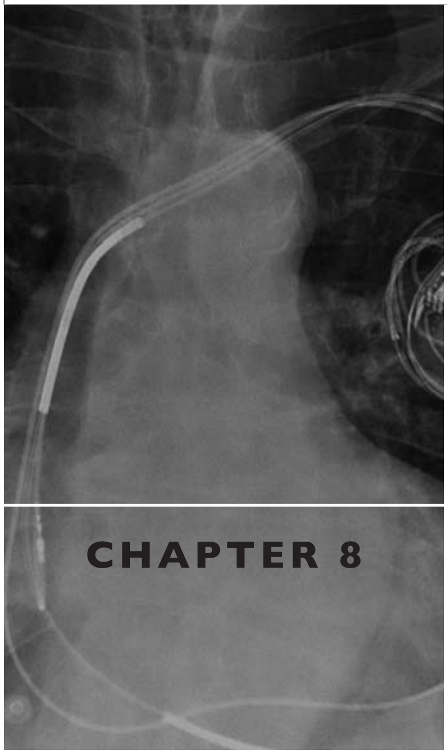

CHAPTER 8

Automatic Threshold Measuring Algorithms

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Introduction

The ability of pacemakers to reliably and automatically assess whether or not pacing stimuli result in successful myocardial capture and depolarization has been a goal since the initial use of implantable devices. The primary clinical goals of automatic verification of capture (AVC) are to conserve battery life by allowing lower pacing outputs to be programmed over the long term, provide immediate backup pacing at high output if failure to capture is detected, and to achieve the safety of maintaining capture. With AVC, a pacemaker is able to periodically assess for changes in thresholds and to automatically adjust pacing output slightly above threshold as opposed to a traditional two-fold safety margin. There are several methods of AVC, which are discussed later.

In the immediate post-implant period and the chronic setting, thresholds may change for a variety of reasons. With older leads, pacing thresholds would rise dramatically over the course of 2 to 8 weeks during lead maturation, as the inflammatory and fibrotic process that followed lead implantation evolved. The maturation process with modern drug-eluting leads is faster and has a less pronounced effect on threshold. Most leads reach steady-state threshold values by 10 weeks. There are, however, a number of medications and disease conditions that can contribute to a rise in myocardial thresholds. Chronic amiodarone use leads to a modest rise in ventricular threshold of, on average, approximately 1 Volt. However, class Ia and Ic antiarrhythmic agents such as propafenone and flecainide[1] can cause up to a two-fold rise in thresholds. Conditions that cause myocardial remodeling, such as diffuse cardiomyopathy or focal myocardial infarction, can also lead to large increases in myocardial thresholds. Sudden spikes in thresholds during acute illnesses,

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Pacemakers and Implantable Cardioverter Defibrillators: An Expert's Manual. © 2010 Amin Al-Ahmad, Kenneth A. Ellenbogen, Andrea Natale, and Paul J. Wang, eds. Cardiotext Publishing, ISBN: 978-0-9790164-6-2.

particularly in epicardial leads, have also been reported and can lead to failure to capture.[2]

Because of threshold fluctuation after lead maturation, a safety margin has traditionally been used to ensure that relatively small rises in thresholds will not lead to loss of myocardial capture. Traditionally, this output safety window was empirically programmed at least twice the threshold voltage, or three times the threshold pulse width. The disadvantage of this excess output energy is a faster rate of battery depletion. One purpose of AVC is that by automatically assessing thresholds on a regular basis, output can be safely maintained at a marginal level above threshold with emergency backup pacing if needed. Saving battery life allows for greater time between generator changes and further miniaturization of devices with smaller batteries.

Automatic Verification of Capture Techniques

The idea that the pacemaker itself could assess whether or not it successfully depolarized the myocardium after delivering a pacing stimulus was first introduced in the early 1970s.[3,4] It was not until 1994 that Pacesetter, later acquired by St. Jude Medical, introduced AutoCapture, the first clinically available AVC algorithm. Today, most pacemakers from the major manufacturers use one of various techniques and algorithms to automatically assess capture.

Evoked Response

The most widely used method for assessing capture automatically is the measurement of the myocardial evoked response (ER). After a pacing stimulus is delivered, positively charged ions cover the negatively charged pole of the lead and result in local lead-myocardial polarization, regardless of myocardial capture (Fig 8.1A). These ions then disperse at varying rates, depending on the makeup of the lead. Polarization results in a deflection that is sensed immediately after the pacing stimulus. This signal usually decays over the course of 10 to 15 ms (Fig 8.1B). ER is the deflection that represents true myocardial depolarization and is usually sensed over the first 60 ms following the pacing stimulus. The critical factor for most AVC is distinguishing ER from polarization signals (Fig 8.1C). Polarization, however, can be of high amplitude and prolonged, thereby obscuring the ER.

To better distinguish the ER from polarization, several techniques, both software- and hardware-based, have been developed. A blanking window of about 15 ms immediately after the pacing stimulus (Fig 8.1C) is programmed to ignore most of the post-pacing stimulation local polarization signal, while the period between 20 ms and 100 ms is usually programmed to detect the myocardial ER. Another technique often used is to create an independent pace/sense (IPS) configuration. For example, pacing is programmed unipolar (tip to can), whereas sensing is programmed bipolar (tip to ring).[5] However, IPS requires the use of bipolar leads and increases the risk of far-field sensing in other chambers. The use of low-polarization leads is a technologic advance that has made ER detection more feasible. Most of the newer leads are coated with titanium-nitrite, which helps minimize the polarization artifact.

Another method for improving ER detection is the adjustment of the pacing output circuitry with reduced coupling capacitor (RCC) technology which can produce a faster decay of the polarization artifact.[6] However, this technique is limited by a relatively low maximum voltage output that can be used. An additional strategy is to improve signal-to-noise ratio by subtracting the polarization signal from the paced ER. To accomplish this, pacing during the myocardial refractory period is performed and the polarization signal is recorded. This signal is then subtracted from a subsequent paced beat and the difference is recorded as the ER.

Most devices that offer detection of AVC propose a combination of these techniques for the most accurate reading of the ER. Although some devices strictly require the use of low-polarization leads, other devices use alternative technologies such as RCC or IPS and are more

Figure 8.1 (A–C) Evoked response.

A

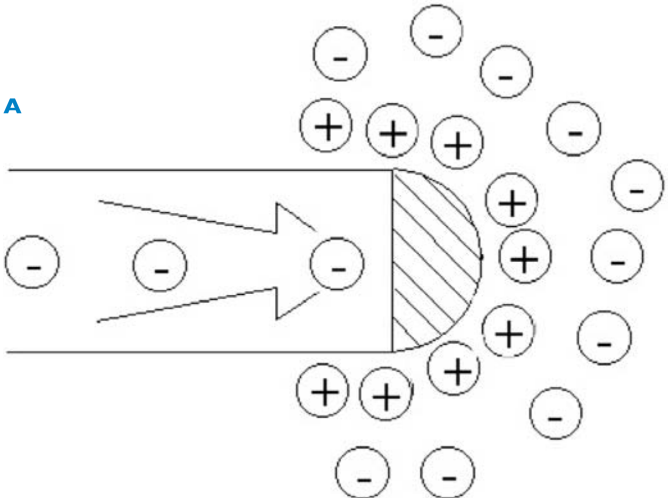

Figure 8.1A Polarized lead.
Positively charged ions surround the lead tip and produce a positively charged layer on the electrode called polarization. (Reproduced with permission of Medtronic, Inc.)

B

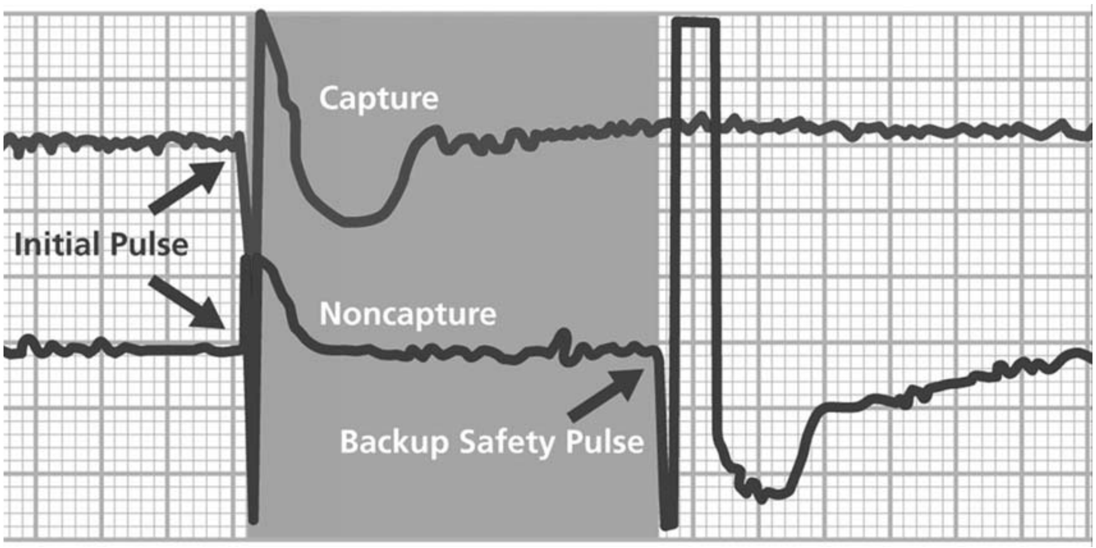

Figure 8.1B Evoked response.
The top tracing demonstrates the initial pacing pulse followed by the lead polarization signal and finally the evoked response which represents myocardial depolarization. The bottom tracing demonstrates the pacing and polarization signals without myocardial depolarization. This is then followed by a large output safety pulse. (Reprinted with permission from St. Jude.)

Figure 8.1C Detecting the evoked response.
The first 10-20 ms (closed) are usually blanked to ignore polarization. The ensuing 14-100 ms (open) are programmed to detect ER. If no ER is detected, a backup safety pulse is delivered at a fixed interval. Reprinted with permission from St. Jude.

C