

Classical Conductance Technique

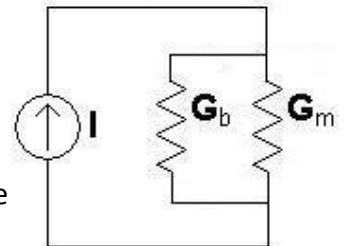
- LV blood conductance is measured on a beat by beat basis using a tetrapolar catheter placed in the LV
- Original theory proposed by Baan *et al.* which related measured conductance to volume through a simple equation

$$Volume = \frac{1}{\alpha} \rho L^2 (G_{meas} - G_p)$$

where ρ – blood resistivity
 L – length between voltage sensing electrodes
 α – constant dependent on the stroke volume (Baan assumed it to be 1)
 G_{meas} – conductance measured
 G_p – parallel conductance of muscle

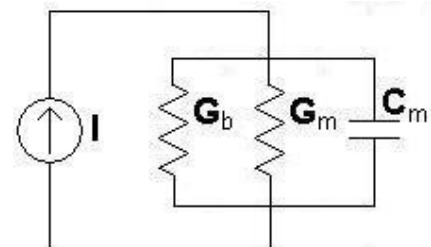
Drawbacks of this technique

- The relationship between blood conductance and volume is non linear, due to non linear shape of stimulating electric field
- Conductance measurement extends into blood pool AND into surrounding tissue (muscle)
 - This implies that the measurement will artificially increase the volume because the catheter will see further than only the blood pool
 - The correction for the parallel conductance G_p is a calculated constant in the above equation, but the parallel conductance is known to be non-constant
- The accepted methods for parallel conductance measurement are outdated
 - Hypertonic saline bolus injection is commonly used to measure G_p
 - This measured value is a constant, and is not time dependent
 - Need a better technique to separate the blood and muscle components of the signal
- Conductance approach is modeled after an inaccurate circuit model for blood and myocardium
 - Traditional approach models both blood (G_b) and cardiac muscle (G_m) as real or resistive components only, ignoring the imaginary or capacitive properties of cardiac muscle
 - Hence, separating blood and muscle is difficult and often done incorrectly in the traditional approach



New Admittance Technique

- Admittance technique measures both conductive and capacitive properties of blood and muscle
- The basis of measuring admittance instead of conductance is that at frequency ranges of about 20 kHz, blood is purely resistive and has no measurable capacitance, but muscle has both capacitance and resistance properties
- This allows separation of the admittance of the muscle from the admittance of blood, using electric field theory
- New proposed circuit model which models the blood (G_b) as conductive, the cardiac muscle as both conductive (G_m) and capacitive (C_m)



The Scisense ADVantage™ addresses two well-known shortcomings of classical conductance volumetry :

- 1. Parallel Conductance Estimation:** classical conductance volume systems provide a raw signal defined as the sum of blood conductance (G_b), myocardial conductance (G_m), and myocardial capacitance (C_m). In order to render this signal valuable we must isolate G_b : the unwanted portion of the signal is referred to as parallel conductance. The most common method used to calculate parallel conductance is the “hypertonic saline bolus injection”: this bolus causes a transient conductance change within the ventricle, and in turn allows an extrapolated constant to be defined. **This technique is essentially an approximation as it is extremely user dependent, with high degree of variability (potentially 15%). Most importantly, this method defines a dynamic variable as a constant.**
- 2. Field Correction Factor alpha :** classical conductance volume systems employ a combination pressure-volume catheter that creates an electrical field in order to measure changes in conductance. For simplicity, this electrical field has been assumed homogenous. **This assumption causes error (a volume underestimation) when attempting to convert the measured raw signal into blood volume.** Researchers attempt to correct this problem by the use of a field correction factor.

To address the inaccuracies associated with shortcoming 1, the Scisense ADVantage™ system provides a computed true volume in real time. This is achieved by the use of a surface probe to measure specific myocardial properties (conductivity and permittivity), and a combination PV catheter to detect admittance magnitude and “phase angle” signals from the ventricle. An onboard digital micro-processor then uses this information to provide the end-user with true ventricular blood volume.

The ADVantage™ system also employs an improved conductance-to-volume conversion equation to address shortcoming 2. Wei’s equation replaces Field Correction Factor alpha (α). This equation corrects for the inhomogeneous nature of the catheter electrical field distribution – it does so by assuming a non-linear relationship between conductance and volume thus improving accuracy over a wider range.

Improvement over traditional conductance

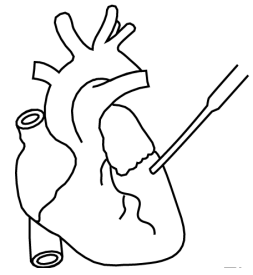
- Eliminates need for volume cuvette calibration
- Eliminates need for hypertonic saline injection to determine parallel conductance
- Real time calculation and removal of varying parallel conductance G_p
 - G_p varies during the cardiac cycle
 - Traditional conductance technology incorrectly assumes a constant G_p
- Absolute blood volumes are obtained
- Improved volume conversion equation that accounts for non-linear electric field within LV
- Phase angle output provides real time feedback of catheter position in LV

Real-time absolute volume in 3 easy steps

1. Surface probe measurement to determine myocardial electrical properties
2. LV catheter measurement of admittance magnitude and phase angle within LV
3. Use of Wei’s equation to convert calculated blood conductance to absolute volume

Surface Probe measurement

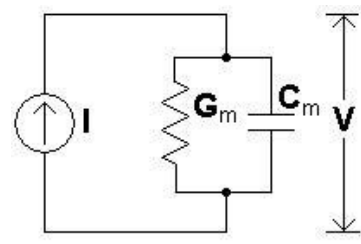
- Used to determine the sigma/epsilon ratio of the muscle
- Myocardial surface probe placed on the myocardial surface, above the LV
- The probe is designed so that the electric field penetrates only the muscle and not the underlying LV blood pool
- Hence, the equivalent electrical circuit for the myocardium consists of a muscle conductance G_m and muscle capacitance C_m
- The probe measures admittance magnitude $|Y|$ and phase angle (θ)



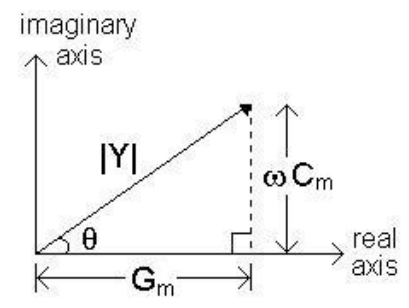
From electromagnetic theory,

$$\frac{G_m}{C_m} = \frac{\sigma_m}{\epsilon_m} = \text{sigma/epsilon ratio} = \text{a constant}$$

where σ_m = muscle conductivity (S/m)
 ϵ_m = muscle permittivity (F/m)



$$Y = G_m + j\omega C_m$$



$$G_m = |Y| \cos(\theta)$$

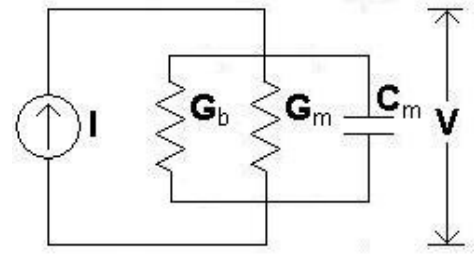
$$\omega C_m = |Y| \sin(\theta)$$

where $\omega = 2\pi \times \text{frequency}$

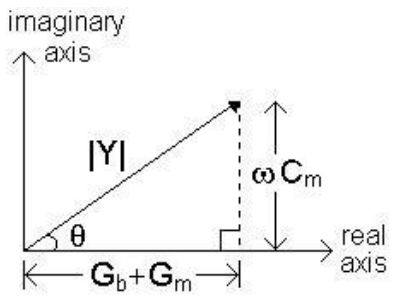
Since G_m and C_m can be calculated from the measurement of $|Y|$ and θ , the sigma/epsilon ratio of muscle is determined

LV Catheter measurement

- Used to determine the instantaneous blood conductance G_b
- LV catheter placed in the LV blood pool
- The equivalent electrical circuit for the LV consists of blood conductance G_b , muscle conductance G_m and muscle capacitance C_m
- The catheter measures admittance magnitude $|Y|$ and phase angle (θ)



$$Y = G_b + G_m + j\omega C_m$$



Calculation of G_m
 $\omega C_m = |Y| \sin(\theta)$
 where $\omega = 2\pi \times \text{frequency}$

i.e. $C_m = \frac{|Y| \sin \theta}{2\pi f}$

Hence, $G_m = C_m \frac{\sigma_m}{\epsilon_m}$

where σ_m / ϵ_m has been determined using the surface probe

Calculation of G_b
 $G_b + G_m = |Y| \cos(\theta)$
 Hence, $G_b = |Y| \cos(\theta) - G_m$

This value of G_b is substituted in Wei's equation to obtain real time absolute volume.

Wei's Equation

- Used to convert the measured blood conductance G_b into absolute volume
- Requires an independent measure of stroke volume
- Uses field form factor γ to compensate for non-linear electric field distribution within the LV
- Generates more accurate volumes than traditionally used Baan's equation, especially for larger volumes
- Wei's equation :

$$LV \text{ Volume} = \frac{1}{1 - \frac{G_b}{\gamma}} \rho L^2 (G_b)$$

Field form factor γ

$$\gamma = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

where

$$a = SV - \rho L^2 (G_{b-ED} - G_{b-ES})$$

$$b = -SV (G_{b-ED} + G_{b-ES})$$

$$c = SV G_{b-ED} G_{b-ES}$$

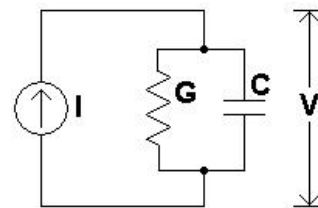
SV = stroke volume (L)

ρ = blood resistivity ($\Omega \cdot m$)

L = distance between sensing electrodes (m)

Review of electrical terminology

The circuit on the right consists of a conductor (G) and a capacitor (C). A constant current (I) flows through this parallel G-C network. V is the voltage developed across this network.



For an AC current I,

$$V = I \times Z \quad (1.1) \quad \text{where } Z - \text{impedance } (\Omega)$$

$$\text{also, } Z = 1/Y \quad (1.2) \quad Y - \text{admittance } (S)$$

In this circuit ,

$$Y = G + j\omega C \quad (1.3) \quad \text{where } R - \text{resistance } (\Omega)$$

$$\text{or } Y = 1/R + j\omega C \quad (1.4) \quad \omega - 2\pi \times \text{frequency } (Hz)$$

$$j - \sqrt{-1}$$

For a DC current I, frequency = 0

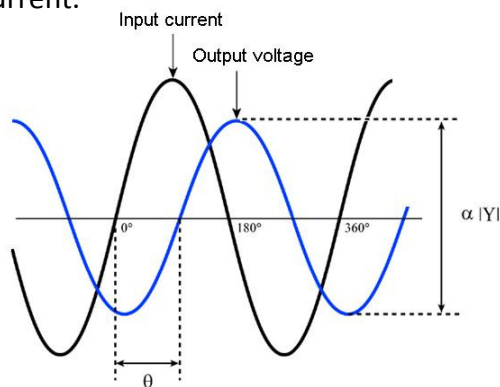
Hence, $\omega = 0$

i.e. $Y = 1/R$ (from eq. 1.4)

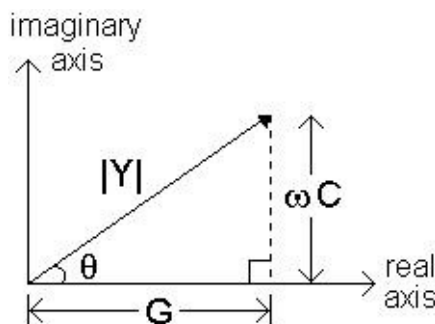
or $Z = R$ (from eq. 1.2)

Therefore, $V = I \times R$ (Ohm's Law)

In equation 1.3, G is the real part and ωC is the imaginary part of admittance. The presence of the capacitor C causes a phase delay (θ) between the voltage and current.



Graphical representation of $Y = G + j\omega C$



The magnitude of Y is defined as

$$|Y| = \sqrt{G^2 + \omega^2 C^2}$$

$$\text{and } \theta = \tan^{-1} \left(\frac{\omega C}{G} \right)$$

$$\text{Also, } G = |Y| \cos(\theta)$$

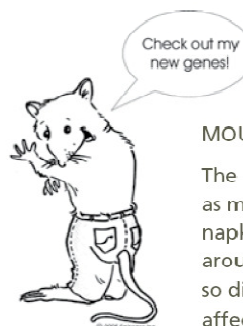
$$\omega C = |Y| \sin(\theta)$$



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The mouse'n genes was conceived, as many great ideas, on a restaurant napkin. As a serious discussion around transgenic mice evolved, so did Sammy Scisense, as he is affectionately known today.

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