Minimally Interrupted Cardiac Resuscitation by Emergency Medical Services for Out-of-Hospital Cardiac Arrest

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OUT-OF-HOSPITAL CARDIAC arrest is a major public health problem and a leading cause of death.[1-4] Unfortunately, in large metropolitan cities, the outcomes are poor for patients with out-of-hospital cardiac arrest.[5-7] Although early defibrillation with automated external defibrillators improves survival, early defibrillation is rare and few patients with out-of-hospital cardiac arrest survive.[5-8] In 2004, the average survival of patients with out-of-hospital cardiac arrest was 3% in the state of Arizona.[9]

Minimally interrupted cardiac resuscitation (MICR), also referred to as cardiocerebral resuscitation, is a new approach to out-of-hospital cardiac arrest for emergency medical services (EMS) personnel developed at the University of Arizona Sarver Heart Center, and first instituted in Tucson, Arizona, in late 2003.[10-12] Minimally interrupted cardiac resuscitation focuses on maximizing myocardial and cerebral perfusion through a series of coordinated interventions. This aproach is intended to minimize interruption of chest compres-

Context Out-of-hospital cardiac arrest is a major public health problem.

Objective To investigate whether the survival of patients with out-of-hospital cardiac arrest would improve with minimally interrupted cardiac resuscitation (MICR), an alternate emergency medical services (EMS) protocol.

Design, Setting, and Patients A prospective study of survival-to-hospital discharge between January 1, 2005, and November 22, 2007. Patients with out-of-hospital cardiac arrests in 2 metropolitan cities in Arizona before and after MICR training of fire department emergency medical personnel were assessed. In a second analysis of protocol compliance, patients from the 2 metropolitan cities and 60 additional fire departments in Arizona who actually received MICR were compared with patients who did not receive MICR but received standard advanced life support.

Intervention Instruction for EMS personnel in MICR, an approach that includes an initial series of 200 uninterrupted chest compressions, rhythm analysis with a single shock, 200 immediate postshock chest compressions before pulse check or rhythm reanalysis, early administration of epinephrine, and delayed endotracheal intubation.

Main Outcome Measure Survival-to-hospital discharge.

Results Among the 886 patients in the 2 metropolitan cities, survival-to-hospital discharge increased from 1.8% (4/218) before MICR training to 5.4% (36/668) after MICR training (odds ratio [OR], 3.0; 95% confidence interval [CI], 1.1-8.9). In the subgroup of 174 patients with witnessed cardiac arrest and ventricular fibrillation, survival increased from 4.7% (2/43) before MICR training to 17.6% (23/131) after MICR training (OR, 8.6; 95% CI, 1.8-42.0). In the analysis of MICR protocol compliance involving 2460 patients with cardiac arrest, survival was significantly better among patients who received MICR than those who did not (9.1% [60/661] vs 3.8% [69/1799]; OR, 2.7; 95% CI, 1.9-4.1), as well as patients with witnessed ventricular fibrillation (28.4% [40/141] vs 11.9% [46/387]; OR, 3.4; 95% CI, 2.0-5.8).

Conclusions Survival-to-hospital discharge of patients with out-of-hospital cardiac arrest increased after implementation of MICR as an alternate EMS protocol. These results need to be confirmed in a randomized trial.

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sions, provide immediate preshock chest compressions for prolonged ventricular fibrillation (VF), delay or eliminate endotracheal intubation, minimize positive pressure ventilations, and decrease the time interval to intravenous epinephrine administration.[10-15]

Implementation of MICR was associated with substantially improved survival for patients with out-of-hospital

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cardiac arrest in rural settings.[14] We investigated whether MICR would improve survival from out-of-hospital cardiac arrest in a large urban setting. First, we report an analysis of before and after training of EMS personnel in 2 metropolitan fire departments in Arizona. Second, we investigated whether survival would be different in patients who actually received MICR (as defined by 4 compliance criteria) compared with patients who did not receive MICR in the 2 metropolitan and 60 additional fire departments throughout the state.

METHODS

The Save Hearts in Arizona Registry and Education (SHARE) program of the Bureau of Emergency Medical Services and Trauma System was established as part of the Arizona Department of Health Services to address the public health problem of sudden out-of-hospital cardiac arrest. This statewide program collects data from multiple EMS systems in rural, suburban, and urban settings. Because cardiac arrest has been identified as a public health issue in Arizona, these incidents are exempt from the Health Insurance Portability and Accountability Act of 1996. Approval was obtained from the Arizona Department of Health Services Human Subjects Review Committee and permission to publish deidentified data was obtained through the University of Arizona Institutional Review Board.

Arizona has approximately 6.3 million citizens living in 15 counties.[16] Our study includes data for out-of-hospital cardiac arrest from 62 EMS agencies, representing approximately 75% of the state's population. Prehospital triage, treatment, and transport protocols vary by local jurisdiction and region.

Data Collection and Definitions

An Utstein-style database for out-of-hospital cardiac arrests was initiated for all 62 participating fire departments.[17] The Utstein-style EMS incident reports collect information on patient demographics, event circumstances, response intervals, presenting rhythm, treatment and procedures, and initial outcomes.[17] Final outcomes were obtained through local hospitals and the Bureau of Public Health Statistics in the Arizona Department of Health Services.

Cardiac arrest was defined as the absence of cardiac mechanical activity determined by the absence of a pulse and the lack of normal breathing. Patients included all patients with out-of-hospital cardiac arrest on whom resuscitation was initiated. Cardiac arrest rhythms included asystole, pulseless electrical activity, and VF/pulseless ventricular tachycardia. Individuals with obvious signs of death (eg, rigor mortis, lividity) or with do not resuscitate documentation on EMS arrival were excluded because resuscitation efforts were not initiated per standard protocol. Other exclusion criteria were age (<18 years), cardiac arrest in adults witnessed by EMS personnel, and cardiac arrest secondary to trauma, drowning, or other noncardiac causes.

Intervention

Before and After Analysis. Minimally interrupted cardiac resuscitation was presented as an alternate treatment strategy for out-of-hospital cardiac arrest by 3 authors (B.J.B., L.L.C., and G.A.E.) to the EMS fire chiefs and medical directors. We provided MICR training with verbal and visual (slide presentation) instructions, psychomotor skill training for trainers (by B.J.B. and L.L.C.), and written supporting material (developed by the University of Arizona Sarver Heart Center Cardiopulmonary Resuscitation Research Group). A train-the-trainer model was used to disseminate the MICR protocol to fire department EMS personnel, and approximately 2000 EMS firefighters were trained in the new approach.

The MICR protocol for prehospital personnel includes an initial 200 uninterrupted chest compressions at 100 compressions per minute, rhythm analysis with a single shock when indicated, immediately followed by 200 postshock chest compressions before any pulse check or rhythm reanalysis. Endotracheal intubation is delayed until after 3 cycles of chest compressions and rhythm analysis. Intravenous epinephrine (1 mg) is administered as soon as possible during the protocol and again with each cycle of chest compressions and rhythm analysis.[12,14,15,18]

Minimally interrupted cardiac resuscitation discourages early and excessive ventilation by advocating passive oxygen insufflation with the placement of an oral-pharyngeal airway, a nonrebreather face mask, and high-flow oxygen rather than positive pressure ventilation.[14] However, because this approach to ventilation was such a dramatic change for the EMS personnel, bag-valve-mask ventilation was still permitted by paramedics and firefighters at an encouraged rate of 8 ventilations per minute. No patient received postresuscitation hypothermia.

For the before and after analysis, we report data collected between January 1, 2005, and June 30, 2007. Six months of baseline data, referred to as "before MICR" (January 1, 2005-June 30, 2005), were collected from the fire departments in the 2 largest metropolitan cities in Arizona. During the before MICR period, these departments followed the EMS protocol set forth in the 2000 American Heart Association (AHA) and the International Liaison Committee on Resuscitation Guidelines.[19]

Data collection for the "after MICR" training period began on the date that MICR training was first implemented. In the first fire department (site 1), MICR training was implemented on July 21, 2005. In the second fire department (site 2), MICR training was implemented on January 1, 2006. For the before and after analysis, data collection concluded in both fire departments on June 30, 2007. The before and after analysis was based on the principles of intention to treat and the analysis included all patients in the 2 time periods, regardless of whether they received MICR or not.

Protocol Compliance Analysis. In the protocol compliance analysis, we compared outcomes from patients who actually received MICR (all 4 compliance criteria present) with those who did not receive MICR between January 1, 2005, and November 22, 2007. The pro-

tocol compliance analysis included patients from the initial 2 fire departments plus an additional 60 fire departments in Arizona. Twelve of the total 62 fire departments were trained in MICR; the other 50 had no MICR training. In the protocol compliance analysis, the MICR training described in the before and after analysis was provided in a similar manner for the 10 other fire departments between 2005 and 2007.

The MICR protocol compliance was assessed by the presence of all 4 of the following criteria: (1) 200 preshock chest compressions, (2) 200 postshock chest compressions, (3) delayed endotracheal intubation for 3 cycles of 200 compressions and rhythm analysis, and (4) patients who received intravenous epinephrine in the first or second cycle of chest compressions.

Main Outcome Measures

The primary outcome measure in both the before and after analysis and the protocol compliance analysis was sur-
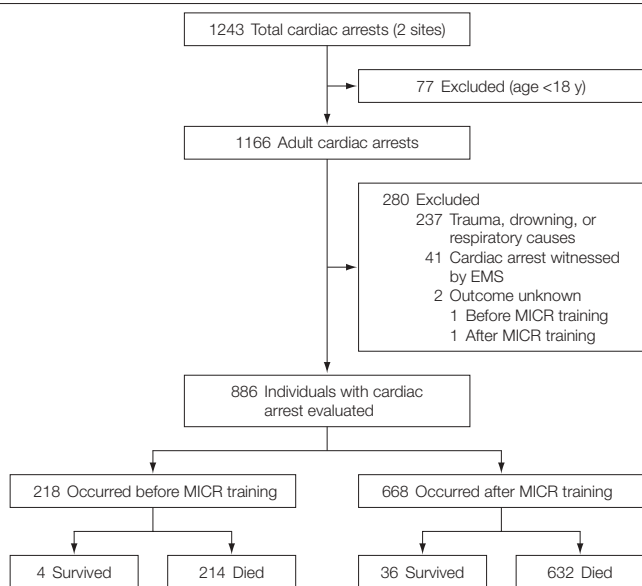
vival-to-hospital discharge for all patients with cardiac arrest and for the subgroup of patients with witnessed collapse and a shockable rhythm. Secondary outcome measures were favorable neurological outcome among survivors, return of spontaneous circulation, and survival-to-hospital admission.

To assess neurological outcome, survivors were contacted by mail and asked if they were willing to participate in a telephone interview or complete a questionnaire. The survivors also had the option of refusing to participate. A telephone interview was conducted or a questionnaire was sent to those patients consenting to assess their neurological status with the Cerebral Performance Categories (CPC) score on discharge from the hospital.[17] A CPC score of 1 indicates good cerebral performance (conscious, alert, able to work, might have mild neurological or psychological deficit); score 2, moderate cerebral disability (conscious, sufficient cerebral function for independent activities of daily life; able to work in sheltered environment); score 3, severe cerebral disability (conscious, dependent on others for daily support because of impaired brain function; ranges from ambulatory state to severe dementia or paralysis); score 4, coma or vegetative state (any degree of coma without the presence of all brain death criteria; unawareness, even if appears awake [vegetative state] without interaction with environment; may have spontaneous eye opening and sleep/wake cycles; cerebral unresponsiveness); and score 5, brain death (apnea, areflexia, electroencephalographic silence). For our analysis, CPC scores of 1 or 2 were considered favorable neurological outcome with sufficient cerebral function for independent activities.

Statistical Analyses

Data were entered into Microsoft Access (Microsoft Corp, Redmond, Washington) and transported into SPSS version 15.0 for statistical analysis (SPSS Inc, Chicago, Illinois). Continuous variables were presented as mean (SD) and

Figure 1. Flow Diagram of Patient Enrollment in the Before and After Analysis

EMS indicates emergency medical services; MICR, minimally interrupted cardiac resuscitation. The before and after analysis consisted of before and after MICR training of EMS personnel in 2 metropolitan fire departments in Arizona, with data collection between January 1, 2005, and June 30, 2007. For cardiac arrests occurring before MICR training at both sites, data were collected between January 1 and June 30, 2005. For cardiac arrests occurring after MICR training, data were collected at site 1 between July 21, 2005, and June 30, 2007, and at site 2 between January 1, 2006, and June 30, 2007.

Table 1. Patient Demographics and Event Characteristics in the Before and After Analysis[a]

Characteristics	Before MICR Training (n = 218)	After MICR Training (n = 668)	P Value
Age, mean (SD), y	65.0 (14.9)	66.0 (15.3)	.37
Men	143 (65.6)	459 (68.7)	.39
Home location	154 (70.6)	495 (74.1)	.32
Bystander CPR performed	75 (34.4)	262 (39.2)	.20
Witnessed	89 (40.8)	302 (45.2)	.26
Ventricular fibrillation	69 (31.7)	200 (29.9)	.63
EMS dispatch-to-arrival time, mean (SD), min	5.6 (2.6)	5.2 (2.0)	.12
Endotracheal intubation	90 (41.3)	437 (65.4)	<.001

Abbreviations: CPR, cardiopulmonary resuscitation; EMS, emergency medical services; MICR, minimally interrupted cardiac resuscitation.
[a] Data are presented as No. (%) unless otherwise specified.

analyzed by *t* test or Mann-Whitney U test. For the before and after analysis, the proportion of patients who survived to hospital discharge in the before MICR training and the after MICR training groups was compared with χ² or Fisher exact tests. A step-wise logistic regression analysis was used to determine the survival association of patients in the after MICR training group compared with those in the before MICR training group, adjusted for potential confounders. A base model was adjusted for age, sex, location of cardiac arrest, witnessed arrest, bystander cardiopulmonary resuscitation, VF, endotracheal intubation, and entire EMS dispatch-to-arrival time. A dummy variable was created to adjust for site differences and was included in the base model. The final model included only statistically significant covariates ($P < .05$). Odds ratios (ORs) for survival and 95% confidence intervals (CIs) were determined. The sample size was not planned. For the protocol compliance analysis, similar statistical tests were conducted comparing survival-to-hospital discharge for those patients who did and did not receive MICR. Neurological outcomes were calculated by using the CPC scale.[17]

RESULTS

Before and After Analysis

Of 1243 cardiac arrests during the data collection period, 886 met the inclusion criteria (218 occurred before MICR training and 668 occurred after MICR training) and underwent further evaluation (**FIGURE 1**). There were no significant differences between patients in the before MICR training group and the after MICR training group, regarding age, sex, location of cardiac arrest, presence of an initial shockable rhythm (VF), or EMS dispatch-to-arrival time. During the after MICR training period, more patients received endotracheal intubation ($P < .001$) (**TABLE 1**).

Among the 886 patients with cardiac arrest, survival-to-hospital discharge was found in 4 of 218 patients (1.8%) in the before MICR training group and in 36 of 668 patients (5.4%) in the after MICR training group (adjusted OR, 3.0; 95% CI, 1.1-8.9) (**TABLE 2**). In the subgroup of 174 patients with a witnessed cardiac arrest and a shockable rhythm, survival was found in 2 of 43 patients (4.7%) in the before MICR training group and

Table 2. Comparison of Major Outcomes in the Before and After Analysis

Outcomes	No./Total No. (%) of Patients		Odds Ratio (95% CI)		Significant Covariates in Final Model[a]
	Before MICR Training	After MICR Training	Unadjusted	Adjusted	
Primary outcomes					
Survival-to-hospital discharge	4/218 (1.8)	36/668 (5.4)	3.0 (1.1-8.6)	3.0 (1.1-8.9)	Witnessed arrest and VF
Survival with witnessed VF	2/43 (4.7)	23/131 (17.6)	4.4 (1.0-19.1)	8.6 (1.8-42.0)	Endotracheal intubation
Secondary outcomes					
Return of spontaneous circulation	34/218 (15.6)	154/668 (23.1)	1.6 (1.1-2.4)	1.3 (0.8-2.0)	Witnessed arrest, VF, endotracheal intubation, and site
Survival-to-hospital admission	35/218 (16.1)	113/668 (16.9)	1.1 (0.7-1.6)	0.8 (0.5-1.2)	Bystander CPR performed, witnessed arrest, VF, endotracheal intubation, entire EMS dispatch-to-arrival time

Abbreviations: CI, confidence interval; CPR, cardiopulmonary resuscitation; EMS, emergency medical services; MICR, minimally interrupted cardiac resuscitation; VF, ventricular fibrillation.
[a] Initial model included age, sex, location of cardiac arrest, bystander CPR performed, witnessed arrest, VF, endotracheal intubation, entire EMS dispatch-to-arrival time, and site. The final model included only significant covariates, as indicated.

Table 3. Compliance and Outcomes in the Before and After Analysis by Site and 6-Month Time Intervals[a]

	Before MICR Training	After MICR Training	6-Month Intervals After MICR Training			
			1	2	3	4
Site 1 (n = 393)						
Compliance, %		70.4	60.3	81.1	69.2	65.2
Overall survival	3/119 (2.5)	18/274 (6.6)	3/58 (5.2)	11/95 (11.6)	1/52 (1.9)	3/69 (4.3)
Witnessed VF survival	2/23 (8.7)	11/52 (21.2)	2/11 (18.2)	7/17 (41.2)	1/6 (16.7)	1/18 (5.6)
Return of spontaneous circulation	16/119 (13.4)	77/274 (28.1)	17/58 (29.3)	29/95 (30.5)	13/52 (25.0)	18/69 (26.1)
Survival-to-hospital admission	15/119 (12.6)	50/274 (18.2)	10/58 (17.2)	20/95 (21.1)	9/52 (17.3)	11/69 (15.9)
Site 2 (n = 493)						
Compliance, %		54.6	57.6	54.3	50.0	
Overall survival	1/99 (1.0)	18/394 (4.6)	11/172 (6.4)	5/116 (4.3)	2/106 (1.9)	
Witnessed VF survival	0/20 (0)	12/79 (15.2)	7/32 (21.9)	4/26 (15.4)	1/21 (4.8)	
Return of spontaneous circulation	18/99 (18.2)	77/394 (19.5)	37/172 (21.5)	25/116 (21.6)	15/106 (14.2)	
Survival-to-hospital admission	20/99 (20.2)	63/394 (16.0)	24/172 (14.0)	21/116 (18.1)	18/106 (17.0)	

Abbreviations: MICR, minimally interrupted cardiac resuscitation; VF, ventricular fibrillation.
[a] Data are presented as No./total No. (%), unless otherwise specified. There was no compliance in the before MICR training at both sites because MICR was not performed. At site 2, there was no after MICR training interval 4. For site 1, the after MICR training interval 1 was between July 21, 2005, and December 31, 2005; interval 2: between January 1, 2006, and June 30, 2006; interval 3: between July 1, 2006, and December 31, 2006; and interval 4: between January 1, 2007, and June 30, 2007. For site 2, the after MICR training interval 1 was between January 1, 2006, and June 30, 2006; interval 2: between July 1, 2006, and December 31, 2006; and interval 3: between January 1, 2007, and June 30, 2007.

in 23 of 131 patients (17.6%) in the after MICR training group (adjusted OR, 8.6; 95% CI, 1.8-42.0). Overall, 61.1% (408/668) of cardiac arrests treated after MICR training met the 4 MICR compliance criteria.

In **TABLE 3**, the primary outcome measures and compliance are reported in the before and after analysis by site and 6-month time intervals. At site 1, overall survival-to-hospital discharge increased from 2.5% before MICR training to 6.6% after MICR training, with a compliance of 70.4% after MICR train-

ing. In addition, survival among patients with witnessed cardiac arrest and VF increased from 8.7% to 21.2%. At site 2, overall survival-to-hospital discharge increased from 1.0% before MICR training to 4.6% after MICR training, with a compliance of 54.6% after MICR training. Furthermore, survival among patients with witnessed VF at site 2 increased from 0% to 15.2%.
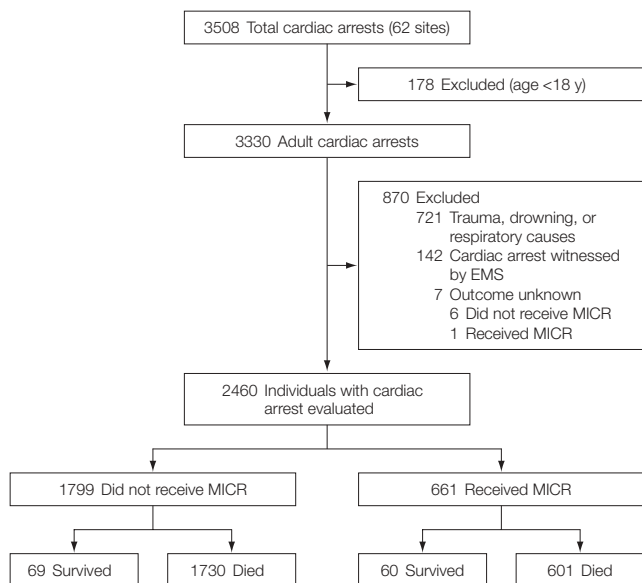
Protocol Compliance Analysis

FIGURE 2 shows the enrollment data for the protocol compliance analysis, an as-

sessment of outcomes for patients who actually received MICR vs those who did not receive MICR in the 2 metropolitan cities and in the 60 additional Arizona fire departments. Overall, 3508 patients in cardiac arrest were assessed from January 1, 2005, to November 22, 2007, with 2460 included in the analysis. A total of 1799 patients did not receive MICR and 661 patients received MICR. Baseline characteristics of each group are shown in **TABLE 4**. In the group that received MICR, there were more men, endotracheal intubation was more frequent, and the patients were slightly younger.

TABLE 5 shows the major outcomes for the protocol compliance analysis. Overall survival-to-hospital discharge was found in 69 of 1799 patients (3.8%) who did not receive MICR and in 60 of 661 (9.1%) who received MICR (adjusted OR, 2.7; 95% CI, 1.9-4.1). Survival with witnessed VF cardiac arrest was found in 46 of 387 patients (11.9%) who did not receive MICR and in 40 of 141 patients (28.4%) who received MICR (adjusted OR, 3.4; 95% CI, 2.0-5.8). Neurological outcome data was available for 84 of 129 survivors (65.1%). Favorable neurological outcomes with CPC scores of 1 or 2 were noted among 81.6% of patients who did not receive MICR and 80.0% of patients who received MICR (**TABLE 6**).

Figure 2. Flow Diagram of Patient Enrollment in the Protocol Compliance Analysis

EMS indicates emergency medical services; MICR, minimally interrupted cardiac resuscitation. The protocol compliance analysis included patients from the initial 2 metropolitan fire departments plus an additional 60 fire departments in Arizona (total 62 fire departments: 12 trained in MICR and 50 not trained in MICR), with data collection between January 1, 2005, and November 22, 2007.

Table 4. Patient Demographics and Event Characteristics in the Protocol Compliance Analysis[a]

Characteristics	Did Not Receive MICR (n = 1799)	Received MICR (n = 661)	P Value
Age, mean (SD), y	67.8 (15.0)	65.7 (15.4)	.002
Men	1169 (65.0)	462 (69.9)	.02
Home location	1276 (70.9)	494 (74.7)	.06
Witnessed	797 (44.3)	298 (45.1)	.73
Bystander CPR performed	707 (39.3)	267 (40.4)	.62
Ventricular fibrillation	561 (31.2)	211 (31.9)	.73
EMS dispatch-to-arrival time, mean (SD), min	5.6 (3.2)	5.2 (2.3)	.32
Endotracheal intubation	1032 (57.4)	414 (62.6)	.01

Abbreviations: CPR, cardiopulmonary resuscitation; EMS, emergency medical services; MICR, minimally interrupted cardiac resuscitation.
[a] Data are presented as No. (%) unless otherwise specified.

COMMENT

The before and after analysis demonstrated that survival-to-hospital discharge after out-of-hospital cardiac arrest in a metropolitan setting improved from 1.8% to 5.4% after 2 fire departments delivering EMS were taught the MICR protocol. The greatest improvement in survival occurred in the subgroup of patients most likely to survive: those with documented witnessed cardiac arrest and a shockable rhythm. Those patients had a 4.7% survival rate before MICR training vs 17.6% after MICR training.

The study by Kellum et al[14] reported a tripling (from 15% to 48%) in neurologically intact survival for patients in a

Table 5. Comparison of Major Outcomes in the Protocol Compliance Analysis

	No./Total No. (%) of Patients		Odds Ratio (95% CI)		
Outcomes	Did Not Receive MICR	Received MICR	Unadjusted	Adjusted	Significant Covariates in Final Model[a]
Primary outcomes					
Survival-to-hospital discharge	69/1799 (3.8)	60/661 (9.1)	2.5 (1.7-3.6)	2.7 (1.9-4.1)	Age, bystander CPR performed, witnessed arrest, VF, endotracheal intubation, and entire EMS dispatch-to-arrival time
Survival with witnessed VF	46/387 (11.9)	40/141 (28.4)	2.9 (1.8-4.7)	3.4 (2.0-5.8)	Age, bystander CPR performed, endotracheal intubation, and entire EMS dispatch-to-arrival time
Secondary outcomes					
Return of spontaneous circulation	312/1799 (17.3)	185/661 (28.0)	1.9 (1.5-2.3)	1.9 (1.5-2.3)	Sex, witnessed arrest, VF, endotracheal intubation, and entire EMS dispatch-to-arrival time
Survival-to-hospital admission	271/1799 (15.1)	145/661 (21.9)	1.6 (1.3-2.0)	1.5 (1.2-2.0)	Age, sex, bystander CPR performed, witnessed arrest, VF, endotracheal intubation, and entire EMS dispatch-to-arrival time

Abbreviations: CI, confidence interval; CPR, cardiopulmonary resuscitation; EMS, emergency medical services; MICR, minimally interrupted cardiac resuscitation; VF, ventricular fibrillation.
[a] Initial model included age, sex, location of cardiac arrest, bystander CPR performed, witnessed arrest, VF, endotracheal intubation, and entire EMS dispatch-to-arrival time. The final model included only significant covariates, as indicated.

rural setting who had witnessed out-of-hospital cardiac arrest and a shockable rhythm after EMS implementation of cardiocerebral resuscitation. We found a similar magnitude of improvement in survival in a metropolitan setting.

In the before and after analysis, 61.1% of the resuscitations after MICR training met all 4 compliance criteria. EMS personnel received only 1 training session in MICR. Perhaps survival rates would have been even better with more training, retraining, and feedback, resulting in higher MICR compliance rates. In the protocol compliance analysis, we analyzed data from 2 fire departments in metropolitan cities and 60 additional Arizona fire departments and compared outcomes of patients who actually received MICR with those who did not receive MICR. In this latter analysis, overall survival was 3.8% in patients not receiving MICR vs 9.1% in patients receiving MICR, with approximately 80% of survivors in both groups having favorable neurological outcomes.

Why should MICR be associated with improved outcomes after out-of-hospital cardiac arrest? One major contributor to the poor survival rates of patients with out-of-hospital cardiac arrest is prolonged inadequate myocardial and cerebral perfusion. During resuscitation efforts, the forward blood flow produced by chest compressions is so mar-ginal that any interruption of chest compressions is extremely deleterious, especially for favorable neurological outcomes.[20-22] Excessive interruptions of chest compressions by prehospital personnel are common.[23,24] Therefore, MICR emphasizes uninterrupted chest compressions.[11,12]

A second contributor to suboptimal survival of adults with out-of-hospital cardiac arrest is that defibrillation is typically provided after 5 or more minutes of VF cardiac arrest, the "circulatory" phase of VF arrest[25] when preshock and/or postshock myocardial perfusion are necessary for attaining return of spontaneous circulation.[26,27] Prolonged VF (the circulatory phase) is different from short-duration VF in regard to myocardial bioenergetics, cellular electrophysiology, whole-organ myocardial electrophysiology, and response to therapy.[13-15,18,19,22,28] Substantial, progressive depletion of myocardial high-energy phosphates occur during prolonged VF.[19,22] Moreover, characteristic changes occur in the VF waveform during prolonged VF from a coarse waveform initially to a fine waveform over time. As the duration of VF increases and the waveform becomes fine, defibrillation into a perfusing rhythm is less likely. Experimental and clinical studies indicate that preshock chest compressions for prolonged VF can

Table 6. Cerebral Performance Category (CPC) Scores Among Survivors[a]

CPC Score	Did Not Receive MICR (n = 69)	Received MICR (n = 60)
1	20 (40.8)	18 (51.4)
2	20 (40.8)	10 (28.6)
3	7 (14.3)	7 (20.0)
4	2 (4.1)	0
5	0	0

Abbreviation: MICR, minimally interrupted cardiac resuscitation.
[a] See "Methods" section for explanation of CPC scores 1 through 5. Some participants were missing a CPC score (20 who did not receive MICR and 25 who received MICR).

"coarsen" the VF waveform and improve the rate of successful resuscitation.[1,13-16,20,21] Furthermore, a recent clinical investigation demonstrated that even 10- to 20-second pauses in preshock compressions decrease defibrillation success.[23] Preshock and postshock immediate uninterrupted chest compressions are emphasized with MICR.[11,12,14]

A third potential contributor is that stacked or 3 sequential shocks[1] with an automated external defibrillator increase the "hands-off" time due to repeated automated rhythm analyses and shock advisories, thereby leading to inadequate myocardial and cerebral perfusion during this circulatory phase of VF cardiac arrest. Therefore, single shocks are used in MICR.[11,12,14]

A fourth potential contributor to the poor survival of patients with out-of-hospital cardiac arrest who are treated

with standard cardiopulmonary resuscitation and advanced cardiac life support is that positive pressure ventilations during cardiac arrest may be harmful because they increase intrathoracic pressure, thereby decreasing venous return and subsequent myocardial and cerebral blood flow.[29] Probably due to the excitement and stress of resuscitation efforts, excessive ventilations by both physicians and EMS personnel are common.[29,30] Positive pressure ventilations are discouraged with MICR in the crucial early resuscitation period.[14,18,31]

Although endotracheal intubation was discouraged in the after MICR training group until after 3 cycles of shocks in the before and after analysis and was not permitted before completion of 3 cycles of shocks for inclusion as MICR in the protocol compliance analysis, more patients overall in the after MICR training group in the before and after analysis and in the MICR group in the protocol compliance analysis received endotracheal intubation. This apparent anomaly presumably occurred because the EMS protocol initiated with MICR training specifically included endotracheal intubation for all unresponsive patients before arrival at an emergency department.

The MICR approach may seem to downplay the importance of oxygen uptake from the lungs and delivery to the tissues. In fact, adequate tissue oxygen delivery is critically important for survival from a cardiac arrest, and chest compressions without rescue breaths can provide adequate oxygen delivery.[21,32,33] Immediately after a sudden VF cardiac arrest, aortic oxygen and carbon dioxide concentrations do not vary from the prearrest state because there is no blood flow and oxygen consumption is minimal. Therefore, when chest compressions are initiated, the blood flowing from the aorta to the coronary and cerebral circulations provides adequate oxygenation at an acceptable pH. At that time, myocardial oxygen delivery is limited more by blood flow than oxygen content. Adequate oxygenation and ventilation can continue without rescue

breathing because the lungs serve as a reservoir of oxygen that allows adequate oxygen exchange with the limited pulmonary blood flow during cardiopulmonary resuscitation (only approximately 10%-15% of pulmonary blood flow during normal sinus rhythm). In addition, substantial ventilation occurs from chest compression–induced gas exchange (ie, small volumes exhaled with each compression and inhaled with chest recoil) and spontaneous gasping by the patient in cardiac arrest during cardiopulmonary resuscitation.[32,33]

Despite increases in survival-to-hospital discharge, there was no demonstrable difference in rates of return of spontaneous circulation or survival-to-hospital admission between the before MICR training and after MICR training periods. This observation is important because it is not uncommon for studies of out-of-hospital cardiac arrest to use the intermediate outcome of return of spontaneous circulation or hospital admission as an end point.

In our before and after analysis, 16% of both groups survived to hospital admission, and yet survival to discharge was significantly greater in the after MICR training group. This finding suggests that initial cardiac resuscitation occurs in an equal percentage of patients receiving and not receiving MICR. However, our data also suggest that MICR provides perfusion sufficient for longer-term survival. Similar findings were observed in the protocol compliance analysis assessment of outcomes for patients who actually received MICR vs those who did not receive MICR.

The limitations of our observational study include the fact that the MICR intervention was not tested in a randomized controlled trial. We encourage others to conduct randomized controlled trials to confirm these results. However, an observational approach has been used effectively during the past few decades to advance resuscitation science, and this method will probably continue to be a major contributor to future advances in resuscitation.[34] The before and after observational design was intended to minimize

selection bias by assessing the same population in the same 2 cities treated by the same fire departments and with the same hospitals before and after implementing MICR instruction. Also, our patient populations were similar in the before MICR and after MICR training periods. It is possible that other factors, such as postresuscitation care, changed during the study period. However, none of the patients in the before and after analysis or the protocol compliance analysis received in-hospital therapeutic hypothermia. Furthermore, the protocol compliance analysis was consistent with the before and after analysis despite the ongoing inclusion of many patients who did not have MICR in the last year of the protocol compliance analysis study (2007).

We cannot exclude the possibility that the MICR training in the 12 fire departments motivated EMS personnel to provide better care independent of the specific MICR protocol (ie, the Hawthorne effect). However, none of the periodic changes in EMS protocols associated with new cardiopulmonary resuscitation and advanced cardiac life support guidelines during the past few decades has resulted in such a dramatic improvement in survival of patients with witnessed out-of-hospital cardiac arrest.

Another limitation of our study is that we compared MICR with the approach used by fire departments in our community during a time period when the AHA Guidelines were updated. Therefore, some of the non-MICR fire departments were following the 2000 AHA Guidelines while others were following the 2005 AHA Guidelines. The study by Rea et al[35] demonstrated that instituting some of the major changes of the 2005 guidelines for advanced cardiac life support (single shock and 200 chest compressions immediately after the shock rather than stacked shocks) was associated with increased survival-to-hospital discharge. A single shock followed by 200 uninterrupted chest compressions rather than stacked shocks is an important component of MICR.[12]

Outcome data are unknown for 2 patients in the before and after analysis

(1 in the before MICR training group and 1 in the after MICR training group) and for 7 patients in the protocol compliance analysis (6 in the did not receive MICR group and 1 in the received MICR group). Neurological outcomes are unknown in 35% of the survivors in the protocol compliance analysis. Nevertheless, the missing data are evenly distributed among the study groups, and we have no reason to believe that this represents a systematic bias.

In the protocol compliance analysis, we compared outcomes between patients who actually received MICR and those who had not to extend our observations to a larger population. We cannot exclude ascertainment biases in this analysis. Perhaps the most enthusiastic and skilled EMS personnel provided MICR and the least enthusiastic or least skilled EMS personnel did not. Furthermore, EMS personnel may have preferentially provided MICR to the patients most likely to survive. Nevertheless, our findings in the protocol compliance analysis were consistent with the data in the before and after analysis.

CONCLUSION

In this study, survival-to-hospital discharge of patients with an out-of-hospital cardiac arrest improved significantly after implementation of MICR as an alternate EMS protocol. These findings require confirmation in randomized trials.

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