Signal Averaged Electrocardiogram

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Introduction

The term “signal averaged electrocardiogram” (SAECG) encompasses any technique that results in an improvement of the signal-to-noise ratio, thus allowing analysis of signals that are too small to be detected by routine measurement. Among such signals are those arising from areas of slow and inhomogeneous conduction in diseased ventricular myocardium [usually referred to as late potentials (LPs)]. These potentials are small because the activation front is slow and fractionated, or the mass of tissue undergoing depolarization is small, or both. Late potentials are of clinical relevance because they may identify a substrate for reentrant ventricular excitation.

Important technical advances in the field of SAECG were made in the early 1980s and included the introduction and refinement of filtering techniques, the selection of bipolar orthogonal leads and their combination into a vector magnitude for maximal sensitivity, as well as the use of computer algorithms to identify QRS offset and provide numerical values for signals in the terminal part of the QRS. In 1991, a Task Force of the American College of Cardiology, the American Heart Association, and the European Society of Cardiology published standards for acquisition and analysis of LPs and attempted to define clinical indications for the SAECG. The recommended applications consisted of risk stratification for future arrhythmic events and sudden cardiac death (SCD) in survivors of myocardial infarction (MI), and prediction of malignant ventricular tachyarrhythmias in patients with coronary artery disease and syncope, or asymptomatic nonsustained ventricular tachycardia (VT). Other groups of patients with organic heart disease in whom the SAECG has been utilized for risk stratification for SCD include patients with idiopathic dilated cardiomyopathy, hypertrophic cardiomyopathy, right ventricular cardiomyopathy, etc. The original recommendations of the Task Force were updated by an American College of Cardiology Expert Consensus Document.

This chapter will review the technical aspects as well as the clinical relevance of the SAECG for risk stratification of SCD.

Technical Aspects of the Signal Averaged Electrocardiogram

Time-Domain Analysis

Electrocardiogram (ECG) data acquisition consists of several steps: proper recording, amplification, digitization, identification and alignment of the signal of interest, time-ensemble averaging, and filtering. Typically, 200–600 cardiac cycles are acquired. The QRS selection process uses a cross-correlation algorithm, where each detected QRS is compared to a preselected template. A correlation coefficient of >0.98 is typically required for a good match; this allows rejection of abnormal QRS such as ventricular premature complexes or noisy beats. Time-ensemble averaging is used because the signal of interest, i.e., the QRS, is repetitive, while much of the interfering noise (environmental noise, electromyographic noise, etc.) is random. Thus, time-ensemble averaging results in an improved signal-to-noise ratio. Filtering is also applied to reduce the residual noise and improve identification of LPs. A bidirectional
Butterworth filter has been recommended for analysis of LPs. By using this filter, the first part of the QRS is bandpass filtered, and then the second part of the QRS as well as the ST segment are filtered in reverse time, starting from the end of the data and moving toward the middle of the QRS. A bipolar orthogonal lead system is used to optimize the recording of LPs because of their unknown distribution on the body surface. The three leads are processed separately, and then combined into a vector magnitude of the form \( \sqrt{X^2 + Y^2 + Z^2} \) and used for subsequent analysis. Bandpass filtering of the SA vector magnitude may further discriminate LPs from noise. Early studies of the frequency signature of LPs showed that they contained predominantly high frequencies, and filters that eliminate low frequencies may expose LPs more clearly. Commercial SAECG systems apply bandpass filtering with a low-pass setting of 250 Hz and a high-pass setting of 25–40 Hz. Computer algorithms are utilized to identify QRS onset and offset. These algorithms depend on the signal-to-noise ratio. Once the QRS offset is defined, time-domain analysis of the SAECG mainly consists of the determination of three parameters: the duration of the filtered QRS complex (QRSD), the duration of low-amplitude signals of <40 \( \mu \)V, i.e., the time that the filtered QRS voltage remains below 40 \( \mu \)V (LAS40), and the root mean square voltage of the terminal 40 msec of the QRS (RMS40). The ad hoc Task Force recommended that for adequate LP analysis, a low noise level of <1 \( \mu \)V with a 25-Hz high-pass cutoff or <0.7 \( \mu \)V with a 40-Hz high-pass cutoff be obtained. The Task Force also recognized that the definition of an LP and the scoring of an SAECG as normal or abnormal have not been standardized. Representative criteria indicate that an LP exists (using a 40-Hz high-pass filter) when (1) QRSD is >114 msec, (2) LAS40 is >38 msec, and (3) RMS40 is <20 \( \mu \)V (Figure 23–1). Time-domain

**Figure 23–1.** Example of abnormal time-domain analysis of the SAECG. Filtered QRS duration and duration of low-amplitude signals are prolonged, while voltage of the terminal QRS is decreased, at a filter setting of 40–250 Hz. Total QRS, high-frequency QRS duration; under 40 \( \mu \)V, duration of low-amplitude signals <40 \( \mu \)V; RMS, root mean square; last 40 ms, RMS voltage of the terminal 40 msec of the QRS.