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Editorial

"Advancements in Pacemaker Lead Technology"

The pacing lead represents the critical interface between the pacemaker and myocardial tissue. As such it must fulfill two major roles: first, the lead transmits pacing pulses generated by the implanted pacemaker into the excitable myocardial tissue. It also provides the link between the electrical signals from the myocardial muscle and the signal processing unit of the active implant. Thus, the overall efficiency and efficacy of a pacemaker system is critically dependent upon the characteristics and performance of the pacing electrode.

Initial refinement and development of pacing leads concentrated on improving the stimulation characteristics by minimizing the losses at the interface between pacing lead and tissue. The goal being to reduce the pacing threshold and thus increase the lifetime of the pacemaker. To achieve this, the surface structure of the pacemaker electrode has been refined to increase the ratio between geometrical and "bioeffective" surface area, thereby improving the reversible capacitive charge transfer across the phase boundary. Fractal coatings, widely used in Biotronik's pacing lead systems, provide an outstanding enlargement of the surface area, increasing the geometric/bioeffective area ratio by more than three orders of magnitude. The fractal surface structure technology has resulted in significant decreases of the pacing threshold. More recently, the fractal concept has been combined with the development of high impedance pacing leads using very small electrode tips, to further reduce the pacing threshold. As a result, modern fractally-coated high impedance pacing leads such as the Synox (Biotronik GmbH, Berlin) pacing leads have acute pacing thresholds well below 0.4V, and become the critical factor in enhancing the lifetime of pacemaker systems.

While the reduction of battery consumption has always been the preeminent focus of developments in lead technology; more recently, improving the sensing characteristics of the pacing lead has taken on greater significance. This emphasis is based on the premise that the lead also represents an excellent monitoring tool, not just for intrinsic electrogram signals, but also the wealth of other information relayed by the myocardium, such as the evoked response, the monophasic action potential (MAP), myocardial impedance, etc. The analysis of these signals provides access to information about the cellular electrical state of the myocardium and, as such, their use extends to technical and clinical applications as varied as automatic amplitude adjustment, physiological rate adaptation, rejection monitoring after heart transplantation, and monitoring pharmacological interventions. For these applications to be successful, however, the lead must have sensing characteristics which allow accurate measurement of myocardial signals without artifacts, with a high signal-to-noise ratio and a negligible afterpotential. In this monitoring role, the use of the fractal surface coating becomes increasingly important, since the sensing performance of the electrode is determined mainly by the active surface area of the electrode.

In conclusion, the refinement of the electrode-myocardium interface by use of fractally coated electrodes has transformed the pacemaker lead so that it is no longer a simple pacing/sensing electrode, but an important monitoring tool allowing access to a variety of sensory information. This allows the developers to reduce the complexity of modern pacemaker systems by introducing automated functionality such as automatic amplitude adjustment and autosensing; as well as re-establishing the physiological status by using the sensory information on the state of the myocardium. In 1979, Auerbach and Furman suggested an "automatic and physiological pacemaker". Their vision comes closer to reality with the advancements in lead technology afforded by fractal coating.

Ronald Fröhlich and Nawzer Mehta

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