

The Conductance Catheter Technique

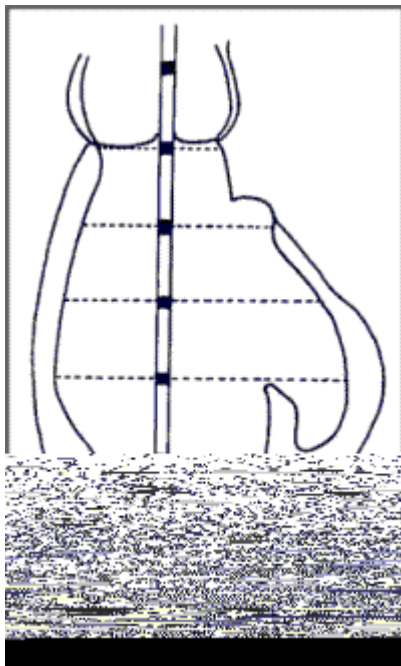
Introduction

The continuous and instantaneous measurement of left ventricular volume has been an important advancement in the assessment of ventricular function. By combining the measurement of left ventricular volume with measured left ventricular pressure, the left ventricular pressure-volume relation can be determined, and all derived parameters, which has been shown to open new possibilities to characterize the pump function of the heart, in experimental (animal) studies as well as for clinical applications.

However, the application of the pressure-volume relationship to evaluate ventricular function, especially in human subjects, has been hampered by the difficulty to measure left ventricular volume in an easy and accurate way. The conductance catheter technique, originally developed at the department of Cardiology of the Leiden University Medical Center, has made it possible to obtain ventricular volume continuously and on-line.

The Method

The conductance catheter technique is based on measuring the time-varying electrical conductance of the blood in the ventricle. This time-varying electrical conductance is, in a first approximation, linearly proportional to the actual volume of blood in the ventricle (based on Ohm's Law). To improve the accuracy, the left ventricle is divided in to 5 segments. The conductance of each segment is obtained by measuring the voltage between 2 consecutive electrodes on the conductance catheter (2-3, 3-4, 4-5, 5-6 and 6-7 in Figure 1).



The segmental volumes are related to the measured segmental conductance using the following equation:

$$V_i(t) = L^2 \cdot \rho \cdot G_i(t) \quad eq.1$$

Where:

$V_i(t)$ = time varying volume of segment i

L = inter-electrode distance

ρ = resistivity of the blood

$G_i(t)$ = (measured) time-varying conductance of segment i

Total ventricular volume simply follows from the summation of the five segmental volumes, using the formula:

$$V(t) = L^2 \cdot \rho \cdot \sum_{i=1}^5 G_i(t) \quad \text{eq.2}$$

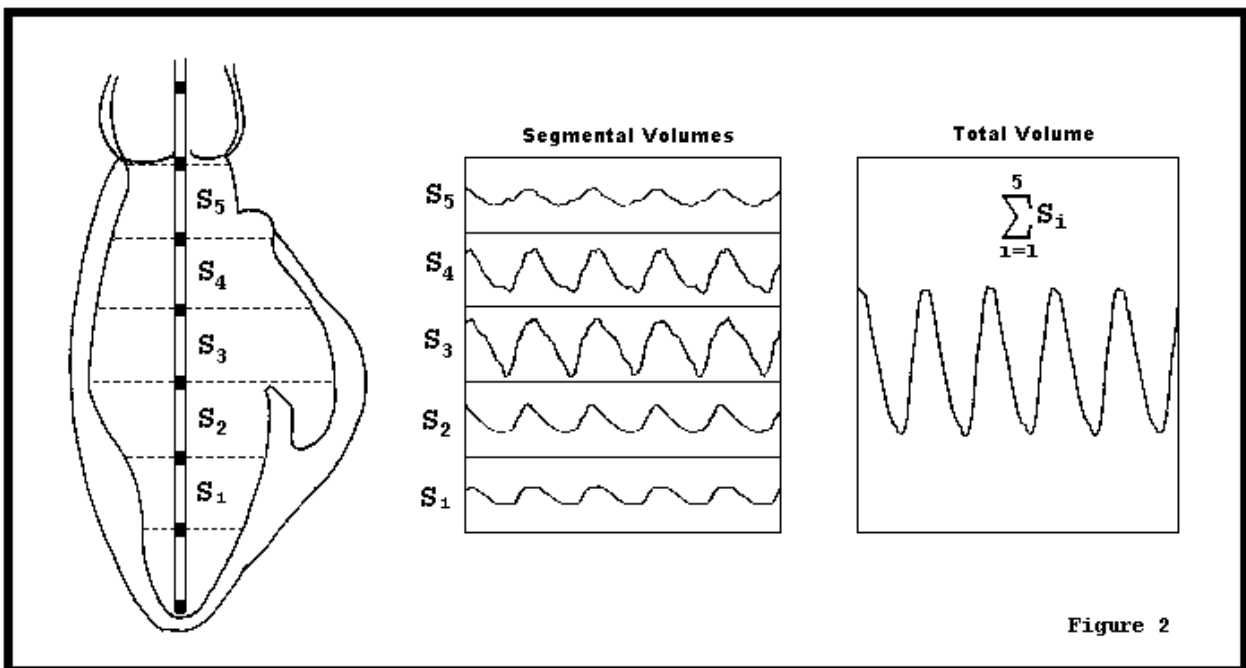


Figure 2

In Figure 2, the five segments in the ventricle are depicted (left), the five segmental volume signals (middle panel) and the “total volume” signal (right panel). From the picture at the left, it is evident that the volume between the apical excitation electrode and the first sensing electrode is not being considered (the excitation electrodes cannot be used as sensing electrodes due to polarization effects). In practice, this missing volume is either ignored or is approximated as 1/3 of the volume of segment 1, assuming a conical apical geometry.

Two items make the calculation of ventricular volume somewhat more intricate than as shown in equation 2:

1. The conductance catheter not only measures the conductance of the blood in the ventricle, but also detects the conductance of the surrounding myocardium. This leads to the introduction of the so-called 'parallel conductance' or G_p . The effect of the parallel conductance is usually taken into account as a 'correction volume', V_c . Determination of V_c is necessary to calibrate measured volume in an absolute sense.
2. In practice, there appears to be a 'slope factor' necessary to calibrate the calculated volume from measured conductance. This 'slope factor', α , in practice varies from about 0.5 to 1.2.

The introduction of these calibration factors leads to the following relation:

$$V(t) = \frac{1}{\alpha} \left(L^2 \cdot \rho \cdot \sum_{i=1}^5 G_i(t) - V_c \right) \quad eq.3$$

Both calibration factors, V_c and α , can be easily determined, as explained below. The software available from CD Leycom (CONDUCT-2000 and CONDUCT-NT) will take care of all calculations, and will guide you through all necessary steps.

Slope Factor Alpha

A factor that can be optimized is the choice of conductance catheter and its position within the ventricle. Ideally, the sensing electrodes will span the entire ventricular long axis, the apical region notwithstanding. As illustrated in figure 1, in the left ventricle the electrode separation should be such that the proximal excitation electrode is in the aorta with the most proximal sensing electrode at the level of the aortic valve. The catheter should be as straight as possible with the tip at the ventricular apex. For this reason, the apical region not being measured will probably be greater when using a conductance catheter with a pigtail, the effects of such a catheter on the slope factor α being exaggerated in smaller hearts.

Even with the above considerations optimized, α will often be less than 1, particularly in large hearts. This is due to properties of the electrical field itself. Figure 3 shows how equipotential lines of an electrical field radiate from the excitation electrodes. Strictly speaking, equation 1 is only valid if the equipotential lines are parallel to one other. From Figure 3 it is clear that is only the case at the point equidistant from the excitation electrodes, and very close to the conductance catheter itself. Consequently, measurements based on Equation 1 will be most accurate at the center segment and when the ventricular short axis is small. Thus, if the five volume segments were considered separately, a segmental α would tend to approach 1 at the center segment and become incrementally smaller for segments approaching the excitation electrodes.

Determination of Slope Factor Alpha

The slope factor α (alpha) can be determined by comparing stroke volume measured by the conductance technique, with stroke volume obtained with another independent method, such as thermo dilution (thermo dilution is the method mostly used to perform this calibration).

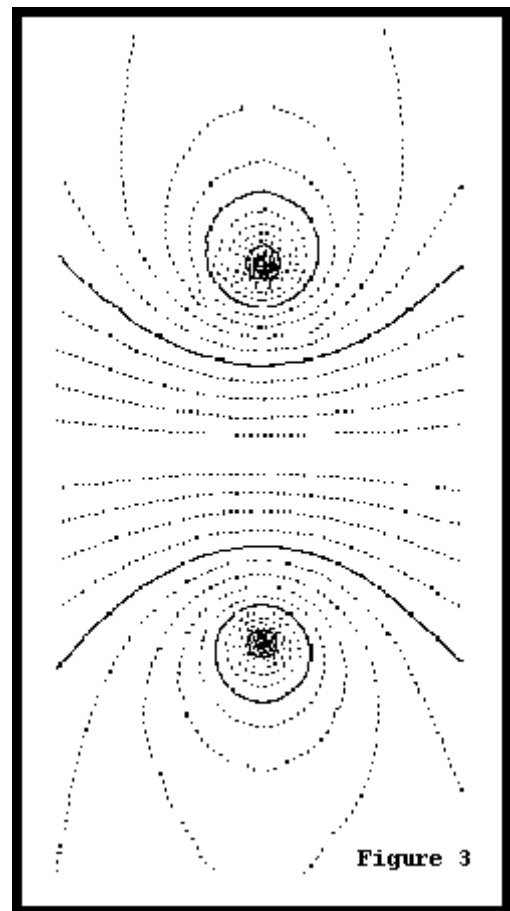


Figure 3

The slope factor α simply follows from:

$$\alpha = \frac{\text{conductance stroke volume}}{\text{reference stroke volume}} \quad \text{eq.5}$$

The CD Leycom software will take care of this calculation, by letting you enter the SV calculated from e.g. thermo dilution. The slope factor α is then automatically applied to calculate calibrated volume.

Parallel conductance volume (Vc)

The conductance signal not only reflects conductivity of the ventricular blood pool, but also that of the surrounding structures. While the conductance catheter measures changes in conductance resulting from changes in ventricular blood volume, it also detects the conductance of the surrounding myocardium, contra-lateral ventricular blood pool, etc. This results in a positive offset of the volume signal, the parallel conductance volume (Vc).

Determination of parallel conductance volume (Vc)

The method most often used to determine the correction volume Vc (to take into account the parallel conductance of the myocardium) is a dilution technique, which relies on the analysis of the conductance signal during an induced transient change in blood conductivity. In order for this method to work properly, the heart must be in a relatively steady state, with no beat-to-beat changes in end-diastolic or end-systolic volume. A small bolus of hypertonic saline (in humans, usually 5 ml of 10% NaCl) is injected into the pulmonary artery, allowing good mixing with the blood before it enters the left ventricle. As the saline/blood mixture enters the left ventricle, a temporary, gradual change in the conductance signal will occur over several beats (see Figure 4).

The increase in the conductance (or volume) signal is then analyzed to extrapolate the effects of decreasing conductivity.

