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Original Research

The Efficacy of Chest Compressions in the Bell 407

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A B S T R A C T

Objective: The Air Medical industry is fraught with obstacles to patient care and providers can recognize that several sub-groups of patients can provide very challenging scenarios while in flight. However, the patient experiencing cardiac arrest in flight is, by its very nature, one that poses the most severe risk to the patient and provider. This study seeks to explore the capability of a highly trained emergency medical provider to provide adequate chest compressions while in a Bell 407 helicopter.

Methods: 59 participants were evaluated in two separate scenarios. Scenario A consisted of 2 rounds of of 200 chest compressions performed on a flat, uncrowded surface. Scenario B consisted of 200 chest compressions performed in the cabin of a Bell 407. Participants performed 2 rounds of 200 chest compressions. The results were then compared to each other and to the AHA 2010 CPR guidelines.

Results: The findings of the study show that compressions performed in the aircraft do not meet AHA guidelines for chest compressions in regard to depth and duration of compressions. The deviation from guideline in regard to rate was found to be not statistically significant.

Conclusion: Chest compressions performed in a Bell 407 helicopter do not meet AHA guidelines.

The Association of Air Medical Services estimates that approximately 400,000 patients are transported by rotor wing aircraft within the United States annually,[1] accounting for about 3% of total ambulance transports.[2] In recent years, growth in the medevac industry has skyrocketed, with a reported 1,100[2] rotor wing aircraft in service able to provide emergency medical services to large parts of the United States within a 10-minute window. Although initial helicopter emergency medical services (HEMS) patients likely benefited from the speed of transfer to definitive care alone, in 2018 the expectation of HEMS crews is to provide the highest level of care to the sickest of patients, including advanced airway management, balloon pump management, extracorporeal membrane oxygenation, and any number of other critical care services.

Although there will always be a role for HEMS in the movement of critically ill or injured patients, there are little data supporting their effectiveness transporting patients in cardiac arrest. The American Heart Association's (AHA) "chain of survival" recognizes that early high-quality cardiopulmonary resuscitation (CPR) plays the biggest impact on patient survival. This link between high-quality CPR and patient survival is echoed in multiple publications.[3-5] There are an estimated 350,000 out-of-hospital cardiac arrests a year suffered in the United States with a 90% mortality rate.[6] Are HEMS medical crews able to provide the high-quality CPR necessary to improve patient survival? This research aims to assess the quality of CPR that can be performed by air medical crews operating in 1 of the most common medical airframes in the United States, the Bell 407.

The Bell 407 and its 206 variant are the most common airframes in use for HEMS work in the United States.[1] In fact, Air Methods Group, the largest HEMS provider in the Unites States, placed an order in 2015 for 200 Bell 407 helicopters.[7] A major difference between the Bell 407 and aircraft used in previous in-flight CPR studies is interior cabin size. The Airbus EC-135, a common HEMS platform used across Europe but sparsely across the United States, has a cabin volume of 173 cubic feet[8] compared with the Bell 407, which has a cabin volume of 83 cubic feet[9] similar to a Volkswagen Beetle (85 cubic feet).[10] Although the 407 is a workhorse of the industry, the smaller cabin dimensions can present challenges to providers attending to the most critically ill of patients.

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Methods

Study Design

This is an institutional review board−approved observational study comparing CPR quality in a nonconfined space compared with CPR quality in a medically configured Bell 407 helicopter.

Participants and Preparations

Participants in this study were made up of crews from Guardian Air Transport (GAT) and Guardian Medical Transport (GMT). GAT is a HEMS service with 7 bases located throughout northern Arizona, with a response area encompassing approximately 84,000 square miles in and around Arizona. GAT operates 7 Bell 407 helicopters and 1 fixed wing Pilatus PC-12. Flight crews consist of either a flight paramedic and flight nurse or 2 flight nurses depending on staffing. GAT flight crews respond to both 911 calls and interfacility transfers and are responsible for managing critically ill or injured patients across the entire life spectrum including neonatal and high-risk obstetrics. GMT is the ground sister agency to GAT, both owned and operated by Flagstaff Medical Center, the regional level 1 hospital. GMT is the ground emergency medical service for the Flagstaff area and surrounding area, providing 911 ground services to over 6,400 square miles of northern Arizona as well as interfacility transfers across the state. GMT crews are made up of either an emergency medical technician and paramedic or 2 paramedics.

A total of 59 volunteer participants (13 emergency medical technicians-basic, 27 paramedics, and 19 registered nurses) took part in the study. Of the participants, 33 were from GMT and 26 from GAT with an age range of 20 to 65 years, with the majority being between 26 and 35 years old. Of the 59 participants, 22 were women. Of the 59 participants initially enrolled in the study, 3 had incomplete data, so they were excluded from the study results. These participants were all active crewmembers who either came in during their time off or were allowed to participate while on duty (if time allowed). They were compensated in the form of gift cards to local businesses, and all signed consent forms.

Trial Scenario

The research protocol consisted of 2 phases, a baseline test (test A) outside the helicopter and a challenge test (test B) inside the helicopter (Bell 407 on the ground). Test B was completed with GAT's standard medical configuration, including all equipment found in the cabin including a cardiac monitor, medication bag, scene bag, intravenous pump, and oxygen cylinder. Participants were not required to wear a helmet (although this is a requirement for flight crews) because of difficulty obtaining a properly fitting clean helmet for each participant. Similarly, night vision goggles were not used because of the potential risk of damaging mission critical equipment. Because of the financial cost of organizing the required number of flights, test B was completed entirely on the ground inside the aircraft with all the doors closed to simulate in-flight conditions and space as closely as possible.

A HAL mannequin (Gaumard Scientific, Miami, FL) was used to complete all CPR compressions. A Zoll X series monitor (ZOLL, Chelmsford, MA) with a CPR “puck” was used for all scenario iterations, and data were collected and imported into code review for evaluation of CPR quality. In all test scenarios, participants were instructed to perform 2 rounds of 200 compressions, meeting the 2010 AHA guidelines of 200 compressions a minute at a 2-inch depth. Providers did not have access to the CPR Dashboard (ZOLL), and the only audio or visual feedback participants received was a 10-second countdown between rounds. Participants were evaluated solely on the quality of their compressions, and no other components of advanced cardiovascular life support or basic life support protocols were demonstrated or evaluated.

Test A was performed in a nonconfined space inside the aircraft hangar or classroom. Test B had each participant assigned to a randomly assigned set position inside the aircraft with the preceptor filling the other seat to mimic the second flight member. The preceptor did not assist in any way other than adjusting the patient stretcher for GMT staff who were not familiar with its operation. Patient compartment doors were closed for each scenario although the 2 forward doors were opened to allow airflow. Regardless of participant seat assignment, participants were allowed to move around as much as they wanted during each test; however the preceptor remained in his or her designated position for the duration of the scenario.

Results

Paired *t* tests were performed for the comparison of compression depth and rate between test A and test B. The average compression depth for scenario A was 1.98 inches (standard deviation [SD] = 0.43), whereas for scenario B the average was 1.25 (SD = 0.35). The difference between means is statistically significant ($P = .000$, 2 tailed). It is worth noting that in both cases the compression depth was below the AHA 2010 minimum depth (ie, 2 inches). The average compression rate for test A was 112.74 compressions per minute (SD = 20.54), whereas for test B the average was 111.94 (SD = 25.27). The difference between means was found to not be statistically significant ($P = .815$, 2 tailed). It is worth mentioning that in both tests the compressions per minute were above the AHA 2010 minimum rate (100 cpm).

A paired *t* test was also conducted to compare the percentage of time in compressions (time in compressions/total attempt time). For test A, 92.03% of the time participants were in compressions; for test B, that number was reduced to 76.81%. The difference between the 2 scenarios is statistically significant ($P = .000$, 2 tailed). All calculations were performed using SPSS Version 22 (IBM Corp, Armonk, NY). The results are reported in Table 1.

Discussion

To our knowledge, this is the first study assessing the efficacy of manual CPR by flight crews in the United States. We believe there to be scant evidence specific to in-flight CPR efficacy, and what evidence does exist does not reflect the state of HEMS in the United States. One such study conducted in Spain[11] showed that flight teams were able to provide adequate CPR quality while in flight. However, the aircraft used was a Sikorsky S-61, which is a much larger twin-engine aircraft that is not used for HEMS work in the United States. Other studies on in-flight CPR share the same limitation (ie, using much larger aircraft that are not commonly used in the United States[12,13]), thus limiting their generalizability to HEMS in the United States.

The limited cabin space of the 407, especially the limited space over the patient, means that providers are not able to get into the desired position to provide adequate CPR. The 2010[14] and 2015[15] AHA guidelines for CPR and ECC both emphasize the importance of high-quality

Table 1
Results of Compression Tests Outside of and Inside a Grounded Bell 407 Helicopter

	Test A (n = 59)	Test B (n =59)	*P* Value From Paired Sample *t* Test
Average compression depth	1.98 (SD = 0.43)	1.25 (SD = 0.35)	<.001*
Average compression rate	112.74 (SD = 20.54)	111.94 (SD = 25.27)	.815
Time in compressions	92.03%	76.81%	<.001*

SD = standard deviation.

CPR, defined as chest compression at the correct rate and depth and allowing for full chest recoil between compressions. The "push hard, push fast" motto developed by the AHA recognizes the importance compressions play in building intrathoracic pressure, which, in conjunction with compressing the heart, helps to circulate blood to the vital organs. The 2010 AHA guidelines focused on targeting a compression depth between 1.5 and 2 inches,[14] whereas the 2015 guidelines increased that target range from 2 to 2.4 inches.[15] Providers are also encouraged to change compressors every 2 minutes to prevent compression fatigue and ensure high-quality compressions are administered. Multiple studies have linked high-quality compressions to improved patient outcomes.[3,4,16]

Real-time audio and visual feedback similar to that provided by the CPR Dashboard, which provides a CPR metronome to ensure the correct rate and real-time compression depth feedback, have been shown to improve CPR quality. A large systematic review and meta-analysis by Kirkbright et al[17] found that real-time CPR feedback leads to higher-quality CPR than without the feedback. The effect of real-time feedback on improved CPR quality has also been studied in research by Yeung et al,[18] Cortegiani et al,[19] and Nassar and Kerber,[20] all of whom found a link between real-time feedback and improved CPR quality. It could be argued that the deficit in compression rate and compression duration during in-flight CPR could be addressed with the implementation of real-time feedback. However, the issue of improving depth of compression to the 2015 AHA target of 2 to 2.4 inches would most likely not be solved by real-time feedback. Despite real-time feedback alerting the providers to the poor quality of compressions, their limited work space effectively prohibits the ability to compress to a greater depth for any length of time, making CPR all but ineffective.

The expectation of modern HEMS programs is to provide the highest level of care to the critically sick or injured in their community. HEMS crews are able to live up to this standard through many factors including utilization of highly trained staff, ability to perform advanced procedures, and the speed with which they can travel to and from a scene. However, when CPR is concerned, HEMS providers are limited not by skill or training but by the limited space they operate in to provide high-quality effective CPR. This leaves the HEMS crew with a decision when tasked with transporting a patient with the potential for in flight arrest.

Some potential ways to mitigate these challenges include the following:

1. Mission planning: providers need to be equipped with a clear understanding of their patients' condition and potential for deterioration. If a flight crew is sent for a grossly unstable patient, all involved must weigh the risks and benefits of placing that patient in the aircraft. Although some agencies may operate in regions where transport times are relatively brief, others, such as those in northern Arizona, routinely face transports upwards of 45 minutes. In all areas, providers should have a worst-case scenario plan in the event the patient deteriorates to the point of needing chest compressions.
2. Area familiarization/interagency cooperation: in regard to the previous recommendation, providers should have a good knowledge of who their ground assets are and, if possible, contact those agencies before transporting the critically unstable patient. HEMS crews concerned with transporting a potentially deteriorating patient can request a ground unit stage approximately halfway between a sending and receiving hospital at a well-known, secure landing zone. En route, if the patient deteriorates into cardiac arrest, the aircrew can land and transport the patient to the receiving hospital by ground with high-quality CPR in situ.

However, at times, even the best interagency cooperation and mission planning will still fail, and a patient will arrest during flight. HEMS crews are then left with a decision. Do they omit compressions they know to be ineffective and simply oxygenate, medicate, and defibrillate or do they land and call for a ground resource to arrive and transport via ground with CPR in progress? Perhaps the most effective solution is for flight crews to carry a mechanical chest compression device with the ability to deploy it on a mission/patient-specific basis.

A recent systematic review by Li et al[21] evaluated 12 studies over the course of 40 years comparing mechanical CPR and manual CPR. Although Li et al did not find any improvement in CPC scores, survival to hospital admission, or survival to discharge between manual and mechanical CPR, they did recognize the role mechanical devices play in the overall strategy for managing patients in cardiac arrest. Mechanical CPR devices can deliver uninterrupted compressions at the correct depth and rate without pausing, tiring, or being affected by limited space, making them an excellent adjunct for managing cardiac arrest inflight. Although this may be a budgetary challenge for some agencies, the implementation of these devices has been shown to provide high-quality CPR while in motion, to maintain flight safety standards (such as safety belts, helmets, etc), and potentially to give the patient the best chance for survival.

Limitations

This study was performed in a simulated and controlled environment on mannequins. Furthermore, the simulations were completed inside the patient compartment of a single airframe. Therefore, the results cannot be generalized to CPR quality and efficacy on larger aircraft types. Because of safety and cost considerations, this study was not completed during actual flights. It is possible that the results could show a different result when in flight. However, we believe this to be unlikely because CPR quality is directly affected by the confined space of the aircraft, which remains the same regardless of whether the aircraft is on the ground or in flight. This study also did attempt to analyze the challenges of providers attempting resuscitation while adhering to all safety standards, including helmet usage, night vision goggle usage, use of seat belts during critical aspects of flight, and both providers being fully attentive during liftoff and landing. Further investigation with staff adhering to all safety guidelines may provide even more distressing and damning results and is worthy of pursuit.

Conclusion

Although more research is needed, the findings of this experimental mannequin study indicate that CPR cannot be effectively implemented by HEMS crews when flying in a Bell 407. Despite the implementation of a real-time CPR feedback device, the confined work space is a hurdle that HEMS crews can simply not overcome. Air medical programs and their medical directors must take a hard look at how their agency manages in-flight cardiac arrest. The idea that "some care is better than no care" or "at least I was trying" is simply not supported by evidence and does a disservice to patients because even a short delay in initiating CPR can adversely affect hemodynamics and adversely affect patient outcomes.[22,23] To truly advocate for their patients, flight crews must recognize their limitations, and local and global governance should have guidelines in place allowing crews to safely and effectively treat their patients.

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