Chapter 6.1
Lessons for the Clinical Implant*

Mark W. Kroll and Charles D. Swerdlow

Our goal in this chapter is to provide a practical review for clinicians of how our understanding of defibrillation scientific results can help with their clinical practice. Some of the typical implant practices are found to be driven by dogma and not by science.

Electrical Parameters of Defibrillation Waveforms

Parameters that Influence Defibrillation

Although no simple electrical descriptor provides a good measure of defibrillation efficacy, the waveform parameters that most directly influence defibrillation are voltage and duration. Voltage is a critical parameter for defibrillation because its spatial derivative defines the electrical field that interacts with the heart (Fig. 1). Similarly, waveform duration is a critical parameter because the shock interacts with the heart for the duration of the waveform. Further, the heart’s response to a defibrillation pulse occurs over a period that depends on the time constants of the cardiac cell membrane and possibly on other ionic, intracellular, cellular, and tissue properties. Implantable cardioverter-defibrillator (ICD) waveforms are most efficient when their phase durations are close to that of cardiac cell membrane time constants.1–5 Thus the electrical measure of defibrillation that is most relevant physiologically is voltage (or voltage gradient) as a function of time.

Parameters that Influence ICD Design

Shock energy is the most often cited metric of shock strength and an ICD’s capacity to defibrillate, but it is not a direct measure of shock effectiveness. For example, the maximum

Mark W. Kroll
Department of Biomedical Engineering, University of Minnesota, Minneapolis, MN, USA, mark@krolls.org

* Portions of this chapter have previously appeared in Kroll MW, Swerdlow CD. Optimizing defibrillation waveforms for ICDs. J Interv Card Electrophysiol 2007;18(3):247–263 and are used with permission of the publisher.

I. R. Efimov et al. (eds.), Cardiac Bioelectric Therapy: Mechanisms and Practical Implications.
© Springer Science+Business Media, LLC 2009

459
The shock potential with respect to the right hand electrode (a) and the spatial derivative or electric field (b). The thick vertical bars symbolize electrodes and the oval the heart. Note that most of the voltage drop and hence the highest fields occurs close to the electrodes.

The shock strength of an ICD is typically in the range of 30 to 40 J. If energy were a good descriptor of defibrillation efficacy, one could defibrillate with a 9 V battery by connecting it to the heart for 20 s through large defibrillation electrodes to deliver 40 J:

$$\text{Energy} = \frac{\text{Voltage}^2 \times \text{Time}}{\text{Resistance}} = \frac{9 \text{ V} \times 9 \text{ V} \times 20 \text{ s}}{40 \Omega} = 40.5 \text{ J.}$$

Although a 9 V battery may reliably induce fibrillation, it will never defibrillate.

However, the maximum energy stored in an ICD’s output capacitor is a major determinant of the size of the battery and capacitor and thus of the overall size of the ICD’s pulse generator. Since minimizing ICD size is an important clinical goal, designing ICDs that defibrillate with minimum stored energy is an important engineering goal.