Analysis of a school bus collision: mechanism of injury in the unrestrained child

Peter C. Lapner, MD; Duong Nguyen, MD; Mervyn Letts, MD

Introduction: The most common type of school bus crash resulting in injury and death involves the "rollover" mechanism, which may be linked to bus design. To investigate this possibility, we carried out a detailed investigation of a severe school bus crash. **Methods:** The crash involved 12 children, passengers in the school bus. Analysis included the determination of crash dynamics by examination of physical evidence at the crash site and deformation sustained by the structure of the bus and the other vehicle involved. The mechanism of injury was determined by comparing physical evidence collected inside the bus to injuries sustained by the children. **Results:** Two children sustained severe injuries and 1 child was killed. The most common injuries involved the head, neck and shoulder as demonstrated by 3 illustrative reports. Specified changes to school bus design, based on mechanism of injury to the occupants include, in addition to the compartmentalization now in effect, more padding to the sides of the bus, over the window headers and on the panelling between the windows. **Conclusions:** Injuries to the head, neck and spine are the most common types when children are involved in rollover school bus collisions. For additional safety, changes to the current bus design are needed.

Introduction : Le type le plus courant d'accident mettant en cause un autobus scolaire et entraînant des blessures et des décès est celui où le véhicule effectue des «tonneaux», problème qui pourrait être lié à la conception des autobus. Nous avons étudié en détail une collision grave mettant en cause un autobus scolaire afin d'examiner cette possibilité. **Méthodes :** La collision a touché 12 enfants passagers de l'autobus scolaire. L'analyse comprenait la détermination des forces dynamiques d'accident par un examen des preuves matérielles sur les lieux et de la déformation de la structure de l'autobus et de l'autre véhicule. Le mécanisme des traumatismes a été établi au moyen d'une comparaison opposant les preuves matérielles recueillies à l'intérieur de l'autobus et les blessures subies par les enfants. **Résultats :** Deux enfants ont subi des traumatismes graves et un enfant est mort. Comme l'indiquent trois rapports illustratifs, les blessures les plus courantes touchaient la tête, le cou et l'épaule. D'après le mécanisme des traumatismes subis par les passagers, les changements qu'il faut apporter à la conception des autobus scolaires comprennent l'ajout de rembourrage sur les côtés, sur les traverses de fenêtre et sur les panneaux entre les fenêtres, en plus du cloisonnement déjà en application. **Conclusions :** Lorsque, à la suite d'une collision, un autobus scolaire effectue des tonneaux, les enfants passagers subissent surtout des blessures à la tête, au cou et à la colonne vertébrale. Pour plus de sécurité, il faudrait modifier la conception actuelle des autobus.

Motor vehicle crashes are a significant cause of injury and death for Canadian children.[1] School-bus-related injury accounts for a significant proportion of injury-related emergency department visits in Canada and elsewhere.[2] The "rollover" type crash is the most common mechanism producing severe injury in children who are passengers in school buses.[3] The 2 strategies for passenger protection currently in use are compartmentalization and the use of passenger restraints.[4–8]

In a pilot study it was demonstrated to be feasible for an emergency department medical team to identify children injured in motor vehicle crashes and to obtain concurrent analysis of the involved vehicles and investigation of the crash scenes by an engineering team. The purpose of the present study was to determine if injuries occurring in school bus crashes were related to school bus design and, hence, were pre-

From the Division of Pediatric Orthopedics, Children's Hospital of Eastern Ontario, Ottawa, Ont.

Accepted for publication Apr. 15, 2003.

Correspondence to: *Dr. Mervyn Letts, Head, Department of Surgery, Children's Hospital of Eastern Ontario, 401 Smyth Rd., Ottawa ON K1H 8L1; fax 613 738-4840*

ventable, and to identify injury patterns in rollover-type crashes. We conducted a detailed analysis of a severe school bus crash, involving a collision and rollover. The mechanism of injury produced in children in different seating positions was determined by correlating the medical injuries with an engineering analysis of the crash site and case vehicle.

Methods

The crash that we analyzed involved a full-sized school bus and a pickup truck. Investigators examined the accident scene for physical evidence (tire marks, gouges, fluid spills). These findings were then used to reconstruct vehicle dynamics and collision configurations. A full investigation of the vehicle included photographic documentation after its removal from the scene. Critical dimensions and the location and extent of the crash profiles were recorded. External damage of both the bus and the truck were similarly documented. The interior of the bus was inspected for physical evidence, including seating geometry and contact points of passengers related to injuries sustained.

All occupants of the bus were interviewed and examined. Information on pre-crash seating positions, and posture of occupants was obtained. Collision severity was determined from measurements of structural damage to the vehicles, using a variant of the CRASH program[9] and interpretation of posted speed limits.

Injury data and crash information were used to determine crash dynamics, occupant kinetics, and specifics of injury. This process was undertaken jointly by the medical team and engineers experienced in studying crash dynamics. The crash site and vehicular assessment data were then correlated with the injuries in an attempt to formulate the mechanism of injury and the role of occupant protection causing the injuries.

Results

The crash occurred at the intersection of 2 undivided 2-lane roads. The posted speed limit was 80 km/h. The truck ran the stop sign at full speed and collided with the left front wheel of the bus. The bus rotated clockwise, then rolled down an embankment, struck a rock pile, and continued to roll over another 2½ times before coming to rest on its left side (Fig. 1). Passengers were all thrown toward the left side of the bus.

Examination of bus structure showed that roof intrusion was concentrated over rows 1–6 (mostly over rows 1–4), with maximum intrusion of 26 cm over row 4 (Fig. 2). All side windows were intact. The windshield and rear emergency exit window both failed. Inspection of bus interior revealed physical evidence (blood, hair or tissue) of passenger contact on surfaces corresponding to rows 8–12. All contact points occurred on the left side of the bus, mainly around the headers over windows and panelling between them. Roof integrity was upheld other than the intrusion noted above. There was no evidence of loosening at seat anchor points.

There were 12 unrestrained children on the bus. They ranged in age from 9 to 14 years and were seated in rows 6–12. Most injuries involved minor lacerations and contusions. There were 3 fractures around the shoulder: 2 fractured left clavicles and 1 fracture of the right scapula occurring in cases 7, 10 and 11 (Table 1). One child (case 7) had cervical spine (c-spine) injury with C2–3 subluxation, and 1 child (case 1) died. Most injuries were left sided. Shoulder trauma was most common followed by neck injuries. A triad of head, neck and shoulder injuries was commonly seen.

Illustrative cases

Severe head injury (case 1)

The child who died was an 11-year-old girl seated in the right row, aisle 10 at the window. She fell to-

FIG. 1. Structural damage to front end and axle of bus in its final resting place.

FIG. 2. The site of maximal roof intrusion lies toward the front of the bus cage.

ward the left side of the bus, her head striking the metal header overlying the window at aisle 10. She sustained a severe head injury with diffuse cerebral edema and a subarachnoid hemorrhage.

Cervical spine injury (case 7)

A 12-year-old boy seated on the right at the aisle in row 11 sustained a subluxation of C2–3. This required treatment with posterior spinal instrumentation and fusion (Fig. 3). He also sustained lacerations to the hands as he attempted to break his fall with his arms overhead. He also has a possible meniscal tear of the left temporomandibular joint with prolonged clicking in that joint that improved after 3 months.

Left-sided shoulder injury (case 8)

A 13-year-old boy was seated at the window on the left in row 12. He suffered a fracture of his left clavicle as well as contusions and lacerations involving the jaw and tongue, the left thigh and knee.

Combined head, neck and left shoulder injury (case 3)

A 12-year-old girl seated at the aisle on the left in row 12 had multiple injuries including a concussion, a soft-tissue injury to the neck and extensive contusions about the left shoulder. Other injuries included a right ankle sprain, abrasions to the left hip and lacerations of the right knee and elbow. We postulate that the left-sided injuries occurred after the initial impact at the embankment bottom, with the patient's head and shoulder striking the area above window 12. Injury to the shoulder and lateral flexion of the neck likely occurred then, with other injuries due to the continued tumbling of the bus.

Discussion

Most injuries in this severe school bus crash involved the head, neck

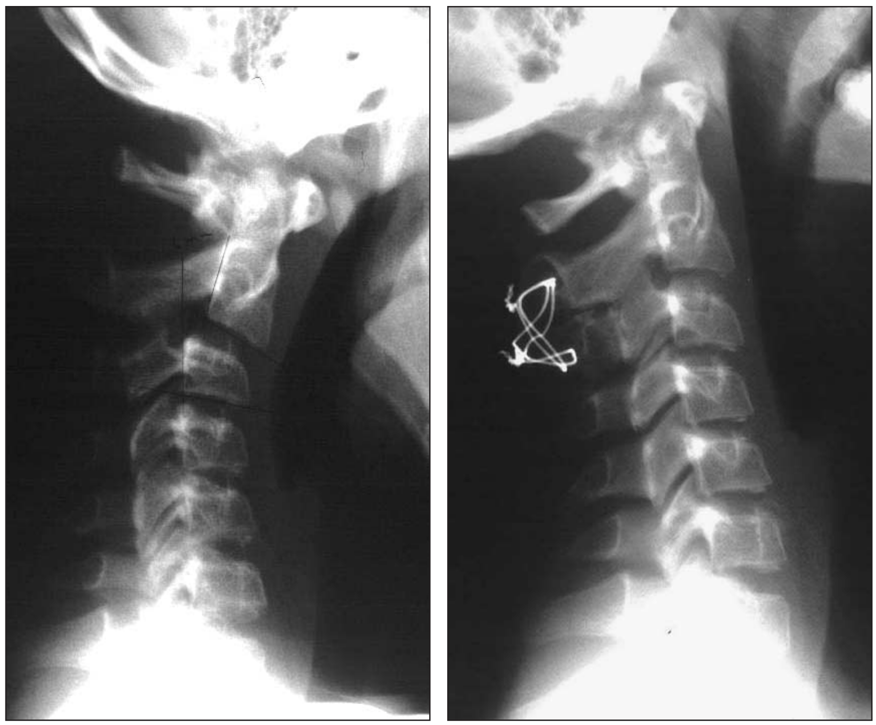

FIG. 3. Left: radiograph demonstrates preoperative subluxation of C2 on C3. Right: postoperative reduction and fixation of C2–3 subluxation.

Table 1

Summary of Passenger Position in the School Bus at the Time of the Crash and Injuries Sustained

Case no.	Sex	Age, yr	Side/row no/ position	Injury sustained
1	F	11	Right, 10, window	Subarachnoid hemorrhage; diffuse cerebral edema
2	M	13	Left, 11, aisle	Laceration left anterior scalp; soft-tissue injury cervical spine; bruising posterior left chest and ribs; abrasions right hip and left chest
3	F	12	Left, 10, aisle	Concussion; soft-tissue injury cervical spine; sprain right ankle; laceration right knee, abrasions left hip, right elbow, left shoulder and left ear
4	F	12	Right, 10, aisle	Soft-tissue injury cervical spine; bruising left shoulder
5	M	14	Right, 12, aisle	Soft-tissue injury cervical spine;, abrasions left axilla, left buttock, thorax
6	M	11	Right, 7, window	Soft-tissue injury cervical spine; bruising right shoulder and scapula; contusions bilateral knees and right thigh
7	M	12	Right, 11, aisle	Subluxation C2–3; lacerations right hand, left ankle, right thigh
8	M	13	Left, 12, window	Fracture left clavicle; contusion/laceration jaw; contusion left thigh, knee; laceration tongue
9	M	13	Left, 12, aisle	Contusion right knee; abrasions left shoulder and knee
10	F	12	Left, 7, window	Fracture left clavicle; contusion left thigh; laceration scalp
11	F	12	Right, 9, window	Fracture right scapula; contusion sacrum
12	F	9	Right, 6, window	Contusions occiput, left elbow and flank

and shoulder on the left side. Severe injuries included a fatal head injury, and a subluxation of the cervical spine at C2–3. Based on seating position, there were few right-sided injuries from passenger–passenger contact. Correlation of injury to physical evidence indicates that these resulted from contact with side panels and headers. There was no evidence of passenger injury resulting from contact with the edge of the seat in the opposite aisle, a mechanism that had been suggested previously.[5] From the accounts of the driver and occupants and from the crash kinematics, we believe that most injuries occurred when the bus struck the rock pile at the bottom of the enbankment.

The strategy currently in use in Canadian school buses involves compartmentalization. The passenger is "cocooned" in the compartment with surrounding passive restraints: padded seat backs; a steel inner structure that bends to absorb energy; strong anchoring points; high, wide and thick backing; even spacing to keep children inside the compartments.[3] In our study, fractures occurred in children seated on the side to which the bus rolled. Both severe injuries occurred in children seated on the side opposite to which it rolled. We believe this is a significant finding, suggesting that compartmentalization failed to contain passengers in this type of crash and to protect passengers along the sides of the compartment.

A test program was undertaken in 1984 to determine the effects of adding seat belts to school buses. Buses of 3 different sizes were equipped with test dummies restrained with lap belts: tests involved rigid-barrier 48 km/h collisions. It was concluded that the use of lap seat belts in all of the 3 sizes of recent model school buses resulted in more severe head and neck injuries for belted than for unbelted occupants in frontal collisions.[10] Equipping school buses with restraints also introduces the possibility for added injury with the presence of housing and extra structural support required to absorb the forces incurred by the restraints. This would counter the benefits of protective padding seen in the compartmentalization model.

Proponents of lap belts in school buses cite "carry-over" value — by introducing "lifesaving" habits in children. However, passenger restraints in cars act mainly to prevent ejection, an event very uncommon in school bus crashes.[7] It is, however, recognized that seat belts also prevent secondary contacts within the occupant compartment, thus minimizing trauma with the sides and ceiling of the vehicle. Seat belts may make the evacuation of a large number of children extremely difficult and prolonged if they are restrained in an overturned bus. Thus, the use of seat belts for children in school buses is controversial.

In the compartmentalization model, protection exists in the event of head-on or rear-end collisions. However, little protection exists along the sides of the compartment over window headers and on panelling between windows. Extra padding in these areas would be helpful to minimize direct-impact trauma.

Conclusions

In summary, the most common injuries in this rollover school bus crash involved the head, neck and shoulder. Although we agree with the principle of compartmentalization, changes to the structure of the compartment by extending the padding to the sides, over the window headers and on the panelling between the windows, would minimize the number and severity of injury seen in this common type of bus crash.

Acknowledgements: The assistance of Dr. Alan German and Mr. Bill Gardner of Transport Canada in conducting the engineering assessment of this motor vehicle collision is gratefully acknowledged. We also thank Ms. Sue Ziebell for her help in preparation of the manuscript.

Competing interests: None declared.

References

1. Hanvey L, Avard D, Graham I. *The health of Canada's children*. 2nd ed. Ottawa: Canadian Institute of Health; 1994.
2. Cass DT, Ross F, Lam L. School bus related deaths and injuries in New South Wales. *Med J Aust* 1996;165:134-7.
3. Gardner WT, Ste Marie S. School bus collision summary, Canada, 1989–1997. In: *Proceedings of the Canadian Multidisciplinary Road Safety Conference XI. May 9–12, 1999, Dalhousie University, Halifax, Nova Scotia*.
4. Leddy JE, Frew EM. Complete transection of the body of the stomach resulting from blunt trauma. *Can J Surg* 1977;20:264-6.
5. Scammell BE, Clarke NM. The unrestrained coach passenger — an injury complex. *Injury* 1987;18:1-4.
6. Spital M. School bus safety [letter]. *N Y State J Med* 1986;86:29-30.
7. Thornwaite S. School transport: seatbelts are not the issue. *Traffic Engineering and Control* 1990;31:588-9.
8. Wineland CL. The case against seat belts on school buses. *Educ Digest* 1986;33-6-12.
9. National Highway Traffic Safety Administration. *CRASH3 User's guide and technical manual*. Washington: Department of Transportation; 1982. Pub. no. DOT-HS-805732.
10. Farr GN. *School bus safety study*. vols I and II. Ottawa: Transport Canada. 1985. rep. no. TP8445.