Chapter

Contamination of Emergency Medical Vehicles and Risk of Infection to Paramedic First Responders and Patients by Antibiotic-Resistant Bacteria: Risk Evaluation and Recommendations from Ambulance Case Studies

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Abstract

Contamination of emergency medical vehicles with pathogenic microbes poses a potential threat to public health considering the many millions of ambulance responses that are made globally each year. This risk of infection is to the patients, to their companions who may travel with them, and to the paramedic first responders whose work involves pre- or inter-hospital transfer. This applies particularly to contamination by those infectious disease-causing microbes for which the threat is heightened because of their recognized resistance to leading antimicrobial agents. Determining the risks should facilitate the advancement of best practices to enhance infection control of routine outbreaks and during a major emergency such as a disease pandemic or a bioterrorism event. This may merit the introduction of amended guidelines for ambulance cleaning and disinfection to achieve more effective pre-hospital infection control among the worldwide community of emergency service providers.

Keywords: ambulance, antibiotic resistance, bacteria, best practice, contamination, emergency medical vehicle, first response, helicopter, infection control, MRSA, paramedic, pathogen, pre-hospital care, *Staphylococcus aureus*

1. Introduction

The emergency services work force, comprising paramedics, police, firefighters, and specialized rescue and response teams, carry out duties on a daily basis that are essential to individual safety and well-being and to the operational functioning of their local community. Beyond these regular, routine activities, emergency medical services also administer life-saving assistance following a critical incident. Against this background, of serious concern is amassing evidence from research case studies to suggest that emergency medical vehicles can act as carriers (so-called vectors) of pathogenic microorganisms, or microbes, thereby promoting human infectious disease transmission [1]. In order to reduce this identified risk, an extensive screening process for pathogens should be performed. Implementation of new or revised policies and procedures would help to safeguard against emergency services crew, equipment and vehicles being inadvertent infectious disease vectors, and so exacerbating the already profound health risks associated with pandemics, natural disasters and bioterrorism.

The contamination of emergency service vehicles with microbes from body fluids or excreta is shown by many recent international studies. This non-systematic review highlights the key findings of selected seminal reports. Raised levels of bacterial species potentially harmful to human health have been detected in a range of emergency medical vehicles and in distinct contexts [2–9]. Notably, ambulances were contaminated with the difficult-to-treat Gram-positive bacterium, methicillin-resistant *Staphylococcus aureus* (MRSA) [2, 3], which is resistant to the commonly used class of penicillin-related antibiotics. In 13 metropolitan ambulances test 49.9% of swab samples showed positive for bacteria; 0.9% were highly drug-resistant pathogenic strains: MRSA; methicillin-resistant coagulase-negative staphylococci (MRCoNS); and carbapenemase-producing *Klebsiella pneumoniae* (KPC) [4]. In a separate study on 21 ambulances, 47.6% of surface swabbings were positive for MRSA [5]. Further, "large numbers of microbes" were isolated from helicopter air ambulances [6], corroborated by more detailed findings from Australia [7]. Microbiological cultures swabbed from four ambulances demonstrated that "four of the seven species isolated were substantial nosocomial pathogens, and three of these four possess formidable antibiotic resistance patterns" [8]. Similarly, 49% of rural ambulances tested positive in at least one internal location for contamination with MRSA [9]. Gram-negative coliforms of a variety of genera including *Enterobacter*, *Klebsiella* and *Escherichia* were commonly detected [3], suggestive of contamination with fecal or soil matter.

Emergency care equipment was discovered to also be a source of contamination. Sphygmomanometer cuffs, stethoscopes and respirator masks in ambulances frequently carried enterococci and *S. aureus* [10]. In one study, 57% of patient-ready trauma equipment swabbed at six hospitals and three regional ambulance services in the UK tested positive for blood contamination [11]. Likewise, of 50 stethoscopes used by paramedics 32% tested positive for MRSA [12].

2. Examining emergency medical helicopters for bacterial contamination

The extent of the problem of bacterial contamination of ambulances is exemplified by a recent proof-of-concept case study that examined two helicopter air ambulances based in separate municipalities in Queensland, the north-eastern state of Australia [7]. Emergency medical helicopters were selected due to the dearth of research on this type of emergency service vehicle as a vector of infection transmission. The two aircraft made a collective 68 call responses over 3 months. These involved patient transfers for specialist care (66.2%), primary responses (23.4%) (including road traffic incidents, cardiac arrest and medical cases), neonatal transfer to or between maternity care facilities (8.8%), and one search and rescue case (1.5%). During the study period samples were collected by swabbing each helicopter on six occasions at approximately weekly intervals. The helicopter's flight log provided for every response details of travel distance, locations of departure, pick-up and destination, and number and role of persons in transit. The presence or absence of bacteria was correlated longitudinally against time with each of geographical location, intra-vehicle surfaces, flight schedules and cleaning timetables.

For each sampling, the helicopter's interior was swabbed in five sites considered by emergency response crew to have a high frequency of contact, either by

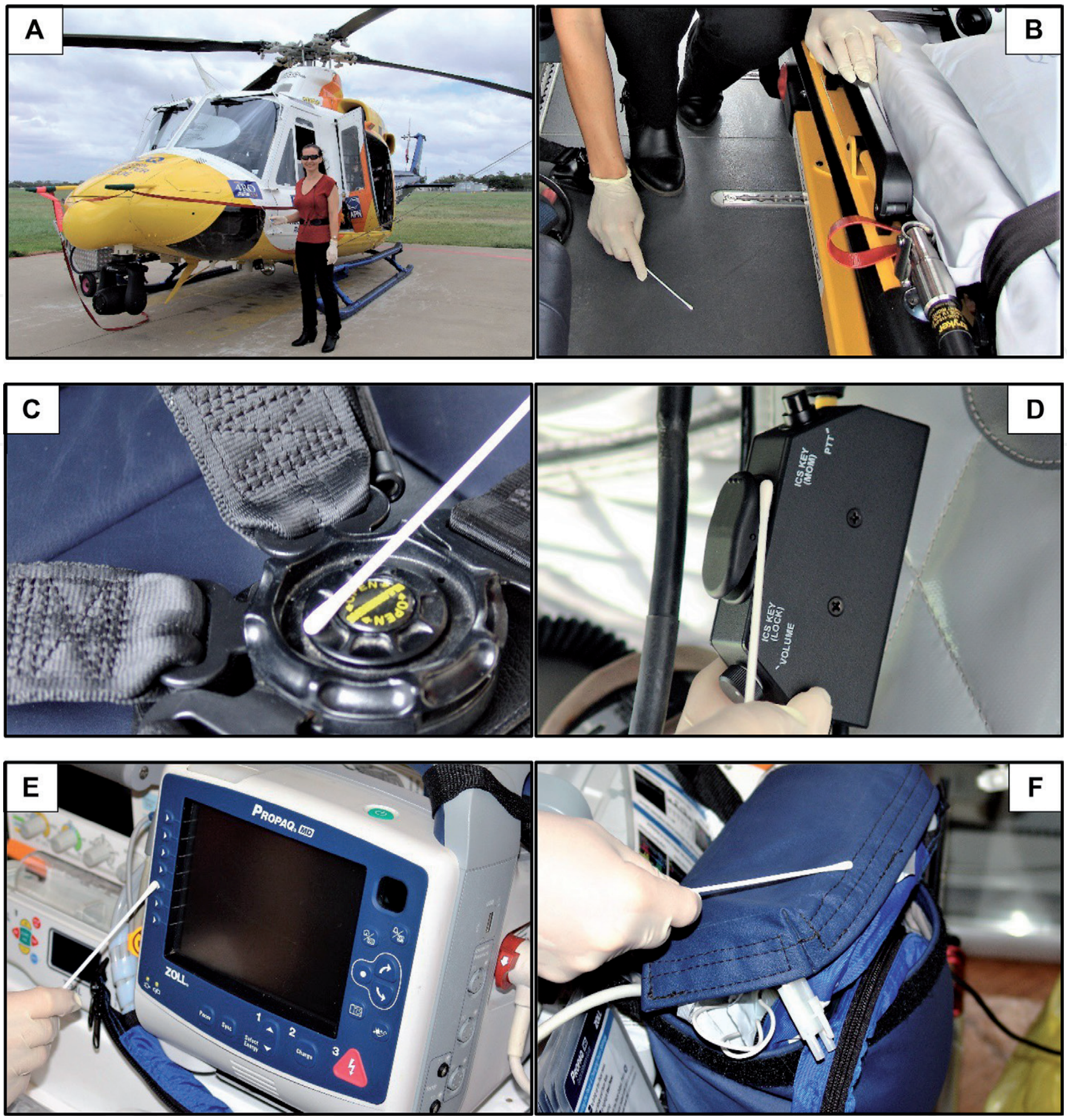

Figure 1.
Sites for microbiological swab sampling for detection of bacterial contamination inside a helicopter air ambulance. Following discussions with paramedic staff and pilots five areas of the aircraft (A) were considered to have a high frequency of contact by emergency crew and patients. These locations were: (B) the floor surface between the emergency crew seats and patient stretcher; (C) the seat belt buckle on the emergency crew seats; (D) the hand piece of the Citizens' Band radio; (E) the buttons on the display panel of the cardiac monitor/defibrillator; and (F) the blood pressure cuff storage bag [13].

themselves, patients and/or their companions, which thus present a raised risk of microbial contamination (**Figure 1**) [7, 13]. The diagnostic procedures followed were those approved by government regulatory bodies including the US Food and Drug Administration, comprising standard medical microbiology culture methods. These involved incubating the samples in a variety of selective media that differentiate positive bacterial colonies based on a difference in color. For example, after incubation on chromogenic MRSA agar for 24 hours at 35°C MRSA colonies are colored mauve whereas all other colonies appear blue, green or cream [14]. Confirmation of identity as either methicillin-resistant or multi-resistant bacteria was gained by conducting the disk diffusion (Kirby-Bauer) method on Mueller-Hinton agar [15]. This diagnostic screening was performed on all samples to determine the absence or presence of MRSA and multi-resistant *S. aureus*, vancomycin-resistant enterococci (VRE) and carbapenem-resistant enterobacteria (CRE), each of which is acknowledged to be a significant contributor to healthcare-associated infections [16, 17].

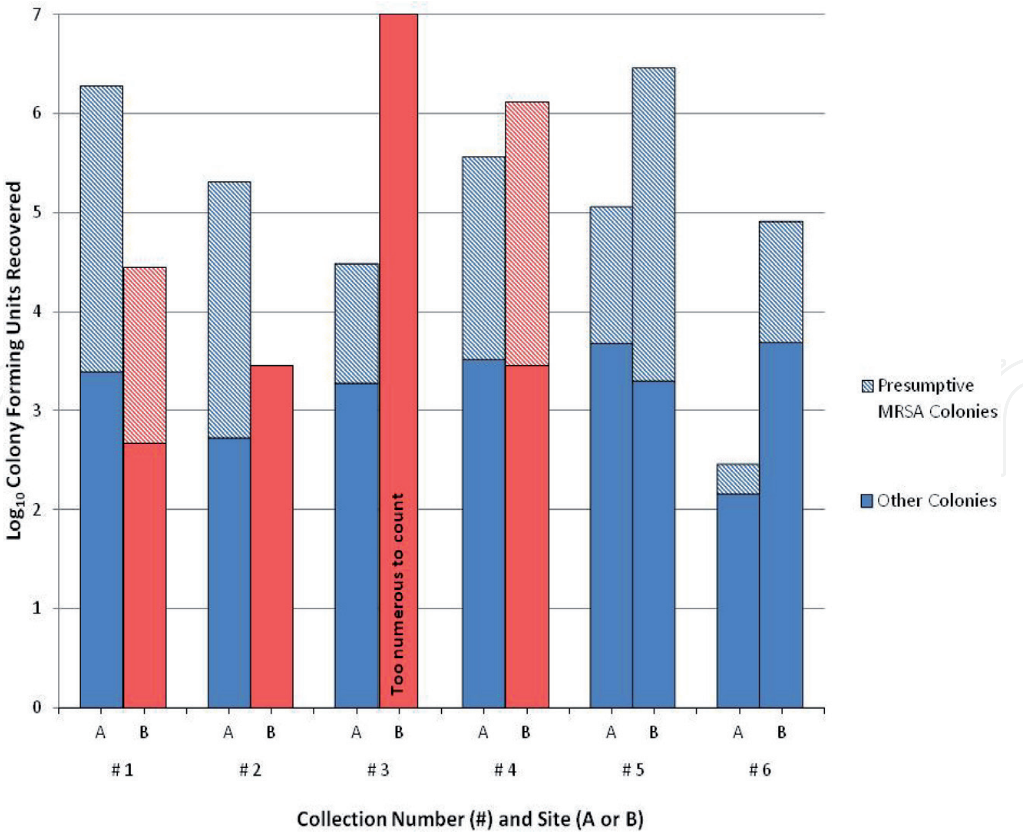

Figure 2.
Number and type of bacterial colonies recovered at each emergency service helicopter site for successive microbiological sampling periods. Bacterial counts are presented as Log_{10} of colony-forming units [7].

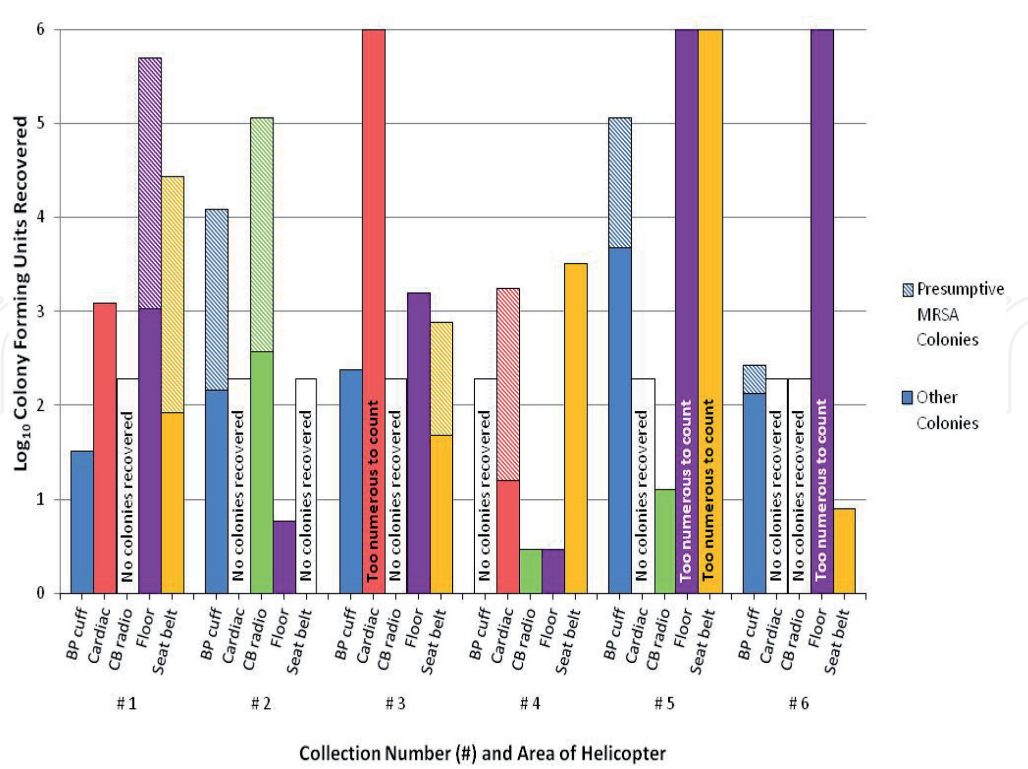

Figure 3.
Number and type of bacterial colonies recovered from different internal areas of the helicopter at emergency service site A for successive microbiological sampling periods. Bacterial counts are presented as Log_{10} of colony-forming units [7].

The equivalent antibiotic-susceptible organisms were also examined for as an indicator of the potential of the above antibiotic-resistant bacteria to be carried by these vehicles.

Both presumptive MRSA and other colonies were isolated from each helicopter at all but two sampling periods (**Figure 2**). Excluding occasions when selective media plates showed confluent bacterial growth the number of colony-forming units recovered from the two helicopters was similar (15,069 and 14,399). Of the presumptive colonies tested 18.7% were typed as *S. aureus*, 76.0% were determined to be other staphylococci (such as *S. haemolyticus* and *S. epidermidis*), and 5.3% were identified as other genera of bacteria [7]. Inside each helicopter, if separate swab sites were compared to each other or if the same swab site was examined over several sampling periods, various indicators of possible associations became apparent. For instance, typically the helicopter floor recorded a higher bacterial count, and the two-way radio and cardiac equipment comparatively lower counts, than for the other swabbed surfaces. Presumptive colonies were not recovered at all sampling periods, but they were isolated from all swab sites during the entirety of the study (**Figure 3**) [7].

As 94.7% of presumptive MRSA colonies tested were classified as *Staphylococcus* spp. the likelihood of MRSA existing inside emergency air ambulances is substantial. This is particularly so given that the prevalence of MRSA among emergency services crew is reported to exceed four times that of the general population [18]. The abundance of microbes recovered in this [7] and a prior study [6] suggests an increased risk of pathogen transfer between the vehicle, emergency services crew, patients and their companions. This serves to stress the need for standardized cleaning protocols as well as high quality staff training for their application.

3. Infection risks to paramedic first responders and patients

Previous research has detected MRSA in road-based ambulances in both metropolitan (47.6% of vehicle tests positive) [5] and rural areas (49% positive) [9]. An assortment of equipment used by emergency services crew has also shown frequent contamination [10–12]. Moreover, examination of nasal swabs demonstrated a disconcertingly raised prevalence of MRSA among paramedic first responders, 6.4%, much higher than the 1.5% MRSA colonization rate of the general public [18]. Of further concern, regarding a parallel issue of work-related stress it was reported that “paramedics ranked outbreaks of new and highly infectious disasters highest for fear and unfamiliarity” [19].

The existence of MRSA and multi-resistant *S. aureus* in emergency medical vehicles could pose a threat to the health of patients and their companions during and after the 4.4 and 32 million emergency ambulance responses each year in, respectively, Australia and the USA [20, 21], as well as to the paramedic first responders who work in these vehicles. This type and level of risk applies equally to emergency service crew in all nations worldwide. It would therefore appear that emergency medical helicopters may act as vectors of transmission of potentially deadly pathogens to the multiple thousands of patients that they transport between sites annually. By amplifying the frequency of response calls per vehicle type the implication is equally clear that road-based ambulances may spread infectious disease-causing microbes among the millions of patients that they transfer to and from hospitals each year. More broadly, inadequate infection control measures across all classes of emergency medical vehicle could exacerbate the major impact on public health of an infectious disease pandemic or bioterrorism event.

4. Cleaning and disinfection protocols for emergency medical vehicles

It is self-evident that surfaces or items that have come into contact with a patient's blood, body fluids, fecal matter or exposed skin should be considered as potentially contaminated. Since pathogenic microbes can survive outside the human body for extended periods the handling of contaminated objects is a means by which infection can spread [22]. A recurrent route of infection transmission is when a paramedic's gloved or ungloved hands touch a contaminated surface or medical equipment and/or there is patient contact with contaminated surfaces or items [23]. For this reason, it is imperative that items of patient care equipment (such as blood pressure cuffs, monitors, stethoscopes and stretchers) that make routine contact with skin and/or mucous membranes undergo a two-step cleaning and disinfection process following every response [24]. Defined as the simple removal of foreign and organic materials from a surface or object, cleaning using water, detergents and a scrubbing action physically removes but does not kill or prevent the growth of microbes. Conversely, disinfection kills or disables microbes present on contaminated surfaces, an operation that is customarily fulfilled with regulated chemical products [25].

The notable findings of one study showed that the number of sites contaminated inside an ambulance increased from 57% before cleaning and disinfection to 86% afterwards [3]. Hence, not only were many areas till contaminated with bacteria others that were previously uncontaminated became freshly contaminated as a result of poor cleaning technique acting as an inadvertent means of spread. The deficiency in performance of regular manual infection control protocols has been associated with operator error, principally concerning selection, formulation, distribution and contact time of the disinfectant [22, 23, 25]. Perspectives on improving effectiveness include staff training programs, continuing education, real-time feedback on the thoroughness of cleaning and disinfection procedures, routine microbiological inspection of surface hygiene, and the use of fluorescent markers or assays to ascertain the robustness of the process [25]. Although these actions can, separately and collectively, improve the efficacy of standard measures to decontaminate in the short-term, their sustainability is yet to be explored. The application of non-manual vehicle disinfection lowers the possibility of human errors linked to traditional cleaning methods and offers the prospect of more effective elimination of pathogens, thereby decreasing infection transmission [26]. However, at present definitive evidence is lacking to demonstrate the clinical effectiveness of non-touch or automated disinfection procedures, including those utilize steam cleaning, hydrogen peroxide or ultraviolet light irradiation, to eradicate or suppress infection rates in ambulances [27, 28].

5. Developing and implementing best practice guidelines for infection control

In view of the collective body of research which highlights that bacterial contamination of ambulances of all types is a frequent occurrence [2–12], the universal implementation of standardized, optimized infection control protocols is a high-priority public health provision [1]. Emergency services crew, their patients and companions have an elevated risk of contracting infection without there being in place clear guidelines and an understanding of, and adherence to, these protocols by paramedics [1, 24]. Compliance with best practices for cleaning and disinfecting inside emergency medical vehicles, equipment and supplies is an important consideration in aiming to prevent the spread of antibiotic-resistant bacteria in pre-hospital care settings. This may also drive the more general development of new or improved policies and procedures the adherence to which could decrease the day-to-day transmission of deadly pathogens and alleviate contagion by pandemic- or bioterrorism-related microbes.

In an attempt to reduce infectious disease transmission, reputedly antimicrobial fabrics have been used to manufacture uniforms for emergency medical service crew. However, in one short-term trial a suit made of one such novel fabric that was designed specifically to reduce contamination risks showed no significant difference in microbial contamination compared to garments made of standard materials [29].

Future investigations should aim to examine microbiological swab samples from a range of emergency service vehicles across a breadth of locations in order to detail and quantify the associated infection threat to the paramedic profession and to those to which they attend. This will help to define more clearly what strategies are needed to safeguard the provision of best practice and in case of natural disasters, pandemic outbreaks or possible bioterrorism events [30]. Integral to any mitigation recommendation should be professional development tailored to paramedic first responders in air ambulance helicopters and other emergency medical vehicles that is conducive to raising levels of awareness of infectious diseases and best practice training in infection control.

6. Discussion

Antibiotic-resistant bacteria are acknowledged to pose a profound and growing threat to human health, which, as recognized by the medical, nursing and paramedic professions, routinely cause a substantial proportion of healthcare-associated infections [31, 32]. Notwithstanding this realization, there is a knowledge gap in relation to the significance of antimicrobial resistance in pre-hospital emergency care [1], which is typically the primary point of patient contact.

While research from several countries has identified possible hazards [2–9], each of these preliminary studies focused on a single vehicle type. There is a shortfall in understanding of the relative contributions to potential infectious disease transmission of a wide spectrum of emergency service providers. The long-term objective should be to gauge the scale of contamination on or in emergency service vehicles, targeting police cars and fire trucks in addition to emergency medical vehicles. These include standard road-based ambulances, first response cars, motorcycle ambulances and helicopter air ambulances, as well as light aircraft used, for instance, by the Royal Flying Doctor Service in Australia to reach isolated patients in extremely remote locations. The data generated would be analyzed to assess the potential for uncontrolled disease spread, thereby facilitating the development of recommendations to minimize transmission risks for emergency response crews and for the communities that they serve.

Reflecting the bulk of findings to date, staphylococci form the focus of this chapter. However, the need to perform more research on Gram-negative coliforms as a source of potentially pathogenic bacterial contamination of emergency medical vehicles is highlighted.

7. Conclusion

The services of paramedics and other emergency medical professionals are a cornerstone of all civilized societies. Paradoxically, however, given the paramount importance of the role that this sector fulfills, there is a paucity of information on the risks of infectious disease transmission from contamination of vehicles, equipment or passengers by microbial pathogens. Assessment of potential threats to paramedics, patients and companions should be considered as an imperative in order to establish effective risk reduction interventions. Recent research has established that all types of emergency medical vehicle can act as vectors for infectious microbes. Items of equipment that are handled frequently by paramedics may be at heightened risk of contamination and should thus be prioritized for regular disinfection.

How to reduce the risk of antibiotic-resistant bacterial contamination of the interior of emergency medical vehicles is a pre-hospital care issue encountered on a daily basis but one which also has far-reaching implications in disaster management situations. Preventive measures intended to mitigate the threat of pathogenic bacterial transmission to ambulance staff, patients and their companions by ensuring a cleaner, safer medical environment exemplify paramedic industry best practice. Further detailed research is required to determine the potential risk of infection transmission among different vehicle fleets and under varied conditions of use. This may underpin the establishment and implementation of new or revised policies and protocols for cleaning and disinfection schedules. Committing to such action should fortify the paramedic sector's mission to save lives, speed recovery and serve the community through providing the highest standards of rapid response critical care.

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Conflicts of interest

The author declares no competing issues of interest.

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