BRIEF REVIEW

Determinants of successful defibrillation

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Ventricular defibrillation by electric counter shock is the definitive treatment for cardiac arrest due to ventricular fibrillation (VF). Ventricular defibrillation is the fundamental cornerstone to a successful outcome. As most deaths from VF occur out of hospital, often in patients without pre-existent recognised cardiac disease, the major public health issue remains the widespread application of external defibrillation. This article therefore concentrates exclusively on transthoracic counter shock, while recognising clinically relevant recent developments in internal defibrillation that are applicable to a small proportion of the total population at risk.

Electrical defibrillation occurs when a sufficient mass of excitable cells is simultaneously depolarised by an adequate intracardiac current,¹ thereby extinguishing activation fronts within a critical myocardial mass. A threshold current density must be attained within the myocardium to achieve defibrillation. The electrical circuit formed during defibrillation includes impedance of two electrode-electrolyte-tissue interfaces and of the intervening tissues. The main determinants of intracardiac current flow during electric counter shock are the energy selected and transthoracic impedance (TTI) of the patient. The development of methods to predict TTI in advance of a defibrillatory counter shock² has been a significant aid, enabling novel techniques for defibrillation to emerge and closer examination of factors involved in determining the success or failure of counter shocks.

Early defibrillation

Early defibrillation is one, if not the major, priority of the new global guidelines recently reported in the advisory statements of the International Liaison Committee on Resuscitation.³

The fundamental importance of early defibrillation as a major predictor of outcome in patients with VF has been known since portable direct current defibrillators were introduced in the 1960s. This clinical observation drove hardware development leading to the manufacture of automatic external defibrillators that are commercially available today, which themselves were dependent on the development of self adhesive electrocardiograph (ECG) defibrillator pads⁴ for easy use by minimally trained personnel during cardiac arrest.

Other approaches have included the use of telemedicine technology. Transtelephonic control of defibrillation using standard telephone land lines was shown to be effective in 1988,⁵ and later extended to use with a cellular device.⁶ Transtelephonic defibrillation in patients with collapse out of hospital due to VF provides defibrillation more rapidly, and offers control and performance of defibrillation by remotely sited trained hospital personnel.

In 1993 the American Heart Association Task Force on Automatic External Defibrillation was asked to consider how access to defibrillation might be achieved more rapidly in patients facing sudden cardiac death. The report from the first public access defibrillation conference⁷ highlighted the challenge of producing lightweight, inexpensive, small, easy to use, durable, maintenance free devices. In the United States, less than 50% of emergency medical technicians and only 20% of public safety personnel are adequately prepared to treat sudden cardiac death. Only 41% of emergency medical technicians are equipped with automatic external defibrillators. The second public access defibrillation conference emphasised the components of public access defibrillation and steps already taken, including broadening the range of people who can act as first responders.⁸ American legislation (the Cardiac Arrest Survival Act) is being introduced in an attempt to pave the way for universal access to emergency cardiac care.

New techniques

Clinical needs drive the design of new devices. Recent research has identified areas of defibrillator design that may be of benefit if incorporated into mainstream commercially available devices. One example is current based defibrillation. Use of a fixed energy level during defibrillation results in a variable range of generated transthoracic currents, as TTI varies significantly between patients. A microprocessor controlled current based defibrillator automatically measures TTI and calculates the energy required to develop a selected current. This system enables rapid delivery of an accurately calibrated preselected transthoracic current to patients with VF.⁹ This device was as effective as conventional defibrillators using a fixed energy protocol, but was superior in delivering less energy and current per shock.

Research in internal defibrillation has confirmed the superior efficacy of different waveforms for ventricular defibrillation.¹⁰ The

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biphasic waveform produces experimentally lower defibrillation thresholds than the commonly employed monophasic waveform for transthoracic defibrillation.¹¹ Superior efficacy with biphasic waveforms was reported in the recently published multicentre, prospective, randomised comparison of monophasic (Edmark) versus biphasic (Gurvich) waveforms for transthoracic cardioversion/defibrillation of patients in the electrophysiology laboratory.¹² Patients were randomised in a blinded fashion to receive either a monophasic or biphasic waveform for the initial shock conversion of induced VF, monomorphic ventricular tachycardia, polymorphic ventricular tachycardia, or ventricular flutter. Delivered energies for the Edmark and Gurvich waveforms were 215 and 171 J, respectively. The first shock for all arrhythmias was successful in 85.2% of patients with monophasic waveforms compared with 97.6% with biphasic waveforms. There was also a higher first shock success rate for patients with VF (78.6% *v* 100%), which was achieved at a significantly lower energy level than with the monophasic waveform. Interestingly, average patient impedance was 81 Ω , higher than in other studies, and ascribed to the use of self adhesive electrodes.

Many mechanisms have been postulated to explain the lower defibrillation thresholds with biphasic waveforms. Blanchard and Ideker¹³ have extensively discussed these mechanisms. One mechanism suggests that lower impedance in the second phase of biphasic shock aids current flow during reversed polarity in the second phase. Other mechanisms include: the ability to stimulate myocardium, detrimental effects in regions of high potential gradient, effects on sodium channels, and the induction of new action potentials or a prolongation of the refractory period. While a few mechanisms may be incorrect, several others may together contribute to the general superiority of the biphasic waveform. The beneficial effect of the second phase of the biphasic waveform may possibly arise from rapid restoration of the transmembrane potential to a level close to that which existed just before the shock, rather than from changing the transmembrane potential to a value of opposite sign to that caused by the first phase.

Research continues into other waveforms and shock pathways such as triphasic, sequential pulse, double pulse, and overlapping pulses. For example, Kerber and colleagues¹⁴ showed in a canine model that sequential overlapping pulse shock waveforms facilitate defibrillation compared with single pulse shocks of the same total energy. This finding may arise from, at least in part, the changing orientation of the electrical vector during multiple pulse shock and directional sensitivity of myocytes to electric field stimulation.

These developments enabling defibrillation with less energy may permit future reductions in defibrillator cost, size, and weight.

Electrodes and patient related factors

Electrodes and the patient-electrode interface are critical for successful defibrillation. Inap-

propriate electrode placement is the most frequently encountered error in the use of automatic external defibrillators. The increasingly widespread use of self adhesive ECG defibrillator pads is the result of the high quality ECG signal for monitoring during cardiac arrest, adhesive qualities ensuring consistently accurate electrode placement, increased operator safety, less artefact, and quicker delivery of shocks.¹⁵ Their development was an essential step for the development and use of automatic external defibrillators by minimally trained personnel. However, whether their performance is equivalent to that of hand held paddles remains doubtful.

The relation between electrode size and TTI was confirmed using three different combinations of electrode pad size in patients with VF.¹⁶ As the combined electrode area increased then TTI decreased, accompanied by improved success rates for first and cumulative shocks. While this was a recognised phenomenon with hand held paddles, these results suggested for the first time in humans that even larger self adhesive electrodes may be of benefit. Optimal electrode size and shape remain to be determined.

What percentage of transthoracic current during defibrillation traverses the heart? Lerman and Deale¹⁷ have suggested that as little as 4% may reach the myocardium. This relatively small percentage is a result of parallel pathways such as those in the thoracic cage and lungs which shunt current around the heart. However, considerable variability in current percentage was reported, ranging between 1% and 10%. This variation may be explained by different thoracic geometry, which may, along with relative resistance per unit length (resistivities) of thoracic tissues, determine current flow in the thoracic volume conductor.¹⁷

Individual patient related factors are important. There is a strong correlation between TTI and body composition as expressed by body mass index, percentage body fat, and skinfold thickness.¹⁸ This relation is likely to be related to the high resistivity of fat tissue, as that between TTI and weight alone is not as strong. Other anthropometric factors significantly related to TTI include geometry of the chest as measured by chest circumference.¹⁸

Electrode position is clearly important and placement difficulties can occur, particularly with women. Pagen-Carlo and colleagues¹⁹ studied the effect of breast tissue on TTI in women who did not receive a shock. Placement of the apical electrode on the breast resulted in significantly higher impedance; the increase was related to breast size. Fat has a high resistivity. In women the apical electrode should be placed under, or lateral to the breast.

The most convenient electrode position for defibrillation in a collapsed patient is the standard anteroapical position. Other electrode positions for cardioversion of atrial arrhythmias, such as anteroposterior, are not appropriate in the management of cardiac arrest when cardiopulmonary resuscitation is ongoing, and are not associated with any meaningful reduction in TTI as had previously been thought.²⁰

The clinical situation may also determine an individual's responsiveness to electric counter shock. The duration of sustained ventricular arrhythmias in patients with out-of-hospital cardiac arrest is obviously very different from the duration of VF in patients in the electrophysiology laboratory, who are frequently participants for defibrillation studies. Weaver *et al* estimated a delay of 10.6 minutes between collapse and first shock.²¹ Yakaitis *et al* reported a decrease in successful defibrillation with increasing duration of arrhythmia.²² Moreover, the pathophysiological milieu in which the VF occurs out of hospital, such as ischaemia, infarction, or heart failure, may itself adversely effect successful defibrillation.

We have reported that patients with cardiac arrest have a significantly higher TTI than patients undergoing elective cardioversion.²³ Possible mechanisms may include the effect of hypoxia increasing cell resistivity of ventricular myocardium,²⁴ increased resistance of ventricular myocardium with ischaemia,²⁵ and reduced skin blood flow. This hypothesis was challenged by Kerber *et al* who conducted an experiment in seven dogs, which have a greatly different chest wall shape (than human chest wall), a determinant of TTI itself.²⁶ The dogs with anatomically normal hearts were ventilated and oxygenated to maintain arterial blood gases in the physiological range, although ventilation was discontinued in five dogs at induction of VF in an attempt to mimic human cardiac arrest. The relevance of this model to the management of human cardiac arrest is questionable. More relevant data, supporting our observations, come from a prospective randomised trial of monophasic and biphasic waveforms for cardioversion/defibrillation of induced ventricular arrhythmias in the electrophysiology laboratory.¹¹ The average patient impedance was 81 (20) Ω ("slightly higher than in other studies"), an observation that the authors thought possibly because self adhesive electrode pads were used, although the electrode area was not quoted in the study.

More direct evidence supporting a high TTI in patients with out-of-hospital cardiac arrest was recently presented at the 70th scientific sessions of the American Heart Association. White and Gliner²⁷ reported their use of an automatic external defibrillator to deliver 150 J biphasic shocks to 21 out-of-hospital patients with VF. A mean TTI of 93 Ω was recorded, and seven patients had a TTI of more than 100 Ω , data which are consistent with our own findings.²³

Improved survival rates for patients experiencing out-of-hospital cardiac arrest may possibly result from external defibrillators becoming less expensive, smaller, lighter, more portable, and therefore more widely available. It is vital, however, that there is a greater understanding of waveforms, efficacy, and mechanisms of defibrillation. It remains to be

proved that lower energy defibrillation, even with biphasic waveforms, is as effective for out-of-hospital defibrillation of VF as current conventional treatment.

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