

Crash Protection for Infants Transported in Incubators

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ABSTRACT

This paper reports the findings from an investigation of an ambulance crash during which an infant, occupying a transport incubator, was seriously injured. In addition, it reports on the results from the development and testing of a methodology for restraining infants being transported by an ambulance while occupying a transport incubator. During the crash, the incubator detached from the ambulance attachment system. The infant was ejected from the incubator and sustained critical head injuries. Sled testing of a similar incubator system, incorporating exemplar hook-and-pile straps (one common trade name is Velcro®) to secure the infant, demonstrated the inadequacy of this restraint for occupant crash protection as used. Additional sled testing with a five-point restraint harness, increased incubator stability, and improved incubator to ambulance attachment demonstrated the feasibility of effectively restraining an infant while being transported in an incubator during a crash. During the simulated frontal crash tests, the alternate restraint prevented ejection of the infant dummy from the incubator and impact of the infant dummy with the incubator or ambulance interior and applied the restraining loads over a wide area of the body to the strong structural skeletal portions.

INTRODUCTION

It is widely recognized that motor vehicles including ambulances are frequently involved in crashes.^{1,2,3,4,5,6} These crashes put the occupants at great risk of injury. Motor vehicle crashes are a significant fatality risk to infants.⁷ However, the risk of injury can be significantly reduced by properly restraining the occupant and/or compartmentalizing the occupant within a small padded space.^{8,9,10,11}

In the U.S., young children are required by state law to be restrained by a child restraint when traveling in a passenger vehicle, in compliance with Federal Motor Vehicle Safety Standard (FMVSS) 213. Infants with medical challenges requiring an incubator are not required to be restrained when transported in the incubator. Nor is a transport incubator required to be crashworthy. Therefore, infants are frequently transported in ambulances within an incubator that will not provide adequate crash protection.¹²

Despite recent research that has investigated ambulance crashworthiness and associated occupant protection,^{13,14,15} few studies have focused on methods for proper restraint and adequate crash protection for neonatal and child transport in an ambulance.¹⁶ Although the American Academy of Pediatrics' published guidelines include crashworthiness recommendations for the overall structure and associated securing equipment

of an incubator transported by air, the guidelines indicate that the safety restraints of the incubator must be used to prevent the infant from sliding into the side of the incubator during normal vehicle operations.¹⁷ Unfortunately, these guidelines fail to consider the inadequacy of these restraints to provide protection to an infant in a crash environment.

The technology to restrain infants in automobiles has been readily available in the United States for decades. The recommended practice for restraining an infant for automobile transport in the U.S. and most other countries is to secure them in a rear-facing child safety seat using a restraint harness. The state-of-the-art restraint harness used by infants is a five-point harness. A five-point harness consists of two shoulder straps, one routed over each shoulder; two lap belts, one routed over each thigh/hip; and a crotch strap that routes from the seat bottom to a buckle positioned low and centered on the infant's pelvis. When so restrained, during a frontal crash the primary restraint to the infant is provided by the child safety seat's seat back.

Compartmentalization is a technique used to passively protect an occupant during crashes, using well-padded surfaces positioned close to the occupant to restrain/contain the occupant and absorb energy when the occupant loads the surface. One example of the use of compartmentalization is a school bus. The seats in many school buses are positioned close to the seat in front, and the back of seat backs are heavily padded to absorb the energy of body impact. Seat belts frequently are not provided. In a frontal crash, the children load against the seat back in front of their occupant position early in the crash pulse, and ride the crash down against the padded seat back. School bus compartmentalization provides some occupant crash protection during frontal and rear crashes, but is ineffective in side impacts and rollovers.¹⁸ Another example of compartmentalization is the infant car bed restraint. While these devices typically incorporate internal straps, nets, or other fabric systems to prevent the infant from being ejected, the primary means of protection is provided by containing the infant within the "tub"-like bed that incorporates padding along all of the side walls.^{19,20}

CRASH INVESTIGATION

An ambulance crash investigated by the authors demonstrates the injury potential resulting from the lack of crash protection for infants being transported in an incubator. Investigation of the crash included: inspection of the ambulance, inspection of the incubator, review of the infant's medical records, review of the police accident report, interview of witnesses, a fit check analysis of a newborn dummy in the subject incubator, and sled testing conducted with an incubator incorporating the same type harness and incubator to ambulance attachment system as in the crash investigated and an alternative occupant restraint system and two different incubator attachment systems.

In this case an ambulance was used to transport a three-day-old infant in a transport incubator. (Figure 1)

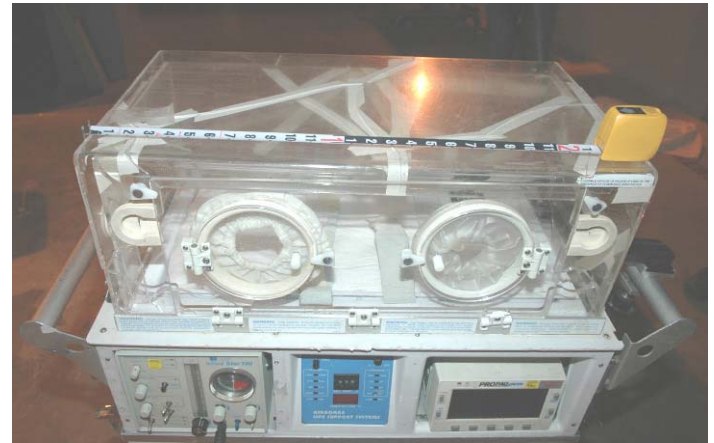


Figure 1. Subject Transport Incubator

Prior to departure, the infant was placed in the incubator and the incubator was latched into the rear patient compartment using the gurney attachment system. The infant was lying on her back with her head toward the front of the vehicle and with the two available hook-and-pile straps fastened over her body. (Figure 2) There were two adult occupants in the front outboard occupant positions of the ambulance cab, both restrained by lap/shoulder seat belts. There were three adult occupants in the patient compartment, restrained by lap-belt-only seat belts. One adult was seated in the rear-facing captain's seat located at the front of the patient compartment. The other two adults were seated on the bench seat on the right side of the ambulance.

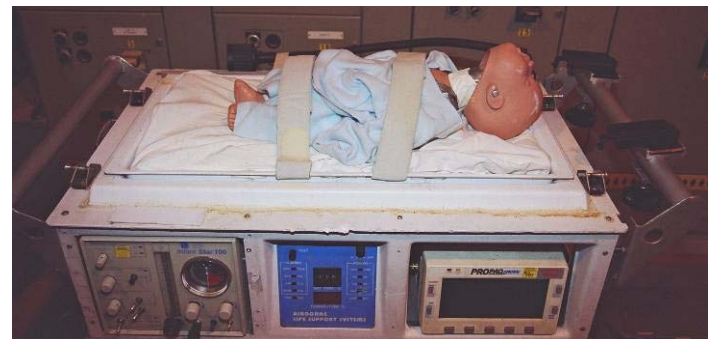


Figure 2. Infant dummy in subject incubator

During transport, the ambulance was impacted frontally by a 1994 Subaru Legacy. The collision experienced by the subject ambulance was a frontal crash with a Delta-V of 31-54 kph (19-34 mph), resulting in crush damage to the cab portion of the ambulance; however, no significant crush damage was sustained by the rear patient compartment. (Figure 3)



Figure 3. Frontal impact damage to the ambulance

During the crash, the infant was ejected from the incubator and the incubator structurally failed. The incubator's Plexiglas occupant enclosure broke into several fragments and the incubator detached from its cart. The infant sustained critical intracranial head impact injuries, including subarachnoid, subdural, intraparenchymal, and intraventricular hemorrhaging, and an inferior occipital skull fracture. In addition to the severe head injuries, the infant sustained; ecchymosis to the forehead, chest, and left elbow, a laceration below the left knee, atelectasis of the left upper lower lobes of the lung, and possible liver damage. Neither of the adult occupants in the ambulance cab was seriously injured. The driver sustained a fractured nose. Limited information is available to the authors regarding the injuries to the adult occupants in the patient compartment. None of the adult occupants were injured as seriously as the infant. One occupant sustained impact-induced injuries from the detached incubator. All were able to return to work.

Frontal Crash Sled Testing

Frontal crash sled testing was conducted with three restraint conditions, the crash pulse used was the same pulse as that used for compliance testing of infant safety

seats in accordance with the Federal Motor Vehicle Safety Standard (FMVSS) 213 (48 kph (30 mph), 24G). This pulse was chosen because it was within the range estimated for the investigated crash and used for the assessment of other child restraint systems, which would allow for comparison with compliance testing of existing child restraint systems. It would also be a likely choice to be used by incubator manufacturers for assessing their restraint systems. All three tests were conducted using a 3.38 kg, 52 cm, newborn Civil Aerospace Medical Institute (CAMI) infant dummy was used because its size most closely resembled the size of the infant involved in the investigated crash and its small size and narrow shoulders challenged the restraint more than larger Child Restraint Air Bag Compatibility (CRABI) infant dummies with larger more rigid shoulders. The test dummy was uninstrumented.

Test 1 - Incubator with exemplar hook-and-pile restraint and attachment to gurney attachment system

Test 1 was conducted with a similar infant incubator incorporating the same hook-and-pile strap restraint design as found on the subject incubator. The incubator was secured to the sled using the same gurney attachment system as used in the previously discussed case. During the test, the infant dummy was immediately ejected from the incubator, and the incubator cart detached from its rear attachment to the gurney attachment system. (Figure 4) The hook-and-pile straps provided no noticeable restraint to the infant dummy. Based on the observed infant dummy kinematics, the infant dummy would have severely impacted the forward bulkhead of the ambulance compartment, had the bulkhead been represented in the test. Based on the rapidity of the dummy's ejection during the test, it is likely that the infant in the investigated case was ejected from the incubator prior to the incubator segments separating or its detachment from the gurney attachment system.

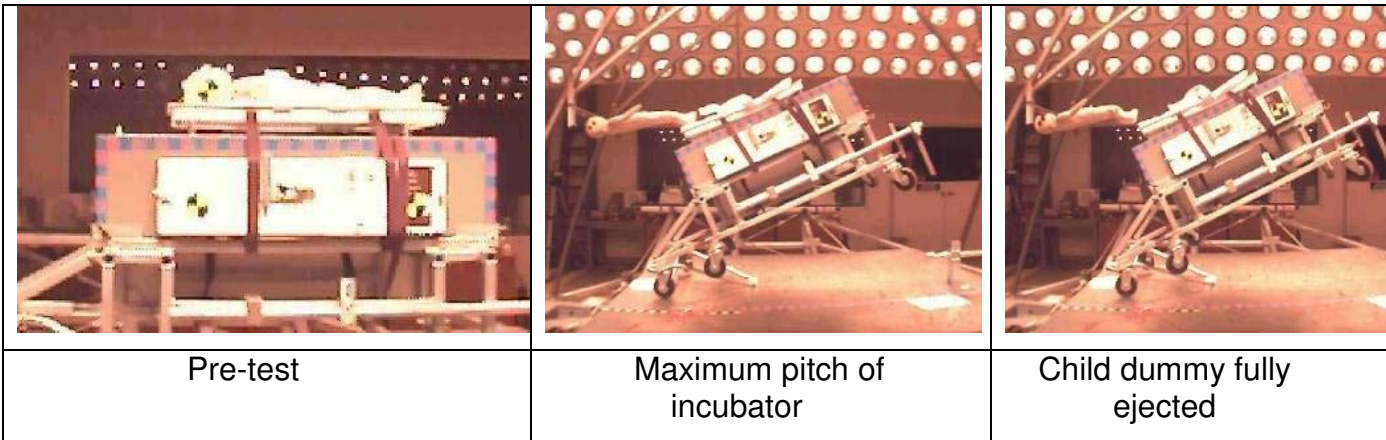


Figure 4. Infant dummy kinematics during frontal crash sled testing with hook-and-pile strap restraint (Test 1)