Weisfeldt and Becker theorize the existence of 3 physiological phases of resuscitation: electrical, circulatory, and metabolic. When cardiac arrest occurs because of ventricular fibrillation (VF), myocardial adenosine triphosphate (ATP) levels begin to fall as fibrillating myocardial cells continue to consume ATP at a nearly normal rate. During this first 3 to 4 minutes (electrical phase), prompt defibrillation is often all that is required to restore circulation. Soon thereafter, myocardial ATP stores drop to critical levels, and a defibrillation shock will usually terminate ventricular fibrillation, but this frequently results in either asystole or pulseless electrical activity as cells run out of high-energy phosphate fuel. During this circulatory phase, a brief (90 s to 3 minutes) period of effective chest compression before defibrillation can boost myocardial ATP stores and increase the likelihood that a perfusing rhythm will result after a defibrillation shock. If the patient remains in cardiac arrest for >8 to 10 minutes, increased cellular ischemic injury develops. Weisfeldt and Becker term this the “metabolic phase” of resuscitation, indicating that additional cellular protective measures will likely be needed to restore vital organ function. Thus, the strategic paradigm for resuscitating VF cardiac arrest victims has evolved from “shock first and then CPR” to a time-critical, orchestrated ballet of high-quality cardiopulmonary resuscitation (CPR), defibrillation, and postresuscitation care.

This new paradigm highlights the importance of high-quality, minimally interrupted CPR to maximize tissue oxygen delivery and intracardiac high-energy phosphate levels. Conventional closed-chest CPR is, at best, imperfect, producing hemodynamic changes similar to those seen in cardiogenic shock, with low systemic arterial pressure, markedly reduced cardiac output, and high left ventricular filling pressure. Minimal interruption of chest compression during resuscitation helps to maximize tissue oxygen delivery and myocardial high-energy phosphate levels. Cardiac output during CPR is, after all, dependent on the stroke volume of each chest compression multiplied by the number of compressions per minute. Aufderheide et al have shown that both high-quality chest compression (adequate depth, force, and duration) and complete chest wall decompression are needed to maximize stroke volume and improve venous filling during the upstroke. An act as simple as not allowing the chest to recoil completely between compressions increases intrathoracic pressure progressively and decreases cardiac output.

The odds of survival increase when continuous, or nearly continuous, high-quality chest compressions are performed during resuscitation. Unfortunately, chest compressions are interrupted frequently during clinical resuscitation, particularly if automated external defibrillators are used, resulting in relatively few effective compressions per minute. Shortening the hands-off time interval from the last chest compression until defibrillation increases the likelihood that a shock will be followed by return of spontaneous circulation by minimizing the decay of myocardial ATP levels after the last chest compression. Recent evidence suggests that hyperventilation may be harmful during resuscitation because it increases intrathoracic pressure, causing a marked decrease in venous filling. Paradoxically, this reduces cardiac output and tissue oxygen delivery.

These parameters—adequate depth, force, and duration of chest compression; complete chest wall decompression during the upstroke; minimally interrupted chest compression at a rate of approximately 100 per minute; avoidance of hyperventilation—are now being referred to collectively as “quality of CPR,” but they really represent both the quality and quantity of CPR. Increasing evidence suggests that attention to these details can affect survival significantly.

Abella et al used a monitor/defibrillator with additional sensing capabilities to measure CPR quality (chest-compression rate and depth, ventilation rate, and the fraction of arrest time without chest compressions) during resuscitation in 67 patients who experienced in-hospital cardiac arrest at the University of Chicago Hospitals. Chest-compression rates were <90 per minute in 28.1% of 30-s CPR segments during the first 5 minutes of resuscitation. Compression depth was too shallow (<38 mm in 37.4% of compressions), ventilation rates were too high (60.9% of segments containing a rate of >20 per minute), and no chest compressions were performed for 24% of the resuscitation period. The authors concluded that the quality of CPR was inconsistent and that it often did not meet published guideline recommendations, even when performed by well-trained hospital staff. In a follow-up study, the same authors developed and validated a handheld recording device to measure chest-compression rate as a surrogate for CPR quality in three different hospitals. Data were analyzed on 97 in-hospital cardiac arrest patients.
in 30-s time segments while rescuers were performing chest compressions.\textsuperscript{11} In 36.9% of the segments, compression rates were $<$80 per minute; 21.7% had rates $<$70 per minute. Higher chest-compression rates correlated significantly with initial return of spontaneous circulation (mean chest-compression rates for initial survivors and nonsurvivors were 90±17 and 79±18 cpm, respectively; $P=0.0033$). Finally, Edelson et al\textsuperscript{13} analyzed data from 60 consecutive in-hospital resuscitations in which a first shock was administered for VF. The primary outcome was first shock success, defined as removal of VF for at least 5 s after defibrillation. A logistic regression analysis demonstrated that successful defibrillation was associated with shorter preshock pauses (adjusted odds ratio of 1.86 for every 5-s decrease; 95% CI, 1.10 to 3.15) and higher mean compression depth during the 30 s of CPR preceding the preshock pause (adjusted odds ratio of 1.99 for every 5-mm increase; 95% CI, 1.08 to 3.66). Thus, chest-compression quantity and quality likely are critical determinants of survival from cardiac arrest.

The 2005 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care\textsuperscript{14,15} incorporate the CPR quality elements and principles into the latest basic and advanced cardiovascular life support recommended techniques and algorithms. Longitudinal data systems such as the American Heart Association’s National Registry of Cardiopulmonary Resuscitation can be used to determine whether these CPR quality guideline changes are associated with better patient outcomes. However, this determination will likely take time, because the majority of evidence-based guidelines that have been shown to improve quality of care generally translate into bedside clinical practice slowly and in a heterogeneous manner. For example, both the American Heart Association’s “Get with the Guidelines” program and the National Registry of Myocardial Infarction program have noted that many eligible patients are still not being treated with appropriate medical therapy, even when clinicians are provided with the data and tools needed to make optimal therapeutic choices.\textsuperscript{16,17}

Fortunately, pioneers often shine the light of progress long before the path is marked clearly for all to follow. In a study published in this issue of \textit{Circulation}, Rea et al\textsuperscript{18} tracked the outcome of bystander-witnessed, out-of-hospital cardiac arrest caused by VF before and after the emergency medical services (EMS) system of King County, Wash implemented resuscitation protocol changes that provided a single shock without rhythm reanalysis, stacked shocks, or a postdefibrillation pulse check and that extended the period of CPR from 1 to 2 minutes. The protocol changes, based on the same evolving science that drove the official AHA guidelines, were instituted by King County EMS crews almost a year before publication of the new CPR guidelines. Although the King County protocols are not identical to the more recently developed AHA CPR guidelines (eg, the CPR compression: ventilation ratio was kept at 15:2 in King County, whereas the new AHA guidelines recommend a 30:2 ratio), they share a remarkable similarity, and both place a strong emphasis on CPR quality. Because of this, the statistically significant ($P<0.008$) and clinically important improvement (from 33% to 46%) in survival to hospital discharge for witnessed, out-of-hospital, VF cardiac arrest cases is an encouraging sign that the newest CPR guidelines are moving the field in an appropriate direction.

There is an even more important lesson in this report—in the era of randomized clinical trials, useful insight can still emerge from registry data and conservatively analyzed “before and after” case series data. Given the difficulties in execution and significant cost of randomized controlled clinical resuscitation trials, there would likely be little clinical advancement in the field if every possible intervention were held to a standard of “level I” evidence before adoption. The issues become even more complicated when the variable being tested is a provider-dependent process rather than a discrete therapeutic intervention.

Once again, our colleagues from the greater Seattle area have affirmed the importance of longitudinal public health community surveillance in tracking our progress in rescuing patients from the clutches of sudden, unexpected death from VF. Since 1976, Seattle and its surrounding King County, Wash have maintained an ongoing registry containing every EMS-treated cardiac arrest patient. This unique tool provides data for the continuous quality-improvement initiative that has allowed the Seattle/King County EMS systems to set the prehospital resuscitation gold standard for decades. Longitudinal registry surveillance of out-of-hospital cardiac arrest cases can accurately define the process of care delivery and can monitor the relationship of such a process to patient outcome. However, one cannot generalize results from this fine system to estimate nationwide progress in salvaging out-of-hospital sudden-death victims, because EMS systems vary widely in their design, staffing, protocols, and capability. For an enormous public health problem such as sudden cardiac death, which claims the lives of hundreds of thousands of Americans each year, we need a nationwide public health surveillance system just like we have for cancer.

The AHA’s National Registry of Cardiopulmonary Resuscitation is a valuable resource for tracking in-hospital cardiac arrest cases that occur in the several hundred hospitals participating voluntarily in this registry.\textsuperscript{19} Data from National Registry of Cardiopulmonary Resuscitation is used on a local participant level to improve the process of care delivered to hospitalized patients who suffer a cardiac arrest, and aggregate data are used to drive both the science and practice of in-hospital resuscitation. Out-of-hospital resuscitation practices need a similar national registry that uses standardized data elements and operational definitions. In the last decade, the National Highway Traffic Safety Administration has established a uniform prehospital EMS dataset.\textsuperscript{20} However, only 43 states currently participate in this program, and only 8 (10%) of the 81 uniform data elements are collected by all 43 participating states.\textsuperscript{20}

In 2004, the National Institutes of Health/National Heart Lung and Blood Institute, in partnership with the Institute of Circulatory and Respiratory Health of the Canadian Institutes of Health Research and other government and nongovernment funding partners (the US Army Medical Research and Materiel Command, the National Institute of Neurological Disorders and Stroke, Defense Research and Development Canada, and the Heart and Stroke Foundation of Canada),
established the Resuscitation Outcomes Consortium, the first large-scale, government-sponsored effort to conduct clinical trials in sudden cardiac arrest and severe traumatic injury, focusing on the very early delivery of interventions by EMS teams in the field, where optimal potential exists for patient benefit. Most recently, the AHA and Canadian Institutes of Health Research added support to develop an ongoing cardiac arrest registry in the 10 regional clinical centers representing 11 distinct geographic regions in the United States and Canada. Although the Resuscitation Outcomes Consortium’s cardiac arrest registry is the largest of its kind in North America, comprising 268 EMS and fire agencies covering 35,000 square miles and serving almost 24 million people, it is not a random sample of the United States and Canada, and thus it can be used only to track secular trends in participating regions. Thus, despite the progress that has occurred to provide some monitoring of out-of-hospital resuscitation outcomes nationally, an urgent need still exists for a broad-based, public health surveillance cardiac arrest registry.

The Centers for Disease Control and Prevention/Cardiovascular Health Branch’s leadership recognize this need and have expressed concern that no national, state-level database exists for tracking the Department of Health and Human Services’ Health People 2010 objectives relating to cardiac arrest (objectives 12-3, 12-4, and 12-5). The Centers for Disease Control and Prevention proposes establishing a national registry that would track the care and outcome of cardiac arrest victims (particularly those cases occurring out of hospital) similar to that implemented at the state level by the Paul Coverdell National Acute Stroke Registry of the Centers for Disease Control and Prevention. Such a registry is long overdue; its creation will require the leadership and support of many national and state medical organizations and societies with a keen interest in cardiovascular health, as well as a governmental mandate and funding. The Centers for Disease Control and Prevention is the appropriate home for such a registry because its public health surveillance mission affords it the lawful right to request and collect data from EMS agencies, hospitals, and other healthcare entities. For the moment, until such a national registry becomes a reality, we must continue to rely on the important public health surveillance efforts of Seattle/King County, the National Registry of Cardiopulmonary Resuscitation, and the Resuscitation Outcomes Consortium. However, for the future, it is clear that we need a better tool to measure our progress in resuscitation science.

Disclosures

Dr Ornato is a consultant for the National Registry of CPR and the Resuscitation Outcomes Consortium. Dr Peberdy is a consultant for the National Registry of CPR.

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