Wireless Recharging of Implanted Batteries via Ultrasound

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In order to expand the applications for implanted rechargeable batteries, and to reduce the frequency of battery replacement procedures, we are investigating a recharging technique complimentary to and improving on the current RF recharging technique. Although the first applications deal with batteries that could be implanted in human bodies to power neurostimulators, sensors, and drug pumps, non-medical applications may exist. Using a transmitter-receiver arrangement, we have recharged batteries wirelessly using ultrasound at several frequencies between 0.75 and 3.0 MHz. Rechargeable implantable batteries of 35, 200 and 600 mA-hr were charged at rates of up to 0.75 C, where C is the charging rate (charging current/maximum battery charging current). Typically the intervening medium was one centimeter of a tissue mimicking liquid (TML), however some in vitro experiments have also been performed. Charging was accomplished at distances of up to 20 centimeters in water, and even through millimeters of plastic and centimeters of aluminum. Temperature measurements were made on both transmitting and receiving transducers, and in the TML. As expected there were significant increases in temperature at the higher charging currents. Experimentally we determined that the "overall efficiency" of the charging process, viz. $E=(I_{batt}*V_{batt})/(\text{net electrical power})_{input}$, was closely correlated with the observed heating. That is, the lower the efficiency, the higher the input electrical power required, the more transducer heat was produced and conducted into and through the medium. The critical issues were the coupling of the transmitter and receiver to the medium, and the efficiency of conversion of the receiver output to charging power by the charging circuitry. These depend on the mechanical and electrical impedances, and we improved the efficiency considerable by appropriate impedance matching. Active and passive methods of cooling the transducers and intervening medium have been constructed and successfully tested. With our system, recharging times will be limited not by heating considerations, but only by the optimum rate at which a given battery can accept charge.

Stimuli-Responsive Triblock Polymers for Multipulse Drug Delivery

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Temperature and pH-sensitive ABC triblock polymers were prepared to form hydrogel membranes capable of changing their structure in response to environmental stimuli, allowing drug release, from a micro implantable device, in short and repetitive pulses. We have previously investigated the capacity of hydrogels to sustain open loop oscillatory behavior, with application in rhythmic hormone release. This novel oscillator is mediated by feedback instability between swelling/shrinking of the hydrogel and an enzyme reaction, whose product modifies pH in the hydrogel. The objective of this work was to prepare and characterize triblock polymer-based hydrogels, to overcome limitations of conventional hydrogels. Our strategy involves reversible arrangement of A and C thermosensitive domains within a strong network, whereas B block is also pH-sensitive. The triblock was mainly based on the use of NIPAAm (N, isopropylacrylamide) and AA (acrylic acid) monomers. Polymers were synthesized by reversible addition fragmentation chain transfer (RAFT) polymerization. Polymers molecular weight (Mn) and polydispersity index (PDI) were determined by matrix-assisted laser desorption ionization/mass spectrometry (MALDI). Monomers conversion was assessed by NMR and copolymers composition by NMR and pH-titration. Temperature and pH responsiveness was studied by turbidity and light scattering experiments. ABC triblock presented Mn close to 40,000 Da and was nearly monodisperse ($PDI < 1.1$). The monomers conversion was 92%, 97% and 39% for A, B and C blocks, respectively. The opposing effects of hydrophobicity and ionization on the aggregation behavior of the diblock have been highlighted through the turbidity and light scattering data. AB diblock cloud points were 32, 34, 35.5 and 37°C for 3, 5, 10 and 20% of AA, respectively. Micelles or aggegrates were observed depending on pH and temperature. ABC triblock polymers with controlled architecture and Mn distribution were synthesized and fully characterized. The results suggest that these block polymers are promising materials for stimul-responsive hydrogel membranes applied to medical devices. Work supported by the Swiss National Fund for Scientific Research and an NSF-funded MRSEC (DMR#0819885) at the University of Minnesota.