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Effect of Crew Size on Objective Measures of Resuscitation for Out-of-Hospital Cardiac Arrest

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Abstract

Background—There is no consensus among emergency medical services (EMS) systems as to the optimal numbers and training of EMS providers who respond to the scene of prehospital cardiac arrests. Increased numbers of providers may improve the performance of cardiopulmonary resuscitation (CPR), but this has not been studied as part of a comprehensive resuscitation scenario.

Objective—To compare different all-paramedic crew size configurations on objective measures of patient resuscitation using a high-fidelity human simulator.

Methods—We compared two-, three-, and four- person all-paramedic crew configurations in the effectiveness and timeliness of performing basic life support (BLS) and advanced life support (ALS) skills during the first 8 minutes of a simulated cardiac arrest scenario. Crews were compared to determine differences in no-flow fraction (NFF) as a measure of effectiveness of CPR and time to defibrillation, endotracheal intubation, establishment of intravenous access, and medication administration.

Results—There was no significant difference in mean NFF among the two-, three-, and four-provider crew configurations (0.32, 0.26, and 0.27, respectively; $p = 0.105$). More three- and four-person groups completed ALS procedures during the scenario, but there was no significant difference in time to performance of BLS or ALS procedures among the crew size configurations for completed procedures. There was a trend toward lower time to intubation with increasing group size, though this was not significant using a Bonferroni-corrected p -value of 0.01 (379, 316, and 263 seconds, respectively; $p = 0.018$).

Conclusion—This study found no significant difference in effectiveness of CPR or in time to performance of BLS or ALS procedures among crew size configurations, though there was a trend toward decreased time to intubation with increased crew size. Effectiveness of CPR may be hindered by distractions related to the performance of ALS procedures with increasing group size, particularly with an all-paramedic provider model. We suggest a renewed emphasis on the provision of effective CPR by designated providers independent of any ALS interventions being performed.

Keywords

cardiac arrest; emergency medical services; crew configuration; cardiopulmonary resuscitation

Introduction

A variety of ambulance staffing patterns exists across emergency medical services (EMS) systems in the United States, and the effectiveness of one staffing pattern over another has not

been proven. In a survey of 200 U.S. cities, a single-tier EMS system was reported most commonly (65.8%), while a two-tier system composed of basic life support (BLS) and advanced life support (ALS) ambulances is utilized in other systems.¹ Advanced life support ambulances are most commonly staffed by two providers, either one paramedic and one emergency medical technician (EMT) (44.9%) or two paramedics (40.8%). While certain systems also provide first responders or additional personnel for certain emergencies, there is little evidence on the optimal number of providers for handling specific emergencies. These are important considerations for EMS administrators and medical directors, who must balance cost and limited resources when making staffing decisions and dispatch protocols.

Cardiac arrest is the penultimate medical emergency that strains EMS providers and systems because of the many skills, procedures, and resources required for providing Advanced Cardiac Life Support (ACLS) care. Return of spontaneous circulation (ROSC) has been linked to obtaining and maintaining adequate coronary perfusion pressures (CPPs).² No-flow fraction (NFF) is a surrogate for maximizing CPP, and cardiopulmonary resuscitation (CPR) that minimizes NFF has been linked to improved survival from cardiac arrest^{3–11} and to the effectiveness of ALS procedures such as epinephrine administration.¹²

Rescuer fatigue and distraction are common in the field and negatively impact CPR performance.^{13–14} Correspondingly, having an increased number of providers has been shown to improve CPR performance when studied in isolation.¹⁵ It has been postulated that an increased number of providers, particularly those who can perform ALS procedures, may be better able to manage cardiac arrest patients.¹⁶ Kelly and Currell compared paramedic-paramedic versus paramedic-EMT configurations in the management of patients with varying complaints and found the all-paramedic configuration to be associated with a small but statistically significant increased number of ALS procedures.¹⁷ However, a more recent study compared a paramedic-paramedic versus paramedic-EMT crew in simulated cardiac arrest scenarios and found that the paramedic-paramedic configuration was more error-prone and did not perform most interventions more rapidly, except for endotracheal intubation.¹⁸ Additionally, Eschmann et al. performed a retrospective review of 10,057 patients with out-of-hospital cardiac arrest (OHCA) and determined that while controlling for various patient and treatment factors, having two paramedics on the scene was associated with improved survival to hospital discharge compared with having three or more paramedics.¹⁹ These studies suggest that while more providers on the scene may be better at performing individual tasks and ALS procedures, increased numbers of ALS providers may not result in improved patient outcomes. This is consistent with the scant literature supporting individual ALS procedures in cardiac arrest.^{6,20–28}

This study sought to compare different crew size configurations on objective measures of patient resuscitation using a high-fidelity human simulator. We compared two-, three-, and four-person all-paramedic crew configurations in the effectiveness and timeliness of performing both BLS and ALS skills in a simulated cardiac arrest scenario. Crews were compared to determine differences in NFF and time to defibrillation, endotracheal intubation, establishment of intravenous (IV) access, and medication administration.

Methods

Participants

Forty paramedic students who had received ACLS training and certification were recruited for participation in this study. All students were near completion and at the same level of paramedic training, and this training included the performance of CPR based on the American Heart Association (AHA) 2005 CPR guidelines.⁶ Participants volunteered for participation and provided informed consent. The study was approved by the University of Pittsburgh

Institutional Review Board. The paramedic students were divided into 10 groups of four providers. Participants took part in the same cardiac arrest scenario as groups of two, three, or four providers, for a total of 10 scenarios completed for each crew size configuration. Participants in each group of four providers were labeled A, B, C, or D and took part as AB, ABC, or ABCD groups. While the A, B, or C participants took part in more than one scenario, participants were not eligible to participate as part of any other four-person group and the order of participation in scenarios of different crew sizes was randomized to eliminate crossover or ordering effects.

Patient Simulator and Cardiac Arrest Scenario

Participants took part in a simulated cardiac arrest scenario using a high-fidelity SimMan human patient simulator (Laerdal Medical Corporation, Wappingers Falls, NY). This simulator was placed on the floor, supine, in a closed, well-lit room adjacent to a monitoring room separated by a one-way mirror and with no specific distractors. Placement of the simulator allowed access around the patient. The simulator has a right arm designed for IV access and a left arm where pulse rate and blood pressure can be assessed, and was staged for each scenario with pants but no top. Means for obtaining alternate intraosseous access was not provided, as this was not yet readily available to paramedics working in this EMS system at the time of the study. Participants were provided with and were allowed to review their resuscitation equipment prior to entering the room, including a monitor/defibrillator, airway devices including intubation equipment and alternative airways, IV setups, and IV medications. Participants were instructed to perform artificial ventilation with a bag-valve-mask, chest compressions, defibrillation, endotracheal intubation, and IV line placement directly on the patient simulator in the usual fashion. They were instructed to prepare medications for administration and then voice administration as part of the scenario. All medications used in this scenario were available in prefilled syringes as available from the manufacturer, except for amiodarone, which was available in a vial. Of the medications administered in the scenario (epinephrine, lidocaine, amiodarone, and atropine), only lidocaine had weight-based dosing, which participants would provide based on estimated weight. Participants were provided the following scenario prior to entering the room:

You are responding to the scene of a 50-year-old man who was found unresponsive by bystanders. Bystanders have left the scene prior to your arrival. No other history is available on this patient.

Participants were told to assume this was a nontraumatic event and the scenario time began when the participants were ready and entered the room. The simulator was set with an initial rhythm of ventricular fibrillation that remained unchanged after an initial defibrillation and converted to asystole after a second defibrillation. The simulated cardiac rhythm was not altered based on any other interventions in order to provide consistency between scenarios and study groups. Each scenario was run for a total of 8 minutes before termination. Participants were not informed of the study interval prior to taking part in the scenario.

Data Collection and Analysis

Data collected included the number of providers, the success of and time to performance of specific procedures, and the total hands-off time for CPR. Recorded procedures included initiation of chest compressions, defibrillation, endotracheal intubation, IV line placement, and initial medication administration. All study scenarios were observed and recorded using a digital video recorder by the study investigators who were behind a one-way mirror. Data were recorded either automatically by the patient simulator (chest compressions, defibrillation) using SimMan software version 3.2 (Laerdal Medical Corporation) or through review of the video recordings by an investigator (CM). The scenario start times for the patient simulation program and video recordings were synchronized to allow the recording of procedure-related

time intervals. No-flow time was calculated as the sum of all time periods when chest compressions were not being performed, beginning with the start of the scenario, as recorded electronically by the SimMan program.

The primary outcome variable was NFF, calculated as total no-flow time divided by the total length of the scenario. NFFs were compared among crew size configurations using a one-way analysis of variance (ANOVA), with plan for multiple two-sample t-tests if a difference was found. Secondary outcome variables included time to performance of specific procedures. Secondary outcomes were compared with the Kruskal-Wallis one-way ANOVA in anticipation of missing values for procedures that were not completed in some groups. Success or failure to perform specific interventions was reported using descriptive statistics. Prior research from our group and others suggested that paramedics performing CPR have an NFF of 0.50.^{14–29} Using three groups of 10 rescuers, a 95% power to detect a difference in NFF from 0.50 to 0.25 would be achieved. For the secondary analyses, a Bonferroni correction was performed, resulting in an alpha of 0.01. Statistical analyses were performed using SPSS 16.0 for Windows (SPSS Inc., Chicago, IL).

Results

Mean NFFs during CPR did not differ among the two-, three-, and four-provider crew configurations (0.32, 0.26, and 0.27; $p = 0.105$). More groups with three and four providers successfully completed individual ALS interventions during the 8-minute scenario (Table 1). There was a trend toward decreased time to intubation with increasing group size, but this was not significant with a Bonferroni-corrected p -value of 0.01 (379, 316, and 263 seconds, respectively; $p = 0.018$) (Table 2). There was no difference in time to performance of other BLS or ALS procedures among the three groups. One group of three providers had a protocol violation whereby no defibrillation was provided during the first 8 minutes of the scenario because of the incorrect reading of ventricular fibrillation on the cardiac monitor as asystole. This group did perform IV placement but did not administer any medications or place an advanced airway.

Discussion

Resuscitation of cardiac arrest patients in the prehospital setting is both labor- and skill-intensive. Survival rates from OHCA vary greatly by region,^{1,30–32} from 3.0% to 16.3% in one study,³² and the number and level of providers available in various systems have been postulated to contribute to this difference in survival. In a meta-analysis by Nichol et al., two-tier EMS systems were associated with a significant increase in survival to hospital discharge compared with one-tier systems (10.5% vs. 5.2%), suggesting that staffing patterns do affect patient outcomes from OHCA.²³ However, the optimal crew configuration for response to these situations remains unknown. We evaluated objective measures of cardiac resuscitation to compare the effectiveness of crews composed of two, three, and four ALS providers.

The results of this study revealed no significant difference between all-paramedic crew size configurations in the NFF during CPR, a measure of effectiveness of CPR linked to maintaining adequate CPPs and improving survival.^{2–12,33} Prior studies had demonstrated that compressions are not performed as much as half of the time during CPR.^{14–29–34} It is, however, possible to obtain significantly lower NFFs, and Losert et al. documented a mean hands-off ratio of 0.13 among highly trained staff in an emergency department setting.³⁵ Our study did find a decrease in baseline NFF across all groups when compared with our previous work, which may be attributed to the change from 15:2 to 30:2 in the compressions-to-ventilations ratio resulting from the 2005 AHA CPR guidelines and subsequent changes in paramedic education.⁶ This improvement in the baseline NFF is encouraging.

Though times to performance of individual procedures were not found to differ among groups, point estimates suggest that groups with three or four providers may successfully complete more specific ALS procedures compared with two-person groups. Additionally, there was a trend toward decreased time to endotracheal intubation with increasing number of ALS providers. This finding is consistent with the study by Bayley et al. comparing paramedic-paramedic versus paramedic-EMT groups.¹⁸ Whether this factor independently impacts survival is uncertain. In a retrospective study of 693 OHCA patients who had endotracheal intubation performed, Shy et al. found a correlation between intubation times and survival to discharge from the hospital.³⁶ Additionally, Kramer-Johansen et al. demonstrated an improved NFF from 0.61 to 0.41 before and after endotracheal intubation.³⁷ If early intubation does have a survival benefit, it may be through improvement of the performance of CPR as part of the resuscitation. However, while early intubation may decrease NFF by allowing for continuous compressions, this benefit must be weighed against the cessation of compressions associated with endotracheal intubation. Perhaps the use of alternative airway devices, which can be placed in less time and without interruption of compressions, represents a better strategy for resuscitation.

The findings of our study may help to explain the seemingly paradoxical results of Eschmann et al.¹⁹ In our study, we demonstrated a lack of improvement in the provision of BLS interventions such as effective CPR and timely defibrillation, which appear to be most important in the resuscitation of cardiac arrest patients. In fact, review of the resuscitation scenarios revealed numerous cases within our study groups where the provider performing chest compressions became distracted by the performance of ALS procedures, resulting in pauses between chest compressions.

This included assisting in preparing intubation equipment or medications, which temporarily interrupted CPR. These findings are consistent with prior work that identified a decrease in quality of CPR by BLS providers with increasing resuscitation complexity.¹⁴ Therefore, having more ALS providers on the scene may distract the group from performing CPR in favor of ALS procedures that do not have a proven survival benefit or that are dependent on the effectiveness of BLS interventions,^{6,12,20–28} and may explain the improved survival seen in two-tier versus one-tier EMS systems.²³ Further studies using a mixed ALS-BLS crew with dedicated BLS providers may demonstrate improved times to ALS intervention without increasing NFF. For an increased number of providers to have an impact on survival in cardiac arrest, the findings of our study suggest that there must be a clear division of tasks and a renewed emphasis on the performance of effective CPR by dedicated providers.

Limitations

Several limitations present in our study warrant consideration. This study was conducted using a human patient simulator, and the findings may not necessarily reflect the performance of paramedic crews under field conditions. Similarly, though lower NFF has been associated with improved survival to hospital discharge in multiple studies,^{3–11} this simulation-based study did not directly assess clinically significant patient outcomes or quality indicators. Participants were told that this was a nontrauma scenario, and these results may not be generalizable to a trauma patient where other additional procedures such as immobilization and wound care may benefit from the presence of additional providers. Only the first 8 minutes of each scenario was evaluated before termination, with the intent of studying the initial interventions of OHCA resuscitation. It is possible that more two-rescuer groups would have completed all ALS procedures during a longer scenario, but completion rates were not objectively compared between groups. It is also possible that fatigue would have negatively impacted performance of CPR at 10–15 minutes in the two-rescuer versus four-rescuer model, resulting in a difference in total NFF between groups.

Paramedic students were selected for participation in this study. This decision was made based on their availability for participation, but also to provide a similar level of experience in ALS care between study participants. These students were near the end of their training and were familiar both with the specific equipment being used and with the high-fidelity human patient simulator.

While a two-provider crew is the most common ambulance crew configuration in the United States,¹ a two-provider scenario may be unrealistic and essentially involves one person performing CPR while another performs all other tasks of resuscitation, leading to fewer ALS procedures. Still, such a scenario provides a basis for comparing crew configurations and may be representative of the initial phase of resuscitation in some EMS systems based on reported staffing patterns. The all-paramedic model also limits generalizability to systems in which BLS providers or first responders are available to provide BLS care. However, prior work has demonstrated that CPR by BLS providers similarly suffers from distractors with increasing resuscitation complexity,¹⁴ as would be the case with increased ALS providers who performed more ALS procedures.

While this study was powered to find a significant difference in NFF between groups, it was not powered for the secondary outcomes of time to performance of ALS procedures. Therefore, this study may have been underpowered to detect a true difference in time to intubation with increased crew size. There may have been practice effects not accounted for in our calculation, in spite of randomization of the order of crew configurations. Additionally, our study participants had a lower NFF across all groups than the NFF of 0.50 found in other studies and used for the power calculation. However, given no consistent trend determined for NFF based on crew size in this study, it is unlikely that an increased sample size would reveal a meaningful difference between groups. This finding does show a considerable improvement in the provision of CPR within this study group, likely influenced by recent training and newer guidelines that emphasize effective CPR and minimize NFF.

Conclusion

This study found no difference in NFF during simulated CPR between groups of two, three, and four ALS providers. There was a trend toward a decrease in time to intubation with increasing crew size, but no significant difference between groups in time to performance of BLS or ALS procedures. The performance of optimal CPR may be hindered by distractions related to the performance of ALS procedures with increasing group size, particularly in an all-ALS provider model. We suggest a renewed emphasis on the provision of effective CPR by designated providers independent of any ALS interventions being performed.

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Table 1

Groups Successfully Performing Advanced Life Support Procedures during the First 8 Minutes of the Scenario (n/%)

	Two-Person	Three-Person	Four-Person
Intravenous access	7/70%	10/100%	10/100%
First medication	6/60%	9/90%	10/100%
Endotracheal intubation	5/50%	8/80%	9/90%

Table 2

Time to Performance of Resuscitation Interventions

	Two-Person		Three-Person		Four-Person		p-Value
	n	Time (sec)	n	Time (sec)	n	Time (sec)	
BLS procedures							
Chest compressions	10	36	10	34	10	31	0.659
Defibrillation	10	161	9	168	10	174	0.810
ALS procedures							
Intravenous access	7	259	10	210	10	168	0.121
First medication	6	265	9	242	10	233	0.530
Endotracheal intubation	5	379	8	316	9	263	0.018

ALS = advanced life support; BLS = basic life support.