SIMULATED CARDIAC ARREST RESUSCITATION

Impact of Ambulance Crew Configuration
Impact of Ambulance Crew Configuration on Simulated Cardiac Arrest Resuscitation

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Abstract

Background. Despite the widespread use of both two paramedic and single paramedic ambulance crews, there is little evidence regarding differences between these two staffing configurations in the delivery of patient care. Objectives. To determine potential differences in care provided by each of these ambulance configurations in the resuscitation of a cardiac arrest victim in ventricular fibrillation. Methods. Fifteen paramedic-paramedic and 15 paramedic-EMT crews were recruited to perform resuscitation on a high-fidelity human simulator (Laerdal SimMan™). Errors and their nature, time to critical interventions, and compliance with continuous cardiopulmonary resuscitation (CPR) were captured by the simulator and videotape. Results. Two paramedic crews averaged 0.7 ± 0.5 more errors of commission, 0.5 ± 0.4 more errors of sequence, and 0.8 ± 0.8 more total errors per resuscitation (±95% CI; p = 0.008, 0.017, and 0.036, respectively). For all interventions analyzed, only time required to achieve intubation differed between the two configurations, with two paramedic crews intubating 63.9 ± 45.8 seconds more quickly (p = 0.009). CPR compliance was highly variable, and a meaningful statistical difference could not be determined, although performance overall was poor, with both configurations averaging less than 50% compliance. Conclusion. Two paramedic crews were more error-prone and did not perform most interventions more rapidly with the exception of intubation. These data do not support the proposition that two paramedic crews provide higher quality cardiac care than paramedic-EMT crews in a simulated ventricular fibrillation arrest. Key words: ambulance crews; paramedic; technician; out-of-hospital; cardiac arrest; mannequin.

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Introduction

Emergency Medical Services (EMS) systems within the United States and abroad are challenged to provide the highest level of care to the patients they serve while at the same time minimizing costs and maximizing efficiency. As these systems face increasing economic constraints and paramedic staffing shortages, many have reduced the number of paramedics per advanced life support (ALS) ambulance from two to one in an effort to maintain or increase the number of ALS ambulances within their systems. Recent examples include the Fire Department of New York (FDNY) and the District of Columbia Fire Department (DCF D).1,2 It is not surprising that these measures have drawn scrutiny from both the lay public and EMS providers themselves regarding possible effects on the quality of patient care.3–5

Currently, approximately 40% of ALS ambulances in the United States are staffed by two paramedics. The remainder have one paramedic and a less-well-trained emergency medical technician (EMT).4 Unlike their paramedic counterparts, EMTs are not trained in Advanced Cardiovascular Life Support (ACLS) and thus do not perform interventions such as cardiac medication administration or intubation.5 It has been hypothesized that during critical scenarios where multiple interventions must be carried out in a time-sensitive manner, paramedic-EMT crews may perform more slowly than paramedic-paramedic crews because of the EMTs reduced skill set.6 It has also been argued that when both providers are ACLS-trained and certified paramedics, there exists a redundancy in critical care decision making that may reduce errors.2

The few relevant studies to date have only indirectly analyzed crew configuration by using "on-scene time" as a proxy for team efficiency. One study found that reducing the number of paramedics from three to two per ambulance greatly increased both on-scene time and the time required to complete interventions.6 On the basis of these findings, it has been hypothesized that further reduction from two paramedics to a single paramedic paired with an EMT might further increase on-scene time and time per intervention. In contrast, an Australian study found that for a similar number of interventions, paramedic-EMT crews actually spent less time on-scene versus paramedic-paramedic crews.3 However, the study concluded that the difference was so small as to be of clinical irrelevance. Thus, there are insufficient data to assess the potential impact of different crew configurations on response efficiency. Furthermore, extant studies do not address differences in the quality of interventions or types of errors performed by different crew configurations.
The present study sought to directly compare paramedic-paramedic and paramedic-EMT crews in their ability to execute one standardized critical scenario—specifically, the resuscitation of a patient in ventricular fibrillation. Using high-fidelity simulation, crews were compared for critical errors, time to complete interventions, and continuous CPR compliance when evaluated against the then current American Heart Association 2000 ACLS guidelines.

METHODS AND MATERIALS

Study Design

Thirty full-time ALS ambulance crews were solicited from the Nashville-Davidson County Fire and EMS system (NFD-EMS) for participation in this study. This large, urban EMS system is a single-provider fire-based service covering 500 square miles. It employs 200 EMS paramedics and EMTs and responds to approximately 60,000 EMS calls per year. In this system, roughly half of ambulances are staffed by paramedic-EMT crews, where the EMTs have training and experience that closely approximates that of the nationally recognized EMT-Intermediate classification. The other half of ambulances are staffed by two paramedics.

A power analysis, assuming a type I error of 5%, calculated that 15 crews of each configuration would provide a 97% chance to detect a 30-second difference in the time required to execute the complete resuscitation assuming a standard deviation of 30 seconds. These assumptions were based on data of simulated two-rescuer ACLS studies using a similar methodology. This same sample size would also provide a 97% chance to detect a 15% difference in CPR compliance (assuming a 15% standard deviation) and 97% chance to detect a difference of 0.5 errors per scenario (assuming a standard deviation of 0.5 errors). Sample size calculations were performed by using the PS Power and Sample Size Program.

The first 15 crews of each configuration to volunteer were chosen with no exclusion criteria. All employees in the NFD-EMS system work full-time, and all paramedics are required to maintain current ACLS certification. At the time of this study, ACLS certification was based on the AHA 2000 ECC guidelines. Crews were blinded to the nature of the simulated emergency (ventricular fibrillation arrest) and to the variables being evaluated, including staffing configuration.

Each crew member signed a written informed consent acknowledging that he or she would be video-recorded and was compensated $50.00 for participation in the study, which lasted approximately 1 hour. This study design was approved by Vanderbilt’s Institutional Review Board.

Experimental Protocol

On the day of simulation, crews were provided a scripted 10-minute orientation to the SimMan™ Patient Simulator (Laerdal, Norway, software v3.1). The script reviewed the airway, breathing, and circulatory capabilities of the SimMan™ as well as how to perform all ACLS interventions on the mannequin. Crews were then given their standard issue defibrillator/monitor (Zoll M series) and jump bags with sufficient equipment and medications to perform all ACLS algorithms. The defibrillator was modified with Laerdal hands-free defibrillation snaps coupled with a Zoll-compatible adaptor to allow for full-energy defibrillation to be performed directly on the simulator. Crews were given time to ask questions and configure the equipment to their own personal preferences before the simulation commenced.

Crews were then asked to wait outside a room in which the SimMan™ was readied and placed supine on the floor 15 feet from the door. When ready, crews were told to enter the room, assess the patient, and perform interventions as dictated by their current standing protocols.

The SimMan™ was programmed to generate a rhythm of refractory ventricular fibrillation until the administration of a ventricular antiarrhythmic medication followed by appropriate defibrillation as detailed under Outcome Measures. This was the standing protocol for NFD-EMS during the study period and conformed to the then current 2000 AHA ACLS guidelines with which all crews had many years of experience.

The SimMan™ logged the occurrence and time of all pulse checks, defibrillations, and intervals during which chest compressions were performed. A video camera recorded the resuscitation on digital videotape (Sony DVCam DSR-1500 ) with time-coding provided by a Horita RM 50 II unit. The video data were imported to digital files in video-editing software (Macintosh Final Cut Pro 4). Frame-by-frame video analysis allowed for validation of the SimMan™ data and crews’ performance elements including the number of chest compressions and times to intubation, IV access, and each medication administration.

After the simulation, participants completed a brief survey and information sheet, intended to assess additional variables that might impact performance such as experience level, instructor experience, frequency working with other crew member, and date of most recent ACLS refresher training.

Outcome Measures

Three categories of outcomes were measured: errors, time required to complete interventions, and compliance with continuous CPR.
Errors were quantified by using an 11-item checklist of ordered clinical actions derived directly from the AHA 2000 FRCC/ACLS guidelines. This checklist was similar to standardized tools used in ACLS practical skills assessment for the management of ventricular fibrillation.10,11 Per the checklist, each team was expected to (in order): check pulses, administer three defibrillations, intubate, initiate IV access, administer 1 mg epinephrine, defibrillate, administer 300 mg amiodarone, defibrillate a fifth time, and perform a final pulse check after rhythm change. Each team’s actions, as recorded by the SimMan™ log, were compared to this checklist. For each of these 11 actions absent from the SimMan™ log, an error of omission was recorded. Actions recorded by the log that were superfluous to these 11 actions were recorded as errors of commission. Once corrected for commission and omission errors, each log was reviewed for the correct order of interventions, with each out-of-order intervention counting as one sequence error. Total errors was the sum of errors of commission, omission, and sequence for each team. For this categorical analysis, all errors were given equal weight.

Time required to complete each intervention was defined as the time elapsed from completion of one intervention to the completion of the next intervention in the sequence. This was calculated by using the time stamps of the SimMan™ log. Time to complete the whole resuscitation was calculated similarly. If a crew failed to complete the scenario to the point of ROSC, a cutoff time of 12 minutes was used as the time to complete the scenario.

The third outcome measure, compliance with continuous CPR, was calculated as the total aggregate time during which chest compressions were performed, divided by the total time from scenario start to ROSC. The SimMan™ mannequin registered each chest compression meeting a threshold depth of approximately one inch. Intervals of continuous compressions were calculated as time periods during which there was a no greater than 5-second pause during compressions (intended to allow for ventilation). No time corrections were made for actions during which chest compressions were correctly suspended (e.g., defibrillation). This method is consistent with other prehospital studies of CPR performance during resuscitation.12 Compresion rate per minute was also calculated, by dividing the total number of effective compressions for the scenario by the total aggregate time in minutes during which chest compressions were performed.

Data Analysis

Descriptive statistics for the two groups and the results of each outcome measure as described above were tested for normal distribution using the D’Agostino-Pearson test for non-normality. Descriptive statistics, time to complete each intervention variables, and CPR compliance were consistent with a normal distribution. All measures of error were found not to be consistent with a normal distribution. Data for variables consistent with a normal distribution were compared by using a one-way ANOVA. Data for all error variables were analyzed by using the Kruskal-Wallis rank sum test, which does not assume a normal distribution. For non-normal data, 95% confidence intervals and their means were generated via an Efron bootstrap calculation which does not assume a normal distribution.

Multivariate linear regressions were also run by using time to complete each intervention and total scenario time as dependent variables. Independent variables included team configuration, CPR compliance, individual and combined years of experience of the EMS providers, instructor status, and frequency with which providers worked with each other as self-reported on a five-point Likert scale. Given the size of the data set, each of the above independent variables was individually investigated by regression, along with team configuration, against time required per intervention.

With the exception of bootstrap sampling, analysis was carried out by using the CoStat software package (Cohort Software, Monterey, CA, PC version 6.311). Bootstrap sampling was performed with Resampling Procedures Software (University of Vermont, Burlington, VT, PC version 1.3) at 5,000 resamplings per calculation. For all calculations, a p ≤ 0.05 was considered significant. Unless otherwise stated, normally distributed data are presented as means ± standard deviation, and non-normal data are presented as median and 95% confidence interval.

RESULTS

Fifteen paramedic-paramedic crews and 14 paramedic-EMT crews were included in the final analysis. One

<table>
<thead>
<tr>
<th>TABLE 1. Descriptive Statistics for Each Crew Configuration</th>
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<tbody>
<tr>
<td>Parameter</td>
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<tr>
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</tr>
<tr>
<td>Total Years of Experience</td>
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<tr>
<td>ACLS Instructors per team</td>
</tr>
<tr>
<td>Total errors per resuscitation</td>
</tr>
<tr>
<td>Errors of commission</td>
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<td>Errors of omission</td>
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<td>Errors of sequence</td>
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<tr>
<td>Continuous CPR compliance</td>
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<tr>
<td>Compressions (rate/min)</td>
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<tr>
<td>Completion of scenario (sec)</td>
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Statistics regarding crew experience, instructor status, and basic performance in regard to errors, CPR compliance, and speed are presented. Statistical differences in the number of total errors, commission errors, and sequence errors are noted.12

*Reported as median value (95% confidence interval), otherwise mean ± SD.

**Statistically significant difference; see Figure 1.

*Paramedic-EMT crews performed no sequence errors during the study.
paramedic-EMT team was excluded because of a simulator malfunction where a loose ECG connector resulted in no rhythm generation on the crew’s monitor/defibrillator, which they interpreted as asystole.

Descriptive statistics for the two different crew configurations are summarized in Table 1. The two configurations did not differ significantly in total years of experience or instructor status. Intragroup performance was highly variable. crews ranged from zero to four errors per resuscitation, required anywhere from 323 to 702 seconds to complete the resuscitation, and had continuous CPR compliance ranging from 1.6% to 84%.

A wide range of types of errors were observed (Table 2). Paramedic-paramedic crews had significantly more commission errors, sequence errors, and total errors than paramedic-EMT crews (Figure 1).

The two configurations were next compared regarding the elapsed time to complete each intervention (Table 3). The only time point for which a statistically significant difference was detected was the time required to achieve intubation, with paramedic-paramedic crews averaging 149 seconds versus 209 seconds for paramedic-EMT crews (p = 0.018). More important perhaps was the substantial variability within each group (see standard deviations of time required per intervention in Table 3).

To determine if factors other than team configuration might be predominantly driving the time required to complete certain interventions, multivariable regressions were performed by using independent variables including CPR compliance, individual and combined years of experience of the EMS providers, instructor status, and frequency with which providers worked with each other. Controlling statistically for each of these independent variables did not significantly affect the results.

There was appreciable intragroup variation in CPR compliance. Paramedic-paramedic crews averaged 48 ± 20% compliance versus 44 ± 20% compliance for paramedic-EMT crews (mean ± 1 SD), with a non-significant 95% confidence interval difference of 3.8 ± 14.2%. Adjustment for individual and combined years of experience of the EMS providers, instructor status, and frequency with which providers worked with each other did not significantly impact the CPR adherence results.

### DISCUSSION

This controlled simulation study of prehospital cardiac resuscitation provides additional insight into factors that affect the ACLS performance of two-person ambulance crews. The results do not support an assertion for superiority of paramedic-paramedic crews. Moreover, the most notable finding was the substantial range of performance of operational crews.

### Errors

Paramedic-paramedic crews averaged almost one whole error more per resuscitation. These crews had

| TABLE 3. Elapsed Time to Complete Intervention as a Function of Crew Configuration |
|---------------------------------------------|-------------|------------|-----------------|--------|
|                                           | Paramedic  | Paramedic  | p value         |
|                                           | -Paramedic | -EMT       |                 |
| Scenario start to initial pulse check    | 15 ± 6.5   | 32 ± 29    | 0.101           |
| Initial pulse check to defib #1          | 55 ± 26    | 51 ± 32    | 0.466           |
| Defib #1 to defib #2                     | 17 ± 6.0   | 19 ± 6.6   | 0.252           |
| Defib #2 to defib #3                     | 32 ± 6.1   | 36 ± 7.8   | 0.257           |
| Defib #3 to intubation                   | 149 ± 23   | 209 ± 71   | 0.019*          |
| Defib #3 to IV access                    | 294 ± 79   | 279 ± 71   | 0.489           |
| Defib #3 to epinephrine                  | 193 ± 57   | 234 ± 65   | 0.105           |
| Epinephrine to defib #4                  | 38 ± 16    | 46 ± 32    | 0.644           |
| Defib #4 to amiodarone                   | 167 ± 46   | 173 ± 138  | 0.215           |
| Amiodarone to defib #5                   | 102 ± 51   | 119 ± 87   | 0.670           |
| Defib #5 to ROSC pulse check             | 10 ± 9.7   | 16 ± 28    | 0.570           |
| Total time to complete scenario          | 310 ± 79   | 524 ± 106  | 0.678           |

Regression outcomes using crew configuration as the independent variable and elapsed time to complete each intervention as the dependant variable. All values are means ± 1 SD (sec).
more commission, sequence, and total errors, but did not differ significantly in omission errors.

On the basis of a qualitative review of the data, the authors speculate that this counterintuitive result may be due in part to differences in how the members of each crew configuration interact. When two paramedics are present, both providers may act as equals contributing to the resuscitation. Without a clear leadership hierarchy, each provider may be more likely to contribute to the resuscitation as each sees fit. This may create an environment permissive to redundancy and erroneous sequencing.

In contrast, there is a clear leader of the paramedic-EMT configuration, leading to better organization. However, the demands on a single paramedic may be so onerous at times that tasks can be delayed or inadvertently omitted. This supposition is supported by the slower time to intubation in the paramedic-EMT group. Further human factor studies are warranted in this area.

Little data exist quantifying the individual impact of any of these interventions on patient outcome. In fact, only defibrillation and CPR have been clearly shown to improve patient outcome. It is thus difficult to ascertain the impact per error or assert unequivocally that one type of error is more clinically significant than another. Eighty-three percent (10 of 12) of the additional interventions performed by paramedic-paramedic crews were defibrillations, which one might argue may be less detrimental to a patient than would be the omission, for example, of an antiarrhythmic drug, or a sequence error, such as intubation before initial defibrillation. Regardless, this study shows a substantial incidence of care process deviations, which many clinical and patient safety experts believe are a meaningful proxy for lower quality care.

Speed of Interventions

There were no significant differences between the two crew configurations in terms of the efficiency with which most interventions were performed, with the exception of time required to complete intubation. There are limited data to suggest that time to intubation may independently affect patient outcome. When intubation times are controlled for other variables and analyzed by quartiles, one study found that patients whose intubation time was in the fastest quartile were twice as likely to survive. In our study, six of the seven crews in the fastest quartile were paramedic-paramedic crews.

In comparison with cardiac medication administration or defibrillation, intubation requires significant time to not only perform but also to prepare for it. Having two providers who perform intubation regularly and thus are familiar with the setup and execution well may facilitate the speed with which it is accomplished. Other interventions that may similarly benefit from the involvement of advanced providers might include intravenous access, IV fluids, and medications. Because intubation and these other complex clinical skills are performed during only a minority of EMS responses, it is understandable why other studies that used total scene time as a proxy for efficiency may not have detected any differences between crew configurations.

CPR Compliance

Total mean compliance for all crews was poor at 46%. There was also large intragroup variation in both the CPR compliance rate and compressions per minute. Thus, this study found no significant difference between CPR compliance rates for the two configurations.

These results are similar to those of a study of CPR performance during actual prehospital cardiac arrests. Using a device to measure CPR compliance during prehospital resuscitations, Wik and colleagues (2005) found that European EMS providers performed CPR only 52% of the time during actual cardiac resuscitations using the same 2000 ACLS guidelines as this study. Research emphasizes the importance of continuous CPR using a high-compression rate. There is a large body of evidence showing that slow compressions, frequent interruptions, and significant "hands-off" time during CPR precludes adequate cardiac and cerebral perfusion pressures, thus adversely affecting outcome. Thus, it is notable that neither crew configuration was able to accomplish CPR that would likely have been of clinical benefit to an actual patient.

Why did some crews dramatically outperform others regardless of crew configuration? In the early minutes of a resuscitation, CPR compliance may be poor due to providers dividing their time between CPR performance and completion of all of the other ACLS interventions. However, CPR compliance does not improve dramatically even after all of these other interventions are completed. While the large variability in CPR compliance in this study could be an artifact of it being a simulated study, our experience with in-hospital resuscitations suggests otherwise and further study seems warranted, particularly with the increased focus on CPR in the 2005 ECC guidelines.

Study Limitations

This study used the 2000 ACLS guidelines, because it was initiated just prior to publication of the 2005 ACLS guidelines and the crews were still operating under the 2000 guidelines. Some states did not revise their EMS protocols with the new guidelines until early 2007, and some providers will not undergo formal ACLS recertification under the new guidelines until early 2008. The use of guidelines with which crews had years of experience in actual clinical encounters is advantageous in that results are less likely to be driven by
crew unfamiliarity or lack of clinical experience with recently changed guidelines. However, given the 2005 ACLS guidelines' emphasis on CPR and attempts to streamline other interventions, the results of this study cannot be assumed to carry over to the new guidelines and must be reconfirmed.

A second limitation is that this was a simulation. Simulator-based studies allow the direct observation of participants under highly controlled and reproducible circumstances. However, participants may act differently than they might during actual patient care. The nature of this confound is unknown: participants may regard a simulation less seriously because it is not "real," or they may perform with more diligence knowing that they are being observed and reimbursed. Furthermore, participants who volunteer in any study may differ from the actual population. Nevertheless, the results of this study do corroborate those of prior field studies of prehospital cardiac resuscitation.

A third limitation of this pilot hypothesis-generating study was that it had a relatively small sample size. Furthermore, the intragroup variability observed was greater than assumed when making initial power calculations. Regardless, the study was sufficiently powered to detect statistical differences in the error rates between the two crew configurations. For the resuscitation time overall and the times to complete many major interventions, differences between the two configurations as small as 20% would likely have been detected if present. The study was not sufficiently powered to detect meaningful statistical differences in CPR compliance. However, the high variability demonstrated is itself noteworthy and serves to highlight future directions for research.

CONCLUSION

This study does not support the assertion that paramedic-paramedic crew configurations provide better resuscitation care than paramedic-EMT crews. In contrast, paramedic-paramedic crews in this study exhibited more total errors, more errors of commission, and more errors of sequence per resuscitation. Moreover, the two configurations did not differ significantly in terms of speed to perform most interventions. Paramedic-paramedic crews did, however, outperform their paramedic-EMT counterparts in the efficiency with which intubation was performed. Whether these findings continue to hold true during actual resuscitations under the new 2005 ACLS guidelines or are sufficient to affect actual patient outcomes requires further investigation. In regards to CPR compliance, the wide intragroup variations reduced the power of this study to detect meaningful statistical differences. However, the data show that crews of both configurations fail to achieve high compliance with CPR guidelines. Notably, the crews in this study demonstrated marked variability in all aspects of performance regardless of crew configuration.

The results of this study suggest other possibilities for future investigation. Larger multicenter simulator-based studies could be undertaken to further elucidate possible differences between crew configurations in terms of efficiency. The differences in error rate noted in this study could be further elucidated by using field data to try to quantify their actual impact on patient care, if any. Perhaps the most important avenue for future research is delineation of the causes of the wide variation in performance and interventions to decrease it. In both configurations, a minority of crews were able to achieve error-free resuscitation with high CPR compliance. These crews could not be reliably identified by any of the independent variables collected including crew configuration or experience. Understanding the factors driving this variability and developing interventions to ensure maximal performance and decreased variability could provide significant benefit to EMS systems regardless of the crew configuration employed.

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