The Effect of Solution Electrical Conductivity in Pacemaker Lead Tip Heating at 1.5 Tesla

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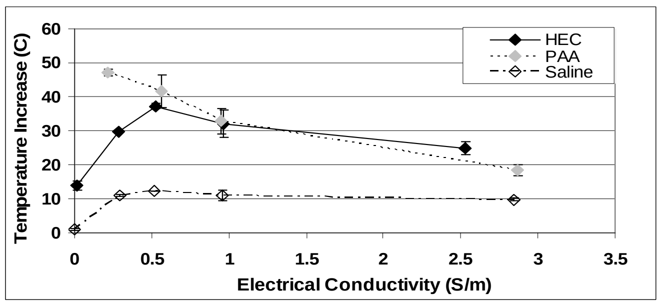
Introduction: MR imaging of patients with implanted pacemakers is associated with the risk of thermal damage to the myocardial tissue due to RF induced heating at the pacemaker lead tip. A uniform liquid phantom is commonly used to make basic temperature measurements of pacemaker lead tip heating and to estimate energy deposition. The three most common solutions are saline, Poly-Acrylic-Acid (PAA), and Hydro-Ethyl-Cellulose (HEC). While it is understood that thermal diffusion properties of each solution will affect temperature measurements[1], previous RF ablation research has shown that temperature increases are dependent on the conductivity of saline solutions[2]. The objective of this study was to investigate the effect of solution conductivity on RF induced heating of pacemaker lead tips using HEC, PAA, and saline solutions.

Methods: *Test Solutions* Three different solution materials were tested, HEC (1% by wt), PAA (5.85 g/L), and saline. For each solution various conductivities were achieved by altering the concentration of NaCl. The conductivity of each solution was measured using a Methlom 720 conductivity meter. Table 1 provides the NaCl concentration of each mixture and the measured conductivity. *MR Temperature* A 1688T 20cm lead was connected to an Identity pacemaker (St. Jude Medical, CA, USA) and placed inside an ASTM head/torso phantom filled with 0.45% saline. The tip of the lead, including the ring electrode, was placed inside a 15mL cylinder filled with each solution. A one minute SSFP sequence with a TE/TR = 1.69/3.37 ms, FA 40^o and scanner reported SAR of 1.9 W/kg was used to induce RF heating in the lead. All measurements were made on a 1.5T Avanto MRI (Siemens, PA USA). Temperature measurements during the scan were taken with a Lumasense fiberoptic temperature probe inserted into the lead tip helix. To compare the heating in each solution the temperature data was fit to $T(t) = T_o + T_\Delta \bullet [1-e^{-t/\tau}]$. T_o is the initial temperature before the scan, T_Δ is the fitting variable used to estimate the temperature rise, and τ is the fitting variable used to estimate the thermal time constant. The maximum thermal time constant τ, for HEC was 20.8 sec, PAA was 22.4 sec, and saline was 11.2 sec. It is expected that during the scan time of 60 seconds thermal equilibrium is sufficiently achieved reached in 3τ for HEC and PAA and 6τ for saline. The fitted variable T_Δ was used to evaluate the temperature increase for each solution as a function of concentration (Figure 1).

Solution	NaCl g/L	Conductivity S/m
HEC	0.0	0.01
HEC	7.0	0.28
HEC	14.0	0.52
HEC	28.0	0.96
HEC	100	2.53
PAA	0.6	0.22
PAA	2.5	0.56
PAA	5.0	0.95
PAA	22	2.87
Saline	0.0	0.00
Saline	1.6	0.29
Saline	3.0	0.51
Saline	5.8	0.95
Saline	18.8	2.84

Table1. The NaCl concentration and conductivity of each solution is given.

Figure1. The temperature measurements for each solution are shown as a function of conductivity.



Results: The largest temperature increase was measured in the PAA solution with conductivity 0.22 S/m. The HEC solution exhibited maximum heating with a conductivity of 0.52 S/m. The greatest temperature increase in saline was with a conductivity of 0.51 S/m.

Discussion: For HEC and saline solutions the maximum heating was obtained when the conductivity was near 0.5 S/m. For conductivities lower than 0.5 S/m heating in the HEC solutions was much lower and for higher conductivities the decrease in heating was a less steep function of conductivity. Heating in saline appears to plateau after 0.5 S/m, suggesting that 0.5 S/m (3g/L NaCl) should be considered a minimum conductivity when using saline solutions. Because of its higher thermal convection saline will consistently yield lower heating measurements than the HEC and PAA gelled solutions, which is a limitation for making worst-case heating measurements. For PAA the heating measurements continued to decrease with increasing conductivity, however, using the lowest conductivity solution invites measurement difficulty due to substantially thicker gel solutions and the possibility of trapped air bubbles. The pattern in conductivity dependence for HEC and saline is similar, possibly due to the fact that the increase in NaCl concentration is not expected to alter the viscosity or subsequently the thermal convection of either solution. The different conductivity dependence observed for PAA could be due in part to the thinning of the gel that occurs as NaCl concentrations increase, thus increasing the thermal convection and heat loss.

Conclusion: HEC and Saline solutions achieve worst case heating with a conductivity near 0.5 S/m while heating in PAA solutions continue to decline with increasing conductivity. To make a conservative estimate of the energy deposited due to the RF induced lead tip heating using a solution of HEC would provide a higher overall temperature increase due to the low thermal convection of the solution and with a conductivity near 0.5 S/m the peak in conductivity dependant heating can also be expected.

References:

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