The Role of Material, Geometry and Environment in the Corrosion Resistance Assessment of High Voltage Cardiac Electrodes

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SUMMARY: This study reviews the operating environment of transvenous cardiac defibrillation electrodes as well as material and geometry considerations related to the assessment of corrosion resistance and electrode performance.

DISCUSSION: Pt/Ir, Ti, Pt, and other corrosion resistant materials have been utilized in implantable transvenous defibrillation electrodes with devices capable of delivering rescue shocks of up to 34 J. The operating environment is a system of blood and tissue with a high degree of anisotropy (1).

In order to defibrillate the heart, modern transvenous electrode systems utilize high voltage biphasic or monophasic DC pulses delivered via high surface area metal coils and can electrodes. Electric field strength targets can be in the order of 6 V/cm over 95% of the heart mass.(2). Simple predictions of electrical far field distributions have been made via Finite Element or Finite Difference computational models. Most of these models are based on quasi-static electromagnetic physics governed by the Poisson's equation

$$\nabla \bullet \sigma \nabla \Psi(r) = 0$$

where
σ = tissue conductivity and
ψ = the potential.

More advanced models have been developed and they include extracellular and intracellular domains with treatments of more relevant parameters such as ionic currents and preferential conduction paths (3). Most of these models focus on far field phenomena and do not account for interfacial phenomena near and on the electrode surface such as bubble release and other material/electrochemical effects. These effects are very important to understand metal ion release and other material reliability factors, another aspect of electrode performance.

Current density distributions in transvenous defibrillation electrodes are non-uniform and charge transfer involves faradaic reactions. Some of these reactions have been studied in physiological media for platinum electrodes(4). Gas evolution due to electrolysis affects electrode impedance by increasing ohmic voltage drop. Mathematical treatments of the bubble layer near an electrode have been performed by various researchers (4,5).

Aside from the change in impedance, which affects system efficiency, high charge densities and chemical reaction products have the potential to cause uniform and localized corrosion, stress cracking and embrittlement in certain materials. Mechanical stresses experienced in these applications include tensile, bending and torsion at frequencies of ~30 million cycles per year. All of those conditions make the design of defibrillation electrodes a formidable task.

This work focuses primarily on describing the demanding operating conditions of implantable transvenous defibrillation electrodes as it relates to voltage driven corrosion and therapeutic objectives. Examples of applications and performance criteria will be given in order to demonstrate the strong interaction between material, geometry and waveform applied.

REFERENCES:

1. R. C. Little "Physiology of the heart and circulation", 4th edition, Year book medical publishers, Inc.
2. J.Marcus et al, "Cardiac potential and potential gradient fields generated by single, combined and sequential shocks during ventricular fibrillation", Circulation, vol 85, No 4, April 1992.
3. K.Gima,Y. Rudy, " Ionic Current Basis of Electrocardiographic Waveforms, A model Study", Circulation Research, May 3, 2002.
4. S.B. Brummer and M.J. Turner, " Electrochemical considerations for safe electrical stimulation of the nervous system with platinum electrodes", IEEE Transactions on Biomedical engineering, vol. BME24, PP 59-63, 1977.
5. C.W. Tobias "Effect of gas evolution on current distribution and ohmic resistance in electrolytes" Journal of the Electrochemical society, vol 9. pp.833-838, 1959