ORIGINAL RESEARCH

Crew and Patient Safety in Ambulances: Results of a Personnel Survey and Experimental Side Impact Crash Test

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Conflicts of interest: The authors have no disclosures or conflicts of interest to report.

Keywords: ambulance; Emergency Medical Services; safety management

Abbreviations:
EMS: Emergency Medical Services
MICU: Mobile Intensive Care Unit
ATD: anthropometric test devices
PMHS: post mortem human subject
IQR: interquartile range
HUMOS: Human Model for Safety
CSF: cerebrospinal fluid

Received: September 1, 2012
Accepted: November 15, 2012
Revised: November 21, 2012

Online publication: May 7, 2013

doi:10.1017/S1049023X13003543

Abstract

Introduction: Ambulance drivers often travel under stressful conditions at high speed while using vehicles with poor high-speed maneuverability. The occupant safety of ambulance vehicles has not yet been addressed by the automotive safety paradigm; particularly for the rear patient compartment. This study had two objectives: (1) to assess by survey the French Emergency Medical Services (EMS) to determine the layout of the vehicle most often used and the EMS personnel's behavior during transport; and (2) to conduct a crash test to analyze the injuries which may affect EMS personnel and patients in the rear patient compartment.

Method: Firstly, a survey was distributed to the 50 largest metropolitan French EMS programs. Secondly, a crash test was performed with a Mobile Intensive Care Unit (MICU) in conditions closest to reality.

Results: Forty-nine of the 50 biggest metropolitan French EMS programs responded to the survey. This represents 108 French MICUs. During the last three years, 12 of 49 EMS programs (24%) identified at least one accident with an MICU, and six of these 12 (50%) suffered at least one death in those accidents. A crash test using a typical French EMS MICU showed that after impact of a collision, the ambulance was moved more than five meters with major consequences for all passengers. A study-approved human cadaver placed in the position of a potential patient was partially thrown from the stretcher with a head impact. The accelerometric reaction of the anthropomorphic manikin head was measured at 48G.

Conclusion: The crash test demonstrated a lack of safety for EMS personnel and patients in the rear compartment. It would be preferable if each piece of medical equipment were provided with a quick release system resistant to three-dimensional 10G forces. The kinetic changes undergone by the "patient" substitute on the stretcher would probably have an effect of causing injury pathology. This study highlights the need for more research and development in this area.

Fournier M, Chenaitia H, Masson C, Michelet P, Behr M, Auffray JP. Crew and patient safety in ambulances: results of a personnel survey and experimental side impact crash test. ***Prehosp Disaster Med.*** **2013;28(4):370-375.**

Introduction

The dispatching of Mobile Intensive Care Units (MICU) and other ambulances to the scene of an emergency and transportation of patients to care facilities is a fundamental component of Emergency Medical Services (EMS). EMS personnel work day and night hours, often in dangerous environments that are associated with weather, road, and traffic conditions. Ambulance drivers often travel under stressful conditions with vehicles that have poor high-speed maneuverability. They are allowed to disobey traffic laws, although their lights and sirens are only partially effective in diminishing the potential for collision.[1-3]

Mobile Intensive Care Units are unique vehicles constructed from a standard truck chassis, comprising two sections. The front section is similar to most light trucks. The rear compartment typically contains equipment cabinets and rear and sideways facing seats. The EMS personnel in the front can adapt for accident avoidance, whereas the positioning of EMS personnel that work in the rear compartment does not allow for anticipation of an accident. The forward jump seat is by the head of the patient and places the provider in a rear-facing position. When using the curbside bench seat, the provider faces the street sidewall of the ambulance and has access to the patient's side. From these positions, EMS personnel assess, monitor and treat patients. The patient care activities from these positions may require a level of mobility that is not attainable with the standard lap belts provided. Considering mobility limitations, prehospital care providers are less likely to use safety belts when sitting in the rear compartment. The size of the rear compartment is such that an unrestrained passenger could be thrown a considerable distance in case of an accident. For these reasons, the rear compartment is potentially more dangerous than the front.

In contrast to comprehensive research and development of occupant protection in passenger vehicles by the automotive safety industry, the occupant safety of ambulance vehicles has not yet been addressed. There has been limited research on the biomechanics of occupant safety in the ambulance environment.[4,5]

In the US, the occupational fatality rate from ambulance crashes is four times that of other occupations[6] The most dangerous part of the ambulance vehicle has been demonstrated in both biomechanical and epidemiological studies to be the rear compartment. These studies show that collisions occur mainly at intersections with a lateral shock at the rear compartment.[7] Previous epidemiological studies have also shown that road accidents are the main cause of death for paramedics, with a risk that is higher than that for ambulance drivers.[8]

In France, no national reporting system or database exists for identifying ambulance crash-related injuries and their nature. To improve safety for EMS providers, since 2010 the French public health code requires the application of European standards EN 1989 and EN 1769 concerning medical transport vehicles and their equipment. These standards require safety performance testing to forces equal to 10G forward, rear, laterally and vertically.

This study had two objectives: (1) to assess French EMS common MICU vehicle design and EMS personnel behavior during transports; and (2) to conduct a crash test to analyze the potential trauma that may affect EMS personnel and a patient in the MICU rear compartment.

Methods

Study Design

This study was performed by the regional EMS system of southeast France (SAMU 13). It was conducted in two parts. First, a survey was distributed to the 50 largest metropolitan French EMS programs. The survey was conducted from January through December 2007. Second, a crash test was conducted using a MICU under field conditions closest to those actually encountered.

Study Setting

Questionnaires were mailed to and returned from EMS program directors. The survey instrument was an anonymous single-sheet form. The form contained three sections. The first asked about the internal design of the MICUs used by the EMS program, the number and arrangement of seats in the rear compartment, and the fixation methods of rear compartment material. The second section asked about the most common positioning of personnel in the rear compartment, their habits regarding their own safety and that of the patient, and how often safety belts were used in the rear compartment. This section had to be completed by as many persons as possible in the EMS program. The third section asked subjects to report their own traffic collision experiences during the last three years.

Figure 1. Interior of Crash Test Vehicle

Crash Test Protocol

The primary purpose of the sled (crash) test was to analyze the injuries that may affect EMS personnel and patients in the MICU rear compartment. The crash test was configured to reflect conditions actually encountered and within reasonable parameters of anthropometric test devices (ATDs). The sled test was designed using data from first phase survey results.

A one-side pole impact test of the rear patient compartment of a typical French Citroën MICU vehicle was carried out. This test was conducted on a test sled which generated a study-required acceleration pulse. The target sled was a standard barrier equipped with a pole, weighing 800 kg, which was projected horizontally against the left side of an immobile MICU, slightly in front of the rear wheel. The crash test was conducted at 50 km/h (30 mph). The MICU weighed 3250 kg, measured 5 m long, 2 m wide and 2.48 m high. The crash test vehicle was equipped in a manner similar to the majority of French MICU (Figure 1).

Two anthropomorphic dummies (Hybrid II, General Motors/NHTSA, Detroit, Michigan USA) were used to simulate the EMS personnel in the rear compartment. They were equivalent to an average male, 1.78 m tall, weighing 75 kg. One was seated and placed laterally with the back against the left side and facing the stretcher; the other was placed standing in the front of the rear compartment. A post mortem human subject (PMHS) was used to simulate the patient. It was placed recumbent on a stretcher and connected to a portable ventilator, a syringe pump and a cardiac monitor. The PMHS had been conserved in a Winkler solution, which assured the fluidity of its joints and conserved the mechanical properties of tissues.[9,10] A tri-axis accelerometer sensor (3-D accelerometer EGAS, 250 g, ENTRAN, Les Clayes Sous Bois, France) was set on the forehead to measure the acceleration of the head during the collision. Recordings were based on the ISO J211 norm.

In addition, three high-speed film cameras (X-VIT, AOS Technology AG, Baden Daettwil, Switzerland) were used to record the test. A camera taking 500 frames per second was attached to the rear compartment. The rear doors had been removed to assure complete visual access to the interior. Another camera

	Always	Often	Sometimes	Never	Total
EMS personnel restrained by seatbelts at departure	77 (72%)	27 (25%)	3 (3%)	0	107
EMS personnel restrained by seatbelts during entire patient transport	14 (14%)	14 (14%)	34 (33%)	40 (39%)	102
EMS Personnel have to stand up during patient transport	33 (31%)	34 (32%)	39 (37%)	0	106
Patient restrained by stretcher belts	37 (35%)	21 (20%)	21 (20%)	27 (25%)	106
Patient restrained by vacuum stretcher	49 (46%)	6 (5%)	35 (33%)	17 (16%)	107

Table 1. Behavior and Safety Characteristics of EMS Personnel and Patient in Rear Patient Compartment. Some respondents did not answer all questions.

taking 1000 frames per second was placed at ground level to register the crash and the consecutive displacement of the MICU. Finally, a third camera taking 1000 frames per second was placed far away to record the complete crash test platform.

Data Collection and Measurements

Data were collected on a standard data sheet by the investigators then computerized on a spreadsheet (Excel version 97-2003, Microsoft, Redmond, Washington, USA) and statistical analyses were conducted using Excel. Descriptive statistics involved frequency and percentages of patients for categorical variables and median with interquartile range (IQR) where appropriate for other variables.

The study protocol was approved by the institutional review board with ethical approval from the Marseille University Hospital's Ethics Committee.

Results

Survey

Forty-nine of the 50 biggest metropolitan French EMS providers responded to the survey giving a combined fleet of 108 French MICUs.

Vehicle Type

Two different systems are used to transport the physician on scene. The stationary system was used by 48 MICUs (44%) in the French EMS system where the physician travels in the MICU. The "rendezvous" system was used by 60 MICUs (56%) in the French EMS system, where the physician arrives in a rapid response car with all necessary equipment, but no facilities for patient transport. In these cases, 58 patients (99%) were transported by fire department ambulances based at fire stations and two (1%) by emergency private ambulances. The seat or bench at the head of the patient, placing EMS personnel in a rear-facing position was present in 32 MICUs (30%). The seats placed laterally with the backs against the sides were present in 78 MICUs (72%). The seats placed laterally with the seat back facing back were present in 36 MICUs (33%). The seats placed laterally and pivoting were present in 12 MICUs (11%). The materials transported were a cardiac monitor (Propacq 202 eL, Protocol Systems, Inc., Dallas, Texas USA) and syringe pumps (Injectomat CP BDS, Fresenius Vial, SAS, Brézins, France) on the stretcher bridge and restrained by belts, a portable ventilator (Oxylog 2000, Draeger, Lübeck, Germany.) on the rails of a stretcher and a bag with the medicines and disposable equipment restrained by belts. All devices were restrained within the vehicles by means of a fixation system (belt or rails).

Personnel Availability and Safety in the Rear Patient Compartment

During patient transport, there were at least two EMS personnel with the patient in the rear compartment in 59 MICUs (54%). There were three persons in 46 MICUs (43%) and more than three in three MICUs (three percent). The safety and the conduct of persons in the rear compartment are described in Table 1.

Traffic Collision History

During the last three years, 12 of 49 EMS programs (24%) identified at least one accident with a MICU, and six of these 12 EMS programs (50%) reported at least one death in those accidents.

Crash Test

The crash test showed that under the impact of the collision the ambulance moved more than five meters. The force exerted on the exterior of the ambulance was transmitted to the interior walls of the rear compartment. The shock led to deformation of the stretcher base causing the ejection of stretcher. The PMHS was partially thrown from stretcher, with the head and legs outside but restrained at the pelvis level by the lap belt. Its head impacted against a sharp corner of a storage compartment. The seated dummy was impacted at chest level by the stretcher and its head tilted violently striking the left side of the "patient." The dummy standing in the front of the rear compartment underwent an upward movement and its head struck the ceiling. It was also impacted at the pelvis level by the stretcher.

All medical equipment was projected towards the left side of the rear compartment without impacting anybody. The portable ventilator was projected with a force estimated at 417 joules, which is equivalent to a fall of ten meters.

Accelerometric reaction of the PMHS' head during the impact is represented in Figures 2 and 3. The resultant acceleration was measured at 48G, 28 ms after impact (25G on axis X, 41G on axis Y, -23G on axis Z). The velocity of the head was measured at seven meters per second (25 km/h), 40 ms after impact (Figure 2). The authors noted a brutal acceleration of the head to 150 ms (Figure 3), corresponding to the impact of the head against a sharp corner of a storage compartment.

Discussion

This study revealed a large disparity in the methods for transport of patients by the French EMS system studied. Transport may be carried out by the MICU, fire department ambulance or private ambulance. However, these vehicles have a similar design constructed from a standard truck chassis. The placement of seats is largely variable depending on the type of vehicle. The number of

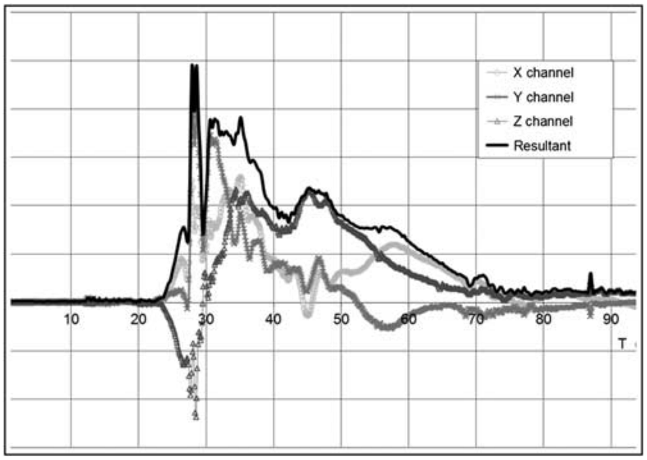

Figure 2. Velocity of the Head at Seven Meters per Second (25 km/h), 40 Milliseconds After Impact

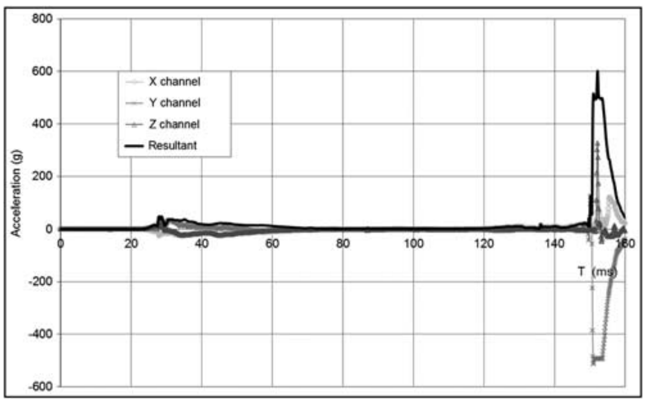

Figure 3. Acceleration of the Head to 150 Milliseconds

personnel in the rear compartment is also variable. Although the guidelines and the legislation recommend that EMS teams consist of three persons, some teams include a paramedic or medical student in addition.

The survey identified the behaviors at risk of EMS personnel in the rear compartment. The principal risk is the lack of seatbelt use by EMS personnel during transport. This lack is cited frequently in the literature as a predominant cause for the high injury and fatality rates for occupants in EMS crashes.[7] Often, one of the EMS personnel has to stand up during the transport. Unrestrained EMS personnel could be thrown a considerable distance in the rear compartment should an accident occur. The patient is not always restrained by a vacuum mattress so the risk of partial expulsion from the stretcher is increased in an accident.

In a previous study, the Advanced Life Support providers gave their opinion about what percentage of their work time would preclude them from wearing a safety belt, and why providers might not wear their safety belt.[3] The study also found that the providers cited patient care as the primary reason for non-use. The great majority attribute non-use to the incompatibility of currently available safety belts and optimum patient care.[3] More than 90% of respondents stated that they would use a functional restraint system if one were designed, thereby implying that the current restraint system is inadequate.[3] Increased safety belt use might be achieved via several means. First, greater emphasis could be placed on training prehospital care personnel about the use of safety belts and the hazards of ambulance work.[3]

More intensive efforts to educate prehospital care providers about the importance of safety restraints in the patient compartment may increase safety belt use. Enumeration of those patient care activities that can and should be performed while wearing a safety belt may also increase compliance. Nevertheless, it appears that the best way to improve the safety of those working in the rear compartment is to redesign the ambulance so that it has a functional restraint system and features that minimize the risks of injury should an accident occur.[3]

Unrestrained ambulance occupants are at substantially increased risk of injury and death when involved in a crash.[3] In addition, personnel could be taught to remove their safety belt only when they have to perform a procedure that has been demonstrated to be incompatible with safety belt use.[3]

Maguire and Porco described a two-phase intervention that reduced the collision rate in one agency by 50%. It involves a new training program and policy changes regarding increased seat belt usage and minimizing driving risk while using lights and sirens during transport.[8] This study shows that improvements are possible and highlights the need for more research and development in this area.

The study survey revealed that MICU accidents are frequent; one in four French EMS programs reported at least one accident involving an MICU during the last three years, and in one in two of these EMS systems had suffered at least one death in these accidents. In the interest of public, provider and patient safety, the French public health agency should require mandatory and standardized reporting of any crash involving an emergency ambulance or MICU.

As in previous studies, this study has identified some predictable and largely preventable hazards, particularly inside the rear compartment. Data reported emphasized the benefit of using restraints for occupants. The importance of over-the-shoulder harnesses or vacuum mattress for the recumbent patient and of firmly securing all equipment as well as a need for head protection cannot be understated.

From the crash test data, it appears that on impact, laterally placed equipment transmits energy to the stretcher, leading to a separation of the stretcher and the stretcher trolley. Moreover, the stretcher separation would lead to multiple injuries for EMS personnel as indicated by chest trauma to the dummy seated on the left side and pelvic trauma to the dummy standing in the rear compartment. This suggests the need for adequate clearance between the stretcher and the sidewall. The stretcher and stretcher base should probably be linked by double-layered sides, which are not subject to distortion.

Attention must also be given to modifications to the rear compartment, including rounded corners on cabinets, straps to secure equipment thereby preventing projectiles, and the installation of airbags. Personal protective gear such as helmets may mitigate injuries in the event of a collision regardless of whether or not safety belts are worn.[3]

The failure to secure equipment in the patient compartment, which has been found to cause serious injuries in the event of a collision, has also been documented. This is supported by the engineering data from ambulance safety research involving crash tests.[1,2] In this crash test, the shock led to projection of medical equipment. The cardiomonitor was strapped to the stretcher

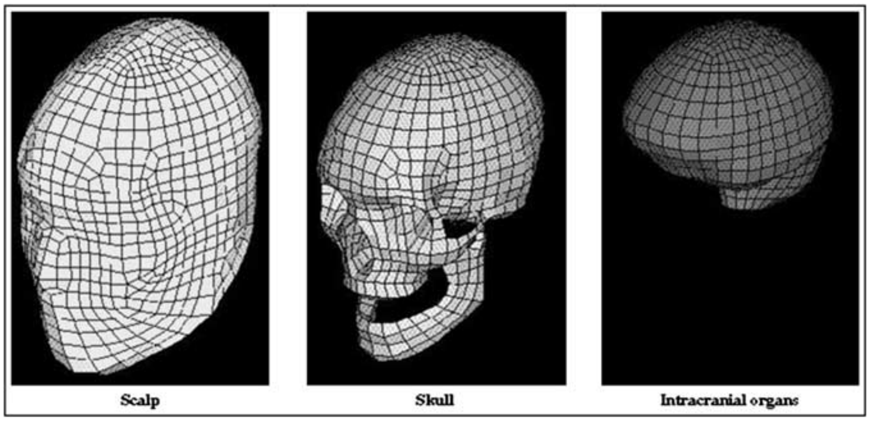

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Figure 4. Cephalic Portion of the Human Model for Safety (HUMOS)

shelf, which is commonly done but not recommended. In fact little equipment is provided with the means of attachment in accordance with established standards. Most often this equipment is secured by means of a strap on the sidewall shelves. This method of attachment is not adapted to practical use. It would be preferable if each piece of medical equipment were provided with a quick release system resistant to three-dimensional 10G forces.

The data results for the collision produced with the study van type vehicle are similar to those observed by Levick et al in a collision of American ambulances.[5] The risk of chest, abdominal and head trauma were noted in both tests where the dummies were placed perpendicular to the road, a position already known to be dangerous.[11] The seatbacks should be placed parallel to the road and secured by seatbelts anchored in three points.

An issue that is of major concern is the practice of using a side facing "squad bench." There is no supporting medical evidence for its need, and there is extensive automotive safety evidence that it is dangerous both in frontal and side impacts, and has limited ergonomic function. Even with the use of automotive designed forward or rear facing seating, the issue of side impact protection is of concern. A potential solution is to design a seat for this environment that integrates some side impact head and upper body protection.[6]

Using a Human Model for Safety (HUMOS) head, it was possible to measure the variation of intracranial pressure exerted for the time period elapsed from impact until the vehicle ceased moving. The head model consists of an elastic scalp (solid elements), an elasto-plastic skull (shell elements) and the intra-cranial space modelled with solid viscoelastic elements (Figure 4).[12] The head weighed 4.9 kg. Validation was based on the intra-cerebral accelerations computed by means of RADIOSS accelerometers along the anteroposterior axis (mass of sensor = 3 g) but also on cerebrospinal fluid pressures (CSF pressures) computed with solid elements of the intracranial space (note CSF is not represented in HUMOS).[13] Even if the head model is a simplified one (falx and tentorium membranes and CSF are missing), results obtained are similar to available experimental data. This numerical model is often used to predict the consequences of an automotive shock. In the authors' experience, the movement of the head was measured at seven m per second with a maximum acceleration of 48 g at 160 ms after impact, corresponding to impact of the head against a sharp corner of a storage compartment. Translating the data on the HUMOS model, this sudden acceleration generated a variable intracranial pressure of 1120 cm of water. This is a very large variation of pressure, with disastrous consequences. As a comparison, in a normal driving emergency braking from a speed of 70 km/h induces a deceleration of about 1 g over two to three seconds. This deceleration would generate a change in intracranial pressure of four cm of water. These variations do not have any consequences for normal subjects but this would probably not be the case for a patient with a head injury and pre-existing intracranial hypertension.

Limitations

The limits of this study included a number of issues that relate to the generalizability of the results. The vehicle patient compartment used in this study may not have been representative of the fleet of ambulance vehicles on the road. The stretcher and its attachment system may not have been representative of all equipment used in the field. The attachment system for the patient compartment to the chassis may not have been representative of the fleet of ambulance vehicles on the road.

Ambulance vehicle design and safety testing should be driven by accepted automotive safety and engineering practice. There is a need for re-evaluation of the design of ambulance vehicles with a varied disciplinary team including EMS providers, automotive engineers and public health researchers. Standards for ambulance vehicle occupant safety need to be developed.

Conclusion

This study survey component revealed a large disparity in the design in the French EMS vehicles. In the interest of public, provider, and patient safety, the French public health agency should require mandatory and standardized reporting of any crash involving an emergency ambulance or MICU.

The study crash test demonstrated the lack of safety for EMS personnel and patients in the rear compartment of a typical French MICU. Results of the crash test show that EMS personnel and the patient in the rear compartment have to be restrained by seatbelts and that seatbelts should even be worn when administering care. The patient should be always be restrained by a vacuum stretcher because the risk of expulsion and impact against a sharp corner of a storage compartment is high. Medical equipment and the stretcher in the rear compartment are an additional risk during a crash and fixations must be stronger

https://doi.org/10.1017/S1049023X13003543 Published online by Cambridge University Press

than belts and tested in crash tests. It would be preferable if each piece of medical equipment were provided with a quick-release system resistant to three-dimensional 10G forces. Seatbacks should be placed parallel to the road and secured by seatbelts anchored in three points. It was observed that head trauma occurred for occupants of the rear compartment. The need for a helmet to protect EMS personnel and the patient during the transport should be studied. Finally, the kinetic changes undergone by the patient on the stretcher most likely would have a pathological impact.

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