CRASH PROTECTION FOR CHILDREN IN AMBULANCES

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ABSTRACT

The objectives of the study were to determine the most effective and reliable means of restraining children on an ambulance cot and to develop recommended field procedures for emergency medical service providers. A series of crash tests at 48 km/h were conducted using convertible child restraints, car beds, and harness systems tested with 3-year, infant, and 6-year size dummies. Belt configuration and backrest position were varied. A new cot and fastener system significantly improved restraint performance over older systems previously tested. A two-belt attachment with elevated cot backrest was found to be the method with the least performance variability for securing either a convertible child restraint or a car bed. It was concluded that children who weigh up to 18 kg, fit in a convertible child restraint, and can tolerate a semi-upright seated position can be restrained in a convertible child restraint secured with two belts to an ambulance cot. Infants who must lie flat can be restrained in a car bed modified for two seatbelt paths and secured to a cot. In each case, the cot backrest must be elevated, and the cot and anchor system must be crashworthy. None of the harness configurations tested proved to be satisfactory, but an effective system could be developed by following accepted restraint design principles.
Safe transportation of children in ambulances presents unique challenges for emergency medical service providers, pediatric transport teams, and child passenger safety advocates. The use of child restraint systems in motor vehicles is recognized as an effective means for the prevention of childhood injury and death. Although child transportation safety strategies primarily focus on passenger vehicles, awareness of the overall importance of child restraint in an alternative vehicle, such as an ambulance, has increased as a result of a number of activities, including research and training programs.

Current research on ambulance crash characteristics supports the use of restraint systems for ambulance occupants and supports the need for defensive driving as well. Kahn et al. [2000] reviewed 11 years of fatal crashes involving ambulances and concluded that ambulances struck another vehicle in 80% of cases, usually in an intersection, but that 78% of all fatalities were not ambulance occupants. Of the ambulance occupants who received fatal and incapacitating injuries, those in the rear compartment were most at risk, especially those who were unrestrained or improperly restrained. Although ambulance occupants suffered fewer fatal injuries than those in other vehicles or on the road, appropriate restraint use in the rear compartment was cited as an issue to be addressed.

In another study, observations of over 200 ambulances arriving at a large pediatric emergency department documented minimal if any effective use of restraints for child occupants, who were being transported on gurneys, bench seats, and adult laps as well as in wheelchairs. Also noted was the potential for injury from unrestrained equipment or other passengers [Levick et al., 2000].

The federally funded Emergency Medical Services for Children (EMSC) Program acknowledges the special circumstances of ambulance transport and the gap that exists between occupant restraint practices in ambulances vs. other highway vehicles [EMSC, 1999]. In the near term, they have concentrated on crash prevention and the general concept of restraint of all occupants and equipment to minimize the risk of injury. They also recommend that children who are not ill or injured be transported in a vehicle other than the ambulance whenever possible. Research is underway and full-scale ambulance crash tests have been conducted to better understand and characterize the ambulance crash environment [Levick and Schelew, 2001]. In the long term, the group intends to develop standards for emergency pediatric transport.

In recent years, awareness of issues related to transporting children in ambulances has increased. The advent of the Standardized Child Passenger Safety Training Program, initiated by the National Highway Traffic Safety Administration (NHTSA) in 1998, has created a national network of child passenger safety advocates.
Introduced to issues related to ambulance transport during the training [NHTSA, 2000b], these well-informed technicians have served as added impetus to explore options related to occupant protection in a variety of vehicles, including ambulances.

RESTRAINT CONSIDERATIONS IN AMBULANCES - Providing effective restraint for children in ambulances is a complex problem with many unique and unresolved issues. The occupant requiring transport may be acutely ill or injured, the vehicle has special characteristics for its function, and the crash environment and exposure are different from that of a family car. The ambulance environment is specifically designed for emergency treatment of passengers. Although there are variations in design, the patient compartment is typically equipped with a captain's chair that faces the rear of the ambulance, bench seats along one side of the ambulance, a cot, and storage for equipment and medical supplies. There are no forward-facing vehicle seats in the patient compartment upon which child restraints can be installed according to the manufacturers’ instructions.

When determining the best restraint of a child in an ambulance, consideration must be given to the reason the child is being transported (patient vs. accompanying passenger), the medical stability of the patient, and the available locations where the child can be restrained. If not ill or injured, the child should be transported in another vehicle if at all possible, as recommended by EMSC. A police vehicle, however, is not usually a good alternative, because of the presence of prisoner screens, plastic seats, and special equipment that may compromise child restraint performance [NHTSA, 2000b].

When transporting a child with an acute medical problem that requires constant monitoring, a current practice is to restrain the child directly to the cot with chest and hip belts, even though this provides virtually no crash restraint, especially in the forward direction. Whenever possible, a restraint system designed specifically for a child should be used, but the difficult problem is determining the most appropriate restraint location and method of securement in the ambulance.

Rear-facing captain’s chairs, or technician seats, can provide a good platform for some types of child restraints, and special instructions can be obtained from some child restraint manufacturers for installation of their convertible models (normal installation being either rear- or forward-facing) on an ambulance captain’s chair. It is also becoming increasingly common to equip these technician seats with a built-in child restraint, suitable for use with an accompanying child or a less critical patient, but not a small infant. Use of this seat by a child, however, in either a portable or a built-in child restraint, precludes use of the captain’s chair by an EMS technician.
Placement of a child restraint on a side bench seat is not recommended, because this usage applies the severity of a frontal impact to the less protected side-facing child. Such installations are specifically prohibited, with good reason, by all child restraint manufacturers.

Some types of child restraint systems can be attached to the ambulance cot. At present, most cots used in the field are anchored to the ambulance floor with a three-point “antler” positioning system along with a single friction clamp at the foot end that allows quick and easy loading of the patient. These cots do not have positive lock-in mechanisms, and they need only meet static loading requirements.

Crash tests conducted with this type of cot and fastening system were reported by Bull et al. [1998]. An example is shown in Figure 1. During the test, the cot frame and friction clamp twisted due to the asymmetrical loading, and the fastener would likely have failed if the cot's motion had not been limited by ropes. The cot and fastener did not provide a secure platform for the child restraint.

A new dynamically tested cot and anchor system uses a slide-in track to hold the cot firmly to the ambulance floor, but this system is relatively new and is not found in ambulances as often as the older antler system.

Current Federal Motor Vehicle Safety Standards (FMVSS) that address transportation of children do not directly apply to ambulances. The 48-km/h (30 mph) crash tests of FMVSS 213, Child Restraint Systems [NHTSA, 2000a], with deceleration peaks of
approximately 23 g, may reflect circumstances that are more severe than would be experienced in a crash of a heavy truck-based ambulance vehicle. The use of frontal impact tests seems to be appropriate, however, in light of the Kahn et al. [2000] findings that over 80% of fatal ambulance crashes are a frontal impact for the ambulance. This compares to only about 61% for passenger cars involved in fatal crashes [NHTSA, 1999].

Although restraint of child occupants in ambulances is recommended, there are no standard dynamic test procedures or requirements for ambulance cots and anchor systems, and specific information regarding the most effective methods have not been published. In the absence of applicable standards, crash tests have been conducted using the nominal test severity and performance criteria of FMVSS 213. In place of the standard flat bench seat and lap belt specified for sled tests, the ambulance cot is used, usually with more than one restraint belt. Until an ambulance-specific test configuration and severity are determined, the approach of using a modified version of the child restraint test procedure remains a reasonable way to ensure that children in ambulances are accorded similar protection to those in passenger vehicles.

METHODS

Sled tests were conducted at the University of Michigan Transportation Research Institute (UMTRI) for the purpose of evaluating the performance of currently available child restraint systems installed on a more crashworthy platform than was available for the previous tests [Bull et al., 1998]. For this series, a Ferno Mobile Transporter 35 cot and a Stat Trac 185 fastener were selected. Several different child restraint systems for different size children were also selected for testing on the cot. These included convertible child restraint systems, car bed systems, and harness systems.

The tests were conducted at 48 km/h (30 mph), with a sled pulse similar to that of FMVSS 213. Each test was recorded on either high speed 35-mm film or digital video, and all but the smallest dummy were instrumented to measure head and chest accelerations.

CONVERTIBLE CHILD RESTRAINT SYSTEMS - A convertible child restraint is designed to be used on a forward-facing vehicle seat in either a rear- or a forward-facing orientation and is suitable for infants or children up to 18 kg. As designed, it has two separate paths for securing it with the vehicle belt against either rearward or forward motion. The rear-facing orientation is known to provide superior crash protection compared to forward- or side-facing orientations [Kamren et al., 1993]. When a convertible child restraint is installed on an ambulance cot facing the rear of the
vehicle, it is necessary to use both belt paths. On the other hand, a rear-facing-only infant restraint, with or without a separate base, cannot be adequately secured using this method, since it has only one belt path and is designed to face rearward in the vehicle but opposite the vehicle seatback.

Two different models of convertible child restraints were first tested using the 3-year size (15 kg) crash dummy specified in FMVSS 213, facing the foot end of a flat cot. The internal harness straps were threaded through slots just below the dummy's shoulders, per manufacturers' instructions for rear-facing restraint, and the back surface of each restraint was adjusted to be reclined as close to 45° from vertical as possible. Cot belts were attached next to stops along the cot frame. A third test was conducted using the same installation but with the backrest elevated to provide additional support for the child restraint and dummy.

After these tests, some modifications to the cot were made, and an additional crash test was conducted. The cot backrest was replaced with a sheet metal version, rather than the original tubing design. To eliminate belt sliding on the cot frame, the pelvic belt was attached at slots on either side of the backrest and the leg belt attached rearward of the side rails (Figure 2). To extend the results to larger children, extra weight was added to the dummy to make it 18 kg, the weight of an average 5-year-old [Weber et al., 1985].

Figure 2. Set-up for a crash test of an 18-kg child dummy restrained in a convertible child restraint secured using two belts to an ambulance cot with an elevated backrest.

CAR BED SYSTEMS - For infants who must lie flat during transport, two car bed models were evaluated. First, a 6-month size (8 kg) crash dummy was placed in a car bed modified with belt loops on each side, through which the cot belts were threaded and secured. This installation oriented the dummy perpendicular to the forces of
the crash, consistent with car bed design requirements. A second smaller model with a single belt path was then tried with an uninstrumented newborn size (3.4 kg) crash dummy with the cot backrest elevated like a vehicle seat and the car bed secured against it with the cot belt. Another modified two-belt model was subsequently tested with the cot backrest elevated and the belts attached to the frame where they could not slide (Figure 3).

HARNESS SYSTEMS - To address the issue of larger children who do not fit into convertible child restraints, child dummies ranging from 18 to 27 kg were placed directly on the cot with a raised backrest to evaluate four different harness designs, including two commercially available harnesses, the cot-equipped harness restraint (Figure 4), and one prototype configuration. Since these harnesses depended on the strength of the cot's backrest and position adjuster, the newer version using sheet metal construction and a gas cylinder adjuster was used.

RESULTS

The Ferno Stat Trac and cot system performed well, even under repeated impact loading for this test series, although some repair to the cot backrest was necessary after a few tests.

CONVERTIBLE CHILD RESTRAINT SYSTEMS - Sled crash tests of two different models of convertible child restraints installed rear-facing on the ambulance cot using two pairs of belts demonstrated mixed results. In the first two tests, one model (Cvt-A)
performed satisfactorily, but the loose, soft cushion and lack of back support resulted in excessive rotation in the direction of the impact for the other model (Cvt-B). When that restraint was retested with the backrest elevated, the latter provided the necessary additional support for the child restraint and test dummy to achieve good performance, even though the backrest itself flexed somewhat.

Table 1. Acceleration and maximum back-angle results for 3-year dummies in convertible child restraints secured facing rearward with two belts on an ambulance cot, with FMVSS 213 criteria.

<table>
<thead>
<tr>
<th>Test</th>
<th>Dummy Mass (kg)</th>
<th>Head Peak g</th>
<th>HIC</th>
<th>Chest Peak g</th>
<th>Chest g ≥3 ms</th>
<th>Max Angle</th>
</tr>
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<tbody>
<tr>
<td>Cvt-A</td>
<td>15</td>
<td>41</td>
<td>362</td>
<td>43</td>
<td>42</td>
<td>53°</td>
</tr>
<tr>
<td>Cvt-B1</td>
<td>15</td>
<td>48</td>
<td>739</td>
<td>48</td>
<td>48</td>
<td>77°</td>
</tr>
<tr>
<td>Cvt-B2</td>
<td>15</td>
<td>52</td>
<td>460</td>
<td>46</td>
<td>45</td>
<td>54°</td>
</tr>
<tr>
<td>Cvt-B3</td>
<td>18</td>
<td>52</td>
<td>501</td>
<td>44</td>
<td>43</td>
<td>52°</td>
</tr>
<tr>
<td>FMVSS 213</td>
<td>15</td>
<td>na</td>
<td>1000</td>
<td>na</td>
<td>60</td>
<td>70°</td>
</tr>
</tbody>
</table>

Figure 5. Crash test sequence of an 18-kg child dummy restrained in a convertible child restraint (Cvt-B3) secured using two belts to an ambulance cot with an elevated backrest and a crashworthy tie-down system.
The fourth test (Cvt-B3) with the sheet metal backrest, improved belt attachment locations, and a heavier crash dummy, resulted in excellent performance in terms of dummy accelerations, child restraint motion control, and structural integrity of the platform, both during impact (Figure 5) and rebound. This installation method does not appear to be affected by variations in child restraint belt path and footprint design and is therefore considered robust enough to be applicable to all models of convertible child restraint systems. Dummy acceleration data and maximum back angle for the four tests are presented in Table 1, along with the FMVSS 213 test criteria for comparison.

CAR BED SYSTEMS - In the initial crash test of the modified two-belt car bed (CB-A) on the flat cot, there was significant uncontrolled motion as the cushion slid along the cot and the belts slid along the cot frame. The crash test with the smaller car bed (CB-B), using only one belt attachment but an elevated backrest, demonstrated unsatisfactory performance as the bed rolled rearward during rebound from the impact and did not effectively contain the dummy. The third test (CB-A2) with the two-belt installation, elevated backrest, and improved belt attachment locations yielded a secure restraint with good containment of the infant dummy (Figure 6). Dummy accelerations were, however, somewhat higher than those commonly measured in rear-facing restraint systems or recommended for this dummy in an airbag environment [Melvin, 1995]. Dummy
acceleration data for the two instrumented tests are presented, in Table 2, along with the Melvin criteria for comparison.

Table 2. Acceleration results for 6-month dummies in car beds secured laterally with two belts on an ambulance cot, with Melvin [1995] criteria.

<table>
<thead>
<tr>
<th>Test</th>
<th>Dummy Mass (kg)</th>
<th>Head Peak g</th>
<th>HIC 22 ms</th>
<th>Chest Peak g</th>
<th>Chest g ≥3 ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB-A1</td>
<td>8</td>
<td>72</td>
<td>520</td>
<td>68</td>
<td>65</td>
</tr>
<tr>
<td>CB-A2</td>
<td>8</td>
<td>52</td>
<td>405</td>
<td>63</td>
<td>55</td>
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<tr>
<td>Melvin, 1995</td>
<td>8</td>
<td>50</td>
<td>390</td>
<td>50</td>
<td>na</td>
</tr>
</tbody>
</table>

HARNESS SYSTEMS - None of the harness configurations tested proved to be satisfactory for both ease of use and effective restraint. Excessive ramping (Figure 7), or the movement of the dummy up the backrest in the direction of the impact, was observed in three tests, while inadequate adjustment range as well as interaction of the harness with the neck were problems in the fourth test. A confounding factor was the thick, soft, and loose cot cushion that compressed and shifted during impact, making the job of the harness all the more difficult. Because harness geometry and dummy kinematics were the primary problems, dummy acceleration measurements were not relevant to the evaluation and are not presented here.

DISCUSSION

The following recommendations for restraint of children being transported in ambulances are preliminary and based only on the results of this limited series of sled tests. They are aimed at providing guidance both for field use and for future research and development. They are not specifically endorsed by any child restraint manufacturers, and the usage recommended here may not be consistent with the official instructions for use of a child restraint in a passenger vehicle. Emergency service providers may wish to contact a specific manufacturer for amended instructions.

These recommendations also assume that the ambulance is equipped with a cot and fastener system that has been successfully tested under vehicle crash conditions. Less crashworthy systems may
perform adequately in lower speed impacts, but their use could have catastrophic consequences in higher severity collisions.

Even with these recommendations, it is recognized that the very nature of emergency circumstances may require some compromises of best practice. For instance, it is recommended that child restraints not be used again, once they have been in a crash. If a child is found in a convertible child restraint that is still visually intact, however, it may be better to move the child in that restraint to the ambulance for transport than to transfer the child to a different restraint. Likewise, time should not be taken to adjust the height of the shoulder straps of an available restraint if they are not in the best position. Rather, a convertible child restraint provided by the ambulance could be set up using the middle pair of slots, which would be adequate in most cases. These are issues that cannot be resolved by crash testing, and decisions may need to be made on an individual case basis.

The limited space within an ambulance makes it difficult to carry a convertible child restraint at all times. There are currently a few space-saving restraints, such as folding or inflatable seats not evaluated here, but specialty restraint systems can be much more expensive than mass-market products. In non-emergency transport, such as a scheduled inter-hospital transport of a ventilator-dependant child, the transportation can be organized and planned to incorporate the safest restraint choices. Convertible child restraints with 5-point harnesses have the advantages of being widely available, able to accommodate a range of child sizes, and easy to install on a crashworthy cot to provide effective crash protection.
With regard to car beds, the two-belt system tested has promise and could be used when a small infant must lie flat. It does not, however, appear to offer an equivalent level of protection to the rear-facing convertible configuration tested.

Appropriate harness systems for older children, and possibly some younger ones, would have the advantages of taking little storage space and potentially being quick and easy to use. Although none of those tested provided satisfactory restraint, adherence to accepted child restraint design principles [Weber et al., 2000] could result in the development of an effective harness restraint for larger children.

CONCLUSIONS AND RECOMMENDATIONS

Safe transportation of children in ambulances presents unique challenges for emergency medical service providers and child passenger safety advocates. Effective restraint is dependent not only on the child restraint equipment used but also on the platform to which it is attached. Although research concerning the ambulance crash environment is limited, fundamental principles of occupant restraint can still be used to develop useful and effective procedures in the field.

Utilization of the EMSC guidelines and the preliminary recommendations provided here will significantly improve the safety of children during ambulance transport. As more information is available about ambulance characteristics and crashes and new products are developed, testing procedures and additional investigations may result in evolving recommendations and establishment of further best-practice procedures. Until additional information is developed, the following recommendations should be incorporated into ambulance transport practice.

CONVERTIBLE CHILD RESTRAINT SYSTEMS - For restraining children up to about 18 kg who can fit into a convertible child restraint and can tolerate a semi-upright seated position (Figure 8):

- Use only a convertible child restraint, which can be secured with belts against both rearward and forward motion, and select one that has a 5-point harness for routine use. Infant restraints, which have only a single belt path, cannot be installed using this method.
- Position the convertible child restraint on the cot facing the foot-end with the backrest fully elevated. Adjust the restraint recline mechanism so that the back surface fits snugly against the backrest of the cot. The resulting angle
should be comfortable for the child but not more than 45° from vertical.

- Anchor the convertible child restraint to the cot using two pairs of belts. One should be attached to the cot backrest in a location that will not slide up or down and routed through the restraint belt path designated for “forward-facing” installation. The other should be attached rearward of the farthest side rail anchor and routed through the restraint belt path designated for “rear-facing” installation.

- Fasten the 5-point harness and snugly adjust it on the child. Ideally, the shoulder straps should be through slots at or just below the child's shoulders, since the convertible child restraint will be oriented rear-facing.

- For small infants, place rolled towels or blankets on either side of the child to maintain a centered position in the restraint [AAP, 2000].

![Figure 8](image)

**Figure 8.** Recommended method for restraining children up to about 18 kg. who can tolerate a semi-upright seated position, showing belt attachment to the cot and routing through the convertible child restraining.

**CAR BED SYSTEMS** - For restraining infants who cannot tolerate a semi-upright seated position or who, for other reasons, must lie flat (Figure 9):

![Figure 9](image)

**Figure 9.** Recommended method for restraining infants who cannot tolerate a semi-upright seated position, showing belt attachment to the cot and routing through the car bed loops.
• Use only a car bed that can be secured with belts against both rearward and forward motion. Car Beds with a single belt installation cannot be installed using this method.
• Position the car bed across the cot, so that the child lies perpendicular to it, and fully raise the backrest.
• Anchor the car bed to the cot with two pairs of belts attached to the cot as described above.
• Fasten the harness or other internal restraint and snugly adjust it on the infant.

HARNESS SYSTEMS - A recommendation cannot be made at this time for restraint of a child who cannot be accommodated in a convertible child restraint or car bed, either due to size or medical condition. Instead, recommendations are made for the design of an effective harness system for use on an ambulance cot.

Harness features needed are
1. fixed shoulder belt attachments or slots at or just below the child's shoulders to limit ramping;
2. a belt anchored to the lower side rails of the cot that is restricted from sliding and is routed over the thighs, not around the waist;
3. a belt running parallel to the cot that connects the lap belt to a non-sliding cot member or perpendicular belt in the leg area to keep the lap belt in place and restrict ramping;
4. a soft, sliding, or breakaway connector holding the shoulder straps together on the chest; and
5. lightweight one-handed strap adjusters.

At present the usual alternative for these children is the standard belt system provided on the cot. In addition, there should be concerted efforts to avoid crashes and to reduce the number of loose objects and unrestrained occupants in the patient compartment. It is hoped, however, that these recommendations will hasten the development of new harness products.

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