MRI Conditional Pacemakers: The Cooling Effect of Blood Flow in the Heart Chambers

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Introduction: Long segments of pacemaker leads reside within blood vessels and the heart chambers, which subjects them to blood flow at cardiac output (CO) rates. This may be beneficial for MRI conditional pacemakers where parts of the lead may increase in temperature primarily due to RF-induced heating. Blood flow around these segments of the lead may provide natural means for heat sinking from the lead body and therefore may allow the implementation of simpler design solutions for MRI conditional leads where minor rise in lead body temperature can be tolerated. This in-vitro study investigates the cooling effect of blood flow on a simulated lead that allows controlled heating and temperature monitoring of various segments along its length.

Methods: *The Flow Setup*: An in-vitro flow setup was developed using a pulsatile pump, a realistic heart model, a water bath, and inter-connecting tubes as shown in Figure 1. The heart model used (Pacemaker Pete, VEN-1200, Anatomical Models, Gig Harbor, WA) has realistic cardiac anatomy of a healthy 5'8" adult male of 180 lbs and dimensions computed after cadaver studies of over 100 specimens and angiographic data of over 1,000 patients. The right atrial (RA) and the right ventricular (RV) chambers of the heart model were used for this study. The pulsatile flow pump (Model 1423, Harvard Apparatus, Holliston, MA) was used to simulate normal cardiac output between 4-5 L/min. The water bath was used to maintain the temperature of the circulating saline solution at 37°±1C to simulate the in-vivo thermal situation. Normal saline was used to simulate blood as its thermal conductivity and specific heat are very close to those of blood.

The Simulated Heating Lead: A simulated lead was built using segments of insulated electrical wire with several resistors positioned in-series between the segments of the wire such that the resistors would heat upon injecting DC current into the two ends of the wire. Fiberoptic temperature probes (FOT, LumaSense, Santa Clara, CA) were placed on the outside surface of each resistor to monitor their temperature.

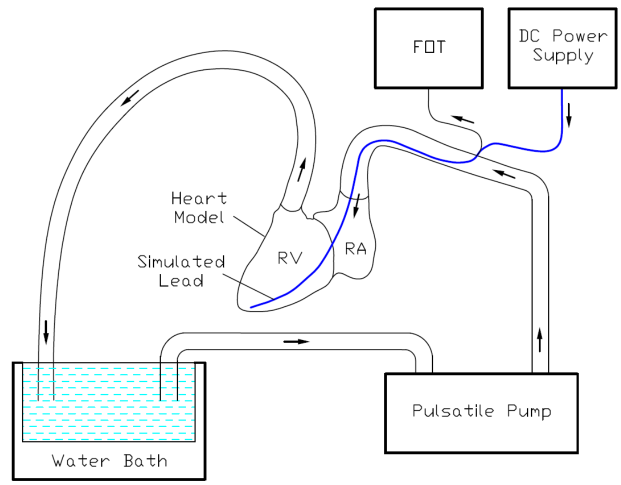

Figure 1 The flow setup

Experimental Protocol: First, the flow was established and the baseline temperature of the circulating saline was measured. Second, flow was stopped and DC current is increased until the temperature reaches a target temperature. Third, the flow was reestablished and the consequent drop in the target temperature is measured.

Results: Figure 2 shows typical temperature curves at the distal end of the lead under the experimental protocol described above. The flow was initially established and the mean baseline temperature ($T_{Baseline}$) was 36°C. The flow was stopped and DC current was injected into the lead until the temperature of the distal end of the lead body ($T_{No\ Flow}$) has reached a steady state mean value of about 59°C, which is 23°C above $T_{Baseline}$. While maintaining the same DC current the flow was reestablished, which caused the temperature to drop to another steady state mean temperature (T_{Flow}) of about 39-40°C, which is 3-4°C above $T_{Baseline}$. This indicates that blood flow was responsible for reducing 83-87% of the temperature-rise on the distal end of the lead body. The data is summarized in **Table 1**.

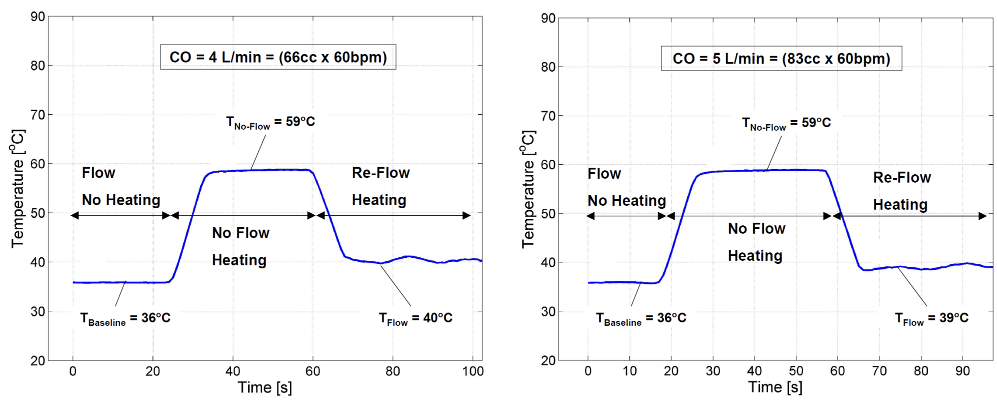

Figure 2 Typical change in the temperature at the distal end of the lead without and with a simulated cardiac flow at: (a) 4 L/min and (b) 5 L/min.

Table 1 Summary of the experimental data

Cardiac Output [L/min]	$T_{Baseline}$ [°C]	$T_{No\ Flow}$ [°C]	T_{Flow} [°C]	$\Delta T_{No\ Flow}$ [°C] $= T_{No\text{-}Flow} - T_{Baseline}$	ΔT_{Flow} [°C] $= T_{Flow} - T_{Baseline}$	% ΔT Reduction $= 100\ (\Delta T_{No\ Flow} - \Delta T_{Flow})/\Delta T_{No\text{-}Flow}$
4	36	59	40	23	4	83
5	36	59	39	23	3	87

Conclusions: Under the above experimental conditions, blood flow in the right cardiac chambers may reduce temperature-rises in the distal end of pacemaker leads by 83-87% and can be used to mitigate moderate heating of the distal segments of MRI conditional leads.