

Risk factors for serious injury to child occupants 0-3 years in motor vehicle crashes

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Abstract

There has been no detailed review of injury outcome among children younger than 3 since 1994. While observational studies indicate age-appropriate restraint use is high in this age group, there have been significant design changes to the restraint systems used by these children over this period.

This study examines the relationship between crash factors, restraint status and outcome for children aged 0-3 who have been injured in car crashes in NSW. To achieve this, all children attending the Children's Hospital at Westmead subsequent to a motor vehicle crash between 2001 and 2011 were identified. Cases involving fatal injury were identified through the Department of Forensic Medicine. Data was extracted from narratives within medical records and analysed using descriptive and logistic regression techniques.

Data was collected for 90 children aged 1-35 months (mean 15 months). ISS scores ranged from 0-75 (mean 8.3) and included 13 children who were fatally injured. Restraint use was reported in all but one of the fatally injured children and 80% of the seriously injured (ISS >8). It was not possible to distinguish between rearward-facing and forward-facing restraint use from the available data, however over 20% of the children with ISS >8 used a booster seat or adult seat belt. The likelihood of serious injury is increased in motor vehicle crashes that occur in rural locations. There is a need for a more detailed study to examine restraint factors influencing outcome in children of this age.

Keywords

Traffic accident, infant, child restraint, risk factors

Introduction

In Australia and other developed nations, transport-related incidents are a significant cause of morbidity and mortality among children (Al-Yaman et al., 2002; UNICEF, 2001). Within New South Wales (NSW), approximately 1130 child occupants are injured and a further 17 killed each year in motor vehicle crashes, based on a 5 year average from 2005-2009 (NSW Centre for Road Safety, 2010). With restraint usage rates over 99% among child vehicle passengers (Brown et al., 2010), these figures highlight the need to examine the scope for further preventing injury and improving injury outcome among restrained child occupants.

Understanding and preventing injury to young children in crashes requires specific attention to the unique features of these occupants. Children are not a homogenous group and require different types of car restraints as they grow from infancy through childhood. This, together with variations in anatomy and biology may result in variations in the pattern of injury sustained in crashes. Previous studies have looked at children over a wide range of ages, or have eliminated younger children, resulting in a need to look specifically at the risk of serious injury for children aged 0-3 years (Arbogast et al, 2002; Blair et al, 2008; Brown et al 2006; Valent et al, 2002). The most recent in-depth Australian crash study that included children aged 0-3 years was conducted in 1994 by Henderson. The Henderson study reported that children correctly using restraints received a high level of protection, particularly in frontal impacts. However, it did not control for potential confounders and did not specifically look at children aged 0-3 years as a population subset. While observational studies indicate age-appropriate use is high in this age group (Brown et al., 2010), there have been significant design changes to the restraint systems used by these children over this period.

This study examines the risk factors associated with serious injury following a motor vehicle crash in children aged 0-3 years at a paediatric trauma centre and forensic medicine facility over a 10-year period. More specifically, this study aims to identify the associations of restraint status, seating position, crash location, impact direction, estimated vehicle speed and occupant ejection with injury severity, based on the hypothesis that these risk factors will affect the severity of injuries sustained by young children.

Methods

Data Collection

This study was performed as a retrospective medical record review. Cases of all children aged 0-3 years presenting at the Children's Hospital at Westmead (CHW) after being involved in a motor vehicle crash between 2001 and 2011 were identified using the CHW Trauma Information System. The Trauma Information System and patient medical records were used to extract age, sex and injury data. The Abbreviated Injury Scale (AIS) (1990 version) was used to assign an AIS-Code, and a maximum AIS-code (MAIS) was recorded for each region of the body, as well as overall. An overall severity score, the Injury Severity Score (ISS) was also calculated from the AIS-codes. The ISS is the sum of the squares of the highest AIS-code in each of the three most severely injured ISS body regions (Baker et al., 1974). Information contained within medical records and ambulance reports was used to compile crash descriptions. Crash data extracted from these descriptions included the child's restraint status and seating position, impact type, impact direction, vehicle speed (based on reported impact speed estimation in the medical notes) and locality of the crash.

In addition, records for all children aged 0-3 years who had been autopsied at the Department of Forensic Medicine (DOFM) following a car crash between 2001 and 2011 were identified from the department's database. Patient demographics and a description of the injuries sustained were extracted from autopsy reports and associated documentation and

crash data was extracted from information contained within coroner's reports and police reports.

Data Coding

Age was analysed as a categorical variable, based on 12-month intervals (0-1 years, 1-2 years, 2-3 years). Restraint status was analysed as a categorical variable (child restraint, inappropriate, unspecified). Children who were restrained in a dedicated child restraint were included in the 'child restraint' group and children unrestrained or using other restraints including booster seats and adult seat belts were included in the 'inappropriate' group. This definition was used as it is in line with current legislation that dictates children must be restrained in a rearward-facing child restraint until at least 6 months of age and a forward-facing child restraint until at least 4 years of age. Estimated vehicle speed, as contained in the medical record was analysed as a categorical variable (<60kph, ≥60kph, unspecified). Impact direction was analysed as a categorical variable (front/rear, side/rollover, unspecified). The impact direction grouping was based on whether or not the crash forces were longitudinal or otherwise, and is a grouping used previously in the literature (Brown & Bilston, 2007). Crash location was dichotomised into metropolitan and rural crash locality, defined by the Local Government Area in which the crash occurred. Seating position was dichotomised into front and rear passenger. Occupant ejection was analysed as a categorical variable (complete, partial, none). Complete ejections were defined as occupant ejections from the vehicle. Partial ejections were defined as instances where the occupant remained within the vehicle but was ejected from their restraint or the restraint became unfixated. The outcome variable, ISS, was dichotomised into serious injury (ISS >8) and not serious injury (ISS 0-8).

Data Analysis

Means and standard deviations were calculated for all continuous variables and frequency distributions were obtained for all categorical variables. Testing for statistical significance was performed on categorical variables using the Chi-squared test of independence and Fisher's exact test where appropriate. Multivariate binomial logistic regression modelling was used to identify the odds of serious vs minor or no injury (ISS>8 vs ISS≤8), while controlling for important cofounders. Potential variables were included in the models if they had a significant association with the outcome variable and included age, restraint status, estimated vehicle speed, crash location and impact direction. Crash location and impact direction could not be included in the same model due to their collinearity. This was due to side/rollover impacts accounting for a majority of the impact direction in crashes that occurred in rural localities and resulted in the model being run once with crash location and once with impact direction. The regression models were replicated excluding cases where restraint status was unspecified, as this could potentially confound the effects this variable had on the study population. Adjusted odds ratios (OR) and 95% confidence intervals (CI) were calculated using SPSS v20.0. Odds ratios were judged to be significant when the 95% CI did not include 1.

This study was approved by the Children's Hospital at Westmead Ethics Committee, the Sydney Local Health District (RPAH zone) Ethics Committee and the University of New South Wales Human Research Ethics Committee.

Results

Study Population

The total number of cases included in this study was 90, with 80 cases included from CHW and 10 cases from DOFM. There were slightly more boys than girls within the sample

(51.1% vs. 48.9%, respectively). The mean age of the child occupants was 15 months, with age ranging from 1-35 months. The largest numbers of children involved in car crashes were in the 1-2 year age group (42.2%) and the smallest numbers were in the 2-3 year age group (18.9%). There were 13 (14.4%) fatally injured children included within the sample, 10 of which were collected through the DOFM.

Injury Severity

Injury severity score (ISS) of the occupants ranged from 0-75, with a mean of 8.3. The mean ISS of cases from DOFM was 25.6. Within the sample, 18.9% were uninjured and 38.9% were seriously injured (defined as ISS >8). In addition, 17.8% of children experienced major trauma (defined as ISS >15). The mean ISS in the fatal outcome group was 30.9, compared with 4.5 in the non-fatal outcome group. Of the children that died, 100% had ISS >8 and 84.6% had ISS >15, compared with 28.6% and 6.5%, respectively, in the non-fatal outcome group.

Restraint Use

Restraint use was reported to be 85.6% within the sample, however 17.8% of children were using restraints (booster seat, seat belt) that were inappropriate for their age. It was not possible from the data available to distinguish between rearward-facing and forward-facing restraints, so the percentage of inappropriate restraint use may be higher than reported. Some form of restraint use was reported in 80.0% of the seriously injured group, however 34% of all seriously injured children were inappropriately restrained either in a booster seat or with an adult seat belt.

Crash Factors

The most common impact types in this study were frontal (42.2%) and side (23.3%). There was a significant association between impact type and serious injury, with 41.4% of side/rollover impacts resulting in serious injury compared with 28.6% of front/rear impacts ($p=0.012$). A large majority of the cases occurred in metropolitan areas (87.8%), compared with rural settings (12.2%). There was a significant association between crash location and ISS >8, with 72.7% of children involved in rural crashes being seriously injured, compared with 34.2% of children involved in metropolitan crashes ($p=0.020$). Within the sample, 10% of motor vehicle crashes occurred at low speed, defined as <60kph and 60% occurred at high speed, defined as ≥ 60 kph, with the speed of the remaining crashes unknown. The proportion of serious injury among those in low speed crashes was not significantly different from those in high-speed crashes (33.3% vs. 35.2%). Ejection occurred in 8.9% of the cases, with 50.0% of these classified as complete ejections from the vehicle. A correlation was found between impact type and ejection, with 75.0% of complete ejections occurring in rollover impacts compared to all other impact types ($p=0.002$).

Logistic Regression

After controlling for age, restraint status and estimated vehicle speed, the odds of sustaining a serious injury were significantly higher in rural areas (Table 1). Children involved in car crashes that occurred in a rural location were over 6 times more likely to sustain an ISS >8 compared with children in metropolitan crashes (OR = 6.6, 95% CI 1.44-30.29). When cases with unspecified restraint status were omitted, the odds ratio for serious injury in rural crashes increased (OR = 9.0, 95% CI 1.59-51.03) and children who were inappropriately restrained were over 3 times as likely to sustain serious injury than those restrained in child restraints (OR = 3.29, 95% CI 1.07-10.07).

Seriously Injured <i>Versus</i> Not Seriously Injured					
Model 1: With unspecified restraint status			Model 2: Without unspecified restraint status		
Independent variable	OR	95% CI	Independent variable	OR	95% CI
Age			Age		
0-1 years	Reference	Reference	0-1 years	Reference	Reference
1-2 years	0.46	0.15-1.38	1-2 years	0.52	0.17-1.62
2-3 years	0.77	0.19-3.16	2-3 years	0.60	0.13-2.74
Restraint status			Restraint status		
Child restraint	Reference	Reference	Child restraint	Reference	Reference
Inappropriate	3.16	0.37-14.94	Inappropriate	3.29*	1.07-10.07
Unspecified	2.34	1.04-9.55			
Estimated speed			Estimated speed		
0-59 kph	Reference	Reference	0-59 kph	Reference	Reference
≥60 kph	0.83	0.17-4.08	≥60 kph	0.86	0.18-4.18
Crash location			Crash location		
Metropolitan	Reference	Reference	Metropolitan	Reference	Reference
Rural	6.61*	1.44-30.29	Rural	9.01*	1.59-51.03

Table 1: Results from logistic regression models comparing the odds of sustaining a serious injury compared with a non-serious injury (the outcome variable), with age, restraint status, estimated vehicle speed and crash location. Cases with unspecified restraint status were omitted in the second model. OR = odds ratio; CI = confidence interval.

Seriously Injured <i>Versus</i> Not Seriously Injured					
Model 1: With unspecified restraint status			Model 2: Without unspecified restraint status		
Independent variable	OR	95% CI	Independent variable	OR	95% CI
Age			Age		
0-1 years	Reference	Reference	0-1 years	Reference	Reference
1-2 years	0.39	0.12-1.17	1-2 years	0.40	0.12-1.29
2-3 years	0.62	0.15-2.60	2-3 years	0.36	0.07-1.74
Restraint status			Restraint status		
Child restraint	Reference	Reference	Child restraint	Reference	Reference
Inappropriate	3.96*	1.22-12.88	Inappropriate	4.67*	1.37-15.93
Unspecified	1.48	0.20-11.07			
Estimated speed			Estimated speed		
0-59 kph	Reference	Reference	0-59 kph	Reference	Reference
≥60 kph	0.72	0.13-3.88	≥60 kph	0.69	0.13-3.73
Impact direction			Impact direction		
Front/rear	Reference	Reference	Front/rear	Reference	Reference
Side/rollover	2.56	0.86-7.60	Side/rollover	3.43*	1.09-10.80

Table 2: Results from logistic regression models comparing the odds of sustaining a serious injury compared with a non-serious injury (the outcome variable), with age, restraint status, estimated vehicle speed and impact direction. Cases with unspecified restraint status were omitted in the second model. OR = odds ratio; CI = confidence interval.

As impact direction and crash location could not be included in the same model due to a strong association between these variables ($p=0.013$), a second model substituting crash location with impact direction was run (Table 2). It demonstrated that children who were inappropriately restrained were 4 times as likely to sustain a serious injury than those who were in a child restraint (OR = 4.0, 95% CI 1.22-12.88). When cases with unspecified

restraint status were omitted, the odds ratio for serious injury among inappropriately restrained children increased (OR = 4.7, 95% CI 1.37-15.93). In addition, children involved in side/rollover impacts were more than 3 times as likely to be seriously injured (OR = 3.4, 95% CI 1.09-10.80).

Discussion

This study examined the factors influencing injury severity following motor vehicle crashes in children aged 0-3 years over a 10-year period. This study has identified that the likelihood of serious injury is increased in car crashes that occur in rural locations, with inappropriate restraint use and in side or rollover impacts. These trends should be investigated in more detail to further our understanding of how serious injury in young children involved in motor vehicle crashes can be prevented.

Restraint Use

Almost 8% of children in this sample were unrestrained. This is substantially higher than observed in a recent cross-sectional study of restraint use among child vehicle passengers aged 0-12 years in NSW where only 0.8% were unrestrained (Brown et al., 2010). In addition, the current study found 17.8% of the children were inappropriately restrained, using either a booster seat or adult seat belt, in comparison to 31.6% of children aged 0-12 years in the same cross-sectional study. The disparity in prevalence of inappropriate restraint use between studies could be due to the differing ages investigated, as the study by Brown et al. (2010) found inappropriate use was most common among children aged 4+ years.

Despite high restraint usage rates, a significant number of children continue to be injured in motor vehicle crashes. The results from this study highlight the implications of premature graduation from child restraints, as over 20% of children who sustained serious injuries were restrained either in a booster seat or an adult seat belt. The importance of using size-appropriate restraints has been demonstrated in previous studies, with inappropriately restrained children estimated to be at 3-4 times greater risk of injury (Du et al., 2008; Orzechowski et al., 2003; Valent et al., 2002). In order to continue to reduce the number of children being injured in motor vehicle, strategies need to continue to be developed that target size-appropriate restraint use.

There is also a need to investigate the mechanisms by which these child occupants are being severely injured despite being appropriately restrained in child restraints. Due to the retrospective nature of this study, correctness of restraint use was unable to be determined, but it is likely to play a significant role. Incorrect restraint use, either through errors in installation or in securing the child within the restraint, is of concern as it degrades the protection provided by that restraint in motor vehicle crashes (Brown & Bilston, 2007; Lalande, et al, 2003; Langwiederet al, 1999; Weinstein et al., 1997). Studies have reported incorrect restraint use to be widespread, particularly among users of dedicated child restraint systems (Blair et al., 2008; Brown et al., 2010; Decina & Lococo, 2005; Koppel & Charlton, 2009). The results suggest a need to better understand the role that incorrect restraint use may have in injury causation among children in the 0-3 age range in crashes.

It was not possible to determine whether the children restrained in child restraints were using rearward-facing or forward-facing restraint systems. Variation in the anatomy and biology of children as they grow creates the need for these two child restraints to be used during specific developmental stages.. Australian law dictates children aged up to at least 6 months should be restrained in a rearward-facing child restraint system. Studies report rearward-facing car restraints reduce the risk of serious injury by about 80-90% (Carlsson et al, 1991; Tingvall, 1987) and forward-facing car restraints by approximately 70% (Weber,

2000). However, there are currently no studies in the literature that look at the injury protection provided by these two dedicated child restraint systems for children aged 0-3 years under Australian conditions and in Australian restraints. In particular, most international studies have not examined restraints with top tethers, which are known to reduce injury risk. The inability to study this factor is a limitation of this study and highlights the need for a prospective study of children in this age group where the data collected can be better controlled.

Crash Factors

This study found that the direction of crash impact was a significant predictor of injury severity for children aged 0-3 years involved in motor vehicle crashes. Almost half the children who were involved in side impacts were seriously injured, and side impacts accounted for almost half of the fatally injured children. This is in agreement with previous research that has shown side-impact collisions pose an increased risk of serious injury, compared to other impact directions (Arbogast et al., 2001; Fildes et al., 2003; Orzechowski et al., 2003; Weber, 2000). When possible confounders were controlled, children involved in side/rollover impacts were more than 3 times as likely as those in front/rear impacts to be seriously injured. It has been highlighted within the literature that rollover impacts increase the risk of injury and death (Rivara et al., 2003), however, further research into the mechanism of injury in this crash type could provide insight into how the injury risk can be reduced.

An interesting finding within the study was the link between rollover impacts and complete ejections of children from the vehicle. The age of children ejected ranged from 1-21 months, with a mean of 10.3 months. The restraint status was not able to be determined in 2 of the 3 ejections that occurred during rollovers. However in the other case, an authorised fitter had secured the child restraint in the vehicle and the child, aged 1 month, was reported to be secured within the restraint, yet was ejected and fatally injured. There is the potential for further research into the dynamic testing used to simulate a vehicle rollover within Australian child restraint regulatory evaluations to determine the effectiveness of child restraints at limiting ejection during rollover impacts and identifying any possible flaws in harness design that would allow a child to be ejected.

It has been reported that there are higher road fatalities for adult occupants in motor vehicle crashes in rural areas compared with urban areas, with delayed medical care cited as a contributing factor (Muelleman & Mueller, 1996; Zwerling et al., 2005). Whilst it did not reach statistical significance, a similar trend of young children being at increased risk of sustaining fatal injuries during rural crashes was noted in this study. They were also over 6 times as likely to sustain serious injuries compared with children in metropolitan crashes. A contributing factor to this disparity could be impact direction, with side/rollover impacts accounting for almost 50% of the impacts in rural locations. There was insufficient data within the medical records on the time elapsed between the crash and patient arrival at the hospital to determine if delayed medical care may also be contributing factor to this disparity. These results indicate further research into the nature of motor vehicle crashes occurring in rural locations may be warranted to identify possible ways to reduce the injury severity and fatality risk of these crashes and again highlights the need for a prospective study where the data collected can be better controlled.

Crash severity has been reported by many researchers to have a major influence on injury outcome for adult occupants. This includes both injury severity (Augenstein et al., 2003; Richter et al., 2001; Siegel et al., 2001) and the occurrence of specific types of injury (Siegel et al., 2002; Smith et al., 2005). There are difficulties faced when trying to define 'crash severity' as a quantity, particularly when using data not collected by crash-

investigation. Estimated vehicle speed was substituted as a measure of crash severity in this study, however it was not known who estimated the speed. In addition it does not take into account all forces involved in the impact. For these reason estimated speed from teh medical record is likely to be a poor measure of actual crash severity. Within the literature, there appear to be very few studies that have examined crash severity and injury outcome in child occupants. One study determined that using delta-V as an indicator of crash severity, calculated based on the measured damage to the vehicles, is a strong predictor of injury risk for children (Nance et al., 2006). However, it is time consuming and expensive to obtain a measurement of delta-V from residual crash damage. Identifying another measure of crash severity that could be collected in a more cost effective manner would increase the future ability of researchers to study the effects of crash severity, and the effect of other factors while controlling for crash severity, n injury outcome among young children.

Injury Patterns

Studying the injury patterns of the children in this sample was not a primary aim of this study but it is interesting to note that the head region was the most severely injured region for almost 70% of children who were fatally injured. Studies of children in motor vehicle crashes report the head as the most frequently seriously injured region of the body (Khaewpong et al., 1995; Valent et al., 2002). However, no literature could be found that examines the relationship between severity of head injuries and fatalities. It would be beneficial to investigate the protection from head injuries provided by car restraints in this younger subset of the child population. This result also suggests a need for greater attention to the biofidelity of dummies used as surrogates, and the injury assessment measures and values used, in crash testing for occupants of this age group. Lower extremity injuries were a predictor of serious injury among the study population, with almost 60% of seriously injured children suffering a lower extremity injury. In 4 children, these injuries occurred in isolation. Nearly 20% of the study population experienced a fracture of one or more long bones of the lower extremity, with femur fractures accounting for three-quarters of these. The occurrence of lower extremity fractures has previously been described in children in forward-facing car restraints, with studies conversely reporting injuries below the knee to be the most common (Arbogast, Cornejo, Kallan, Winston, & Durbin, 2002; Jermakian, Locey, Haughey, & Arbogast, 2007). Variations in restraint design may play a role in these differences between studies in the United States of America and Australia. While lower extremity injuries do not often present a threat to life, they can have significant long-term complications. In a study of functional outcomes of seriously injured children, lower extremity injury was second to head injury in the cause of disability at 6 months post-injury (Wesson et al., 1989). A further understanding of the risk and mechanisms of these injuries is needed to reduce the occurrence and improve injury outcome of children involved in motor vehicle crashes.

Limitations

Several limitations of the methodology must be acknowledged when interpreting the results from this study. The study sample does not represent the outcomes for all car crash occupants aged 0-3 years in the NSW population. As subjects were all either admitted to a paediatric hospital in Sydney or autopsied at DOFM the sample is likely to be biased towards injured, and more seriously injured, children. Furthermore, child passengers in rural impacts are usually only transferred to a paediatric hospital in Sydney if they are seriously injured, so the subset of rural crash victims is likely to be more biased towards seriously injured children. Thus, it is not possible to directly ascertain whether the children in this sample reflect the overall injury risk within the wider community or whether clinically significant and fatal

injuries are over-represented in our sample. Future reports on this population should also include a greater number of hospitals in Sydney, for a more representative sample.

The retrospective nature of this study was also a primary limitation, as it reduced the control that the researchers had over the data that was collected. The restraint status and crash factors were obtained from data that was present within the medical records. Although systematic information was available from ambulance reports where available, a proportion of the data originates from parents or carers and may therefore contain inaccuracies. Estimated vehicle speed was used as a de facto measure of crash severity. While this was the only way to account for the potential confounding due to crash severity and is better than using no measure of crash severity, as noted above this is unlikely to be an accurate measure and is a limitation that should be kept in mind. In addition, there was missing data for one or more variables in almost all of the cases, which also likely impacts upon the significance and validity of most results.

Finally, using ISS as a measure of serious outcome may not be the most accurate measurement. It does not allow more than one injury within a body region to be included in the calculation. This means that the ISS is unchanged by multiple injuries in the same body region, and it does not accurately quantify the overall severity of injury and mortality risk.

Conclusion

This study has described the injury outcome of children aged 0-3 years involved in motor vehicle crashes and the association between restraint usage, crash factors and injury types. The odds of serious outcome were increased when the crash occurred in a rural locality, and when the child was not appropriately restrained. However the strong association between crash locality may be a reflection, at least in part, to the high number of side or rollover impacts that occur in rural locations. These impact types are also predictive of serious outcome in this age group. The retrospective nature of this study prevented a full examination of the potential influence of restraint and crash factors on injury outcome due to a lack of available data in the medical record. In particular, there is a need for a more detailed prospective study to examine restraint factors such as the influence rearward and forward facing restraints, and incorrect restraint use has on injury outcome in children of this age.

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