MVCs in our state, we reviewed records from the Department of Public Health from 2000 to 2011. During this 12-year period, 119 infants presented to a level I, II, or III trauma center with injuries sustained in an MVC. This group included 28 infants who presented between 2007 and 2011, indicating that 28/833 (3.4%) of all infants involved in MVCs presented to a trauma center with injuries during this time period. Of these 28 infants, 17/28 (60.7%) were properly restrained and 11/28 (39.3%) were improperly/unrestrained. Comparing these data to the Department of Transportation data revealed that a relatively higher proportion of all improperly/unrestrained infants were injured in MVCs (Fig. 2). The odds of a properly restrained infant presenting to a trauma center with injuries after an MVC was 12.7 times less than that of an improperly/unrestrained infant (OR = 12.7, CI 95% 5.6–28.8, $p < 0.001$). When evaluating the entire 12-year period, 67/119 (56.3%) injured infants were properly restrained, and 52/119 (43.7%) injured infants were improperly/unrestrained.

2.2.1. Types and severity of injuries in infants

We evaluated rates of injury to specific body areas for infants who presented to a trauma center after being involved in an MVC from 2000 to 2011 (Table 1). The most commonly injured area was the head (73/119, 61.3%), and overall rates of injury to areas other than the head and skin were low. We also examined the severity of injury sustained by these infants (Fig. 3). The average ISS was 13.2 ± 1.1 for

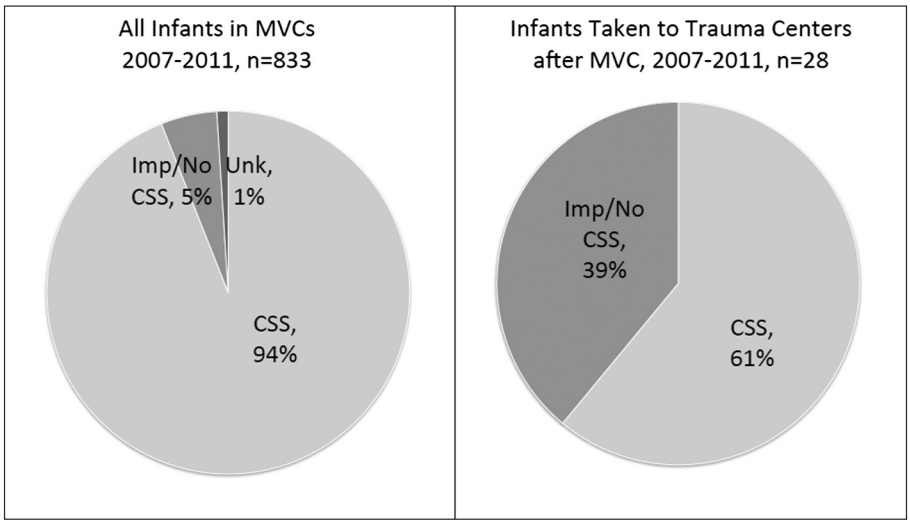

Fig. 2. Comparison of infants involved in an MVC by restraint status. A greater proportion of improperly/unrestrained infants presented to a trauma center after MVC compared to those who were properly restrained in a car safety seat. Imp/No CSS = Improper/No Car Safety Seat, Unk = Unknown, CSS = Car Safety Seat.

Table 1
Types of injuries sustained by infants presenting to a trauma center after an MVC from 2000 to 2011.

Injury	# of Infants (%)
Head	73 (61%)
Face	9 (8%)
Chest	14 (12%)
Abdomen	10 (8%)
Extremity	17 (14%)
Skin	48 (40%)

all infants. There was no difference in ISS between injured infants that presented to a trauma center who were properly and improperly/unrestrained ($p = 0.29$, Fig. 3A). However, ISS was significantly higher for children diagnosed with a TBI compared to those who were not diagnosed with TBI ($p < 0.001$, Fig. 3B).

2.2.2. Infants with traumatic brain injury

TBI was the most commonly observed injury (Table 1). Of infants who suffered a TBI in an MVC, 42/73 (57.5%) were properly restrained and 31/73 (42.5%) were improperly/unrestrained. The odds of a properly restrained infant being diagnosed with a TBI after presenting to a trauma center with injuries sustained in an MVC were similar to those of an improperly/unrestrained infant (OR = 1.14, CI 95% 0.54–2.39, $p = 0.34$, Fig. 4A). Average head AIS was reported for 54 infants with TBI, 33 properly restrained infants and 21 improperly/unrestrained infants. The average head AIS for all infants diagnosed with TBI was 3.3 ± 0.2, representing serious injury. For infants who presented to a trauma center after MVC and were diagnosed with a TBI, the average AIS head was similar for those who were properly restrained (3.2 ± 0.2) and improperly/unrestrained (3.5 ± 0.2, $p = 0.37$, Fig. 4B).

2.2.3. Mortality

Within our data set, 8/119 (6.7%) infants died from their injuries. The majority of these infants, 7/8 (87.5%), sustained a TBI. The incidence of mortality for properly restrained infants was 3% (2/67), compared to 12% (5/52) for infants who were improperly/unrestrained. The odds of mortality increased greater than 4-fold for infants who were improperly/unrestrained, however this did not achieve statistical significance (OR 4.24, CI 95% 0.82–21.95, $p = 0.09$).

3. Discussion

Current state laws mandate the use of a car safety seat and the American Academy of Pediatrics recommends using rear-facing car safety seats for children up to 2 years of age [6]. These directives are based on reports that proper use of infant car safety seats prevent injury, and that rear-facing car safety seats are better at preventing injury compared to forward-facing car safety seats [4,10,11]. Unfortunately, non-medical professionals provide the injury assessment in many studies [10,12,13]. As a result, some types of head injuries are excluded from evaluation [12]. Head injuries are the most common type of injury sustained by children in MVCs and have been identified as a target of injury prevention [4,14,15]. Prior reports evaluating use of child restraints and protection from head injury are conflicting, but these reports group a wide age range of children in their analyses [16,17]. No previous study has evaluated restraint use with the frequency and severity of head injury specifically for infants.

Our study confirms that proper use of car safety seats prevents injury to infants involved in MVCs. By comparing the overall rates of properly restrained and improper/unrestrained infants in MVCs to the rates of injury and presentation to a trauma center of properly restrained and improper/unrestrained infants, we were able to show that properly restrained infants were 12.7 times less likely to be injured in an MVC and subsequently present to a trauma center. Importantly, however, this study also shows that head injuries affect the majority of infants who present to a trauma center after being involved in an MVC. These children are in vehicles traveling at moderate to high speeds. They often sustain serious head injuries, and when injured, proper restraint use does not diminish the odds of injury, or the severity of injury to the degree one would expect. Thus, while infant car safety seats work to prevent injury, we demonstrate that improvements are needed to minimize injury when it does occur, and should focus on minimizing head injuries. A review of current test standards and the crash test dummy literature suggests why infant car safety seats may not provide adequate protection from TBI, and how they might be altered to provide better protection.

Current testing standards for child restraints in the United States are found within Federal Motor Vehicle Safety Standards document number 213 [18]. Car safety seats are tested at 19.9 miles/h (32 km/h) and 29.8 miles/h (48 km/h). In our study, the average speed of a moving vehicle with an infant passenger involved in an MVC was 34.2 miles/h, and this increased to 44.6 miles/h when the reporting officer documented concern for injury. In another analysis of vehicle speed in MVCs involving older children, the case fatality ratio increased incrementally with increasing road speed, and MVCs on moderate-speed (45–54 miles/h) and high-speed roadways (>55 miles/h) were predictors for death in tow-away crashes [19]. These findings indicate that test speeds to determine efficacy and safety of car safety seats are too slow to capture those circumstances in which infants are being injured. Based on this information, we suggest that current testing

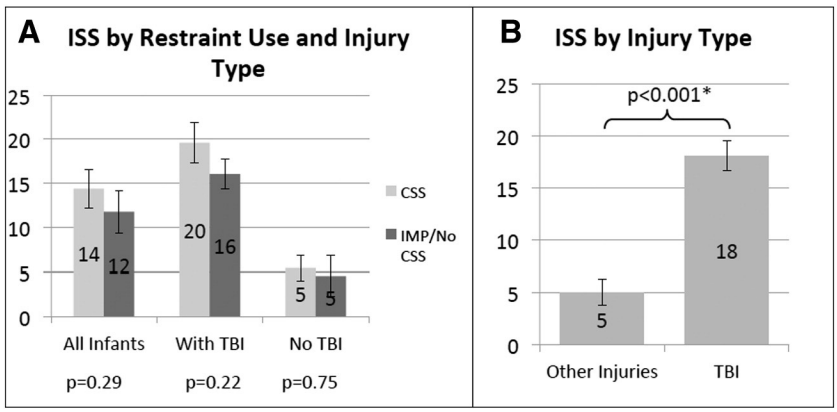

Fig. 3. (A) ISS by restraint use and injury type. For all infants that presented to a trauma center after an MVC, restraint use did not statistically change ISS. This did not differ when only evaluating patients who were diagnosed with a TBI. (B) ISS by injury type. Infants who presented to trauma centers after involvement in an MVC had statistically higher ISS if they were diagnosed with a TBI. P-values are derived from Student's t-test. *Statistically significant, CSS = car safety seat, IMP/No CSS = Improper/No car safety seat.

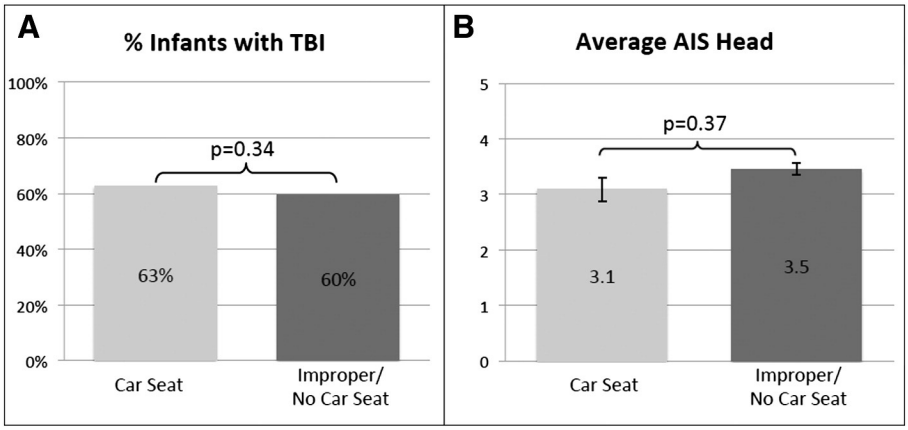

Fig. 4. Infants who presented to a trauma center after involvement in an MVC and suffered a TBI, compared by restraint type. (A) Frequency of TBI was similar for infants who presented to a trauma center that were properly restrained in a car safety seat compared to infants who were improperly/unrestrained. P-values are derived from the odds ratio. (B) Severity of TBI was similar for infants who presented to a trauma center that were properly restrained in a car safety seat compared to infants who were improperly/unrestrained. P-values are derived from Student's t-test, error bars represent standard error.

speeds for car safety seats be increased to help identify which car seats provide superior head protection at higher speeds. We also recommend that those driving with infant passengers drive slowly (<30 miles/h), and avoid highway driving whenever possible.

A report from the US Department of Transportation evaluating frontal barrier crashes using infant dummies showed that tests in which the rear-facing car safety seats interacted with the front seatback had higher head injury criterion-36 (HIC-36) measurements [20]. Furthermore, several car safety seats have a removable base, and the majority can be used with or without the base. In a second report from the US Department of Transportation on child occupant protection in side impact crashes, it was reported that test dummies had higher HIC-36 when the base was attached to the car safety seat [21]. This finding has been consistent between car safety seat models [22], and was confirmed by Transport Canada, which performed 57 rear-facing car safety seat crash tests with the base attached; 10/57 (17.5%) dummy heads hit the front seat back with an impact of more than 80 g, which is considered the threshold for injury [23]. Additional tethering of rear-facing car safety seats to the vehicle is used in Europe and Australia to control rotation during frontal impact, however, in the US, most rear-facing car safety seats are not tethered. One study demonstrated that absence of tethering was also associated with higher HIC-36 values [24]. We recommend that further testing be done to determine if elimination of the car seat base, additional tethering, or if altering the design of the car seat to avoid interaction with the front seat back decreases the HIC-36 measurements, and ultimately decreases the rates of TBI in properly restrained infants.

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Discussion

Unidentified speaker: I think that a lot of people would agree with your first comment about car seats being tested at high speed, but it is well recognized the department or what transportations sometimes calls UD10 reports that are filled in by the police are very inaccurate and being familiar with whether something was properly or improperly restrained is very subjective and I worry that somebody will look at this and say, well, why do I have to put my kid in a car seat, so I think you have to be careful about that.

That is my concern. Have you thought of any way of validating the proper restraint?

Response: Dr. Camille Stewart: That is a great question and it is very difficult to do, especially after a car accident. You know things move around. You are kind of dependent a lot of times on what the parents tell you or what you can see at the scene. We queried the Department of Transportation data essentially to give us our n value. How many children are getting injured? How many children are in motor vehicle crashes to begin with? When I spoke to people at the Department of Transportation, they said that there was rigorous training of all these officers and the reason why there is a difference in the time frame – so for the DOT our data are from 2007 to 2011 – is because they actually changed the way that they collected this information. Unfortunately, it is very difficult to abstract that information, but I don't think that these data say you shouldn't put your kid in a car seat. In fact, the first point that I made absolutely supports that you should, because you are much less likely to even get injured if you are in a car seat. The problem is children who are injured — unfortunately there is not a difference in traumatic brain injury.

Unidentified speaker: Again, sort of elaborating a little bit on what Dr. Erhlich said, I think the problem with the study is the question. The issue of properly restrained in a car seat depends on who is reading it. You can have a child who is properly restrained in the car seat where the car seat is not properly attached to the car. We get patients who come to our trauma center who were properly restrained in the car seat but the car seat is 30 ft outside the car. That I think is the issue with head injuries. They are not designed to be a bubble over the child's head, so if the child is a projectile inside the car or outside the car, it doesn't make any difference if he is in the car seat or not for his head injury. It may prevent other things like abdominal injuries, which is what you apparently saw here. So again I think it is the question you are asking.

Discussant: Dr. Tres Scherer (Boise, ID): A follow-up on those two questions. One, what are the parameters that are considered "properly restrained"? What were your parameters or what are the DOT's parameters on "properly restrained" — do you have a definition for that?

Response: Dr. Camille Stewart: I am not sure what they used for their specific parameters. I mean I know what is properly or improperly restrained, so for infants they should be located in the rear seat of the vehicle, not in the front seat. That would be one parameter, and then they should be rear facing versus forward facing for infants. Those were two considerations that I know were taken into consideration as far as proper or improper restraint.

Dr. Scherer: Well the NHTSA data did not come out in 2010 in regards to rear facing so I doubt that they had the rear facing in particularly the age groups of 1 year to 2 years,

Response: Dr. Stewart: We only looked at infants, so we are only looking at children less than 1 year of age.

Dr. Scherer: Okay, and then the second would be that 80% of children that are restrained (when reviewed by trained safety restraint officers) are not restrained properly or at least the car seat is not properly installed. Did you have licensed 40-h trained officers looking at these?

Response: Dr. Stewart: I don't know the credentials of the officers that went to the scenes.