Transient RF Heating of a Conductive Implant: Coupled Electromagnetic/Thermal Simulation and Experimental Validation

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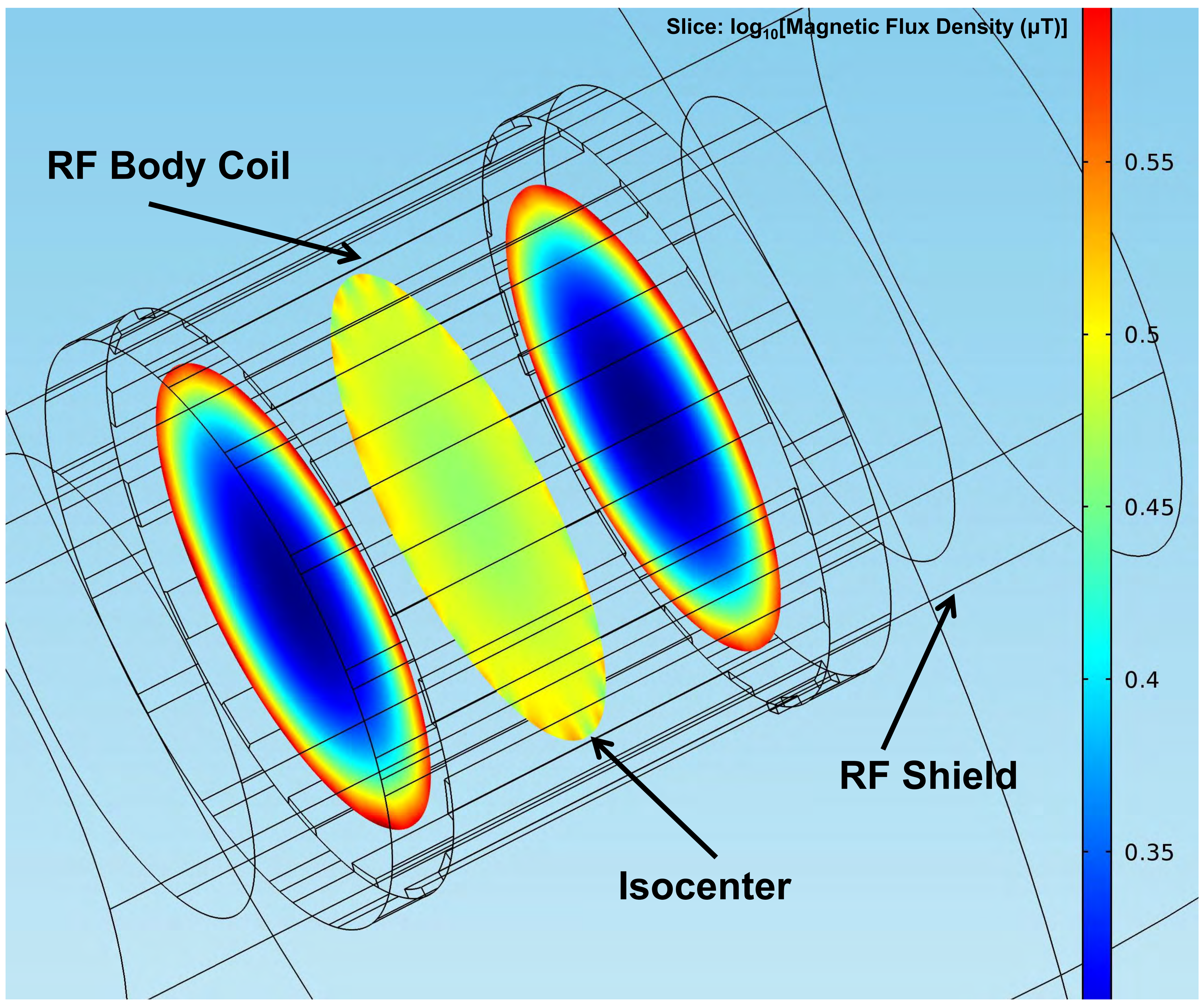
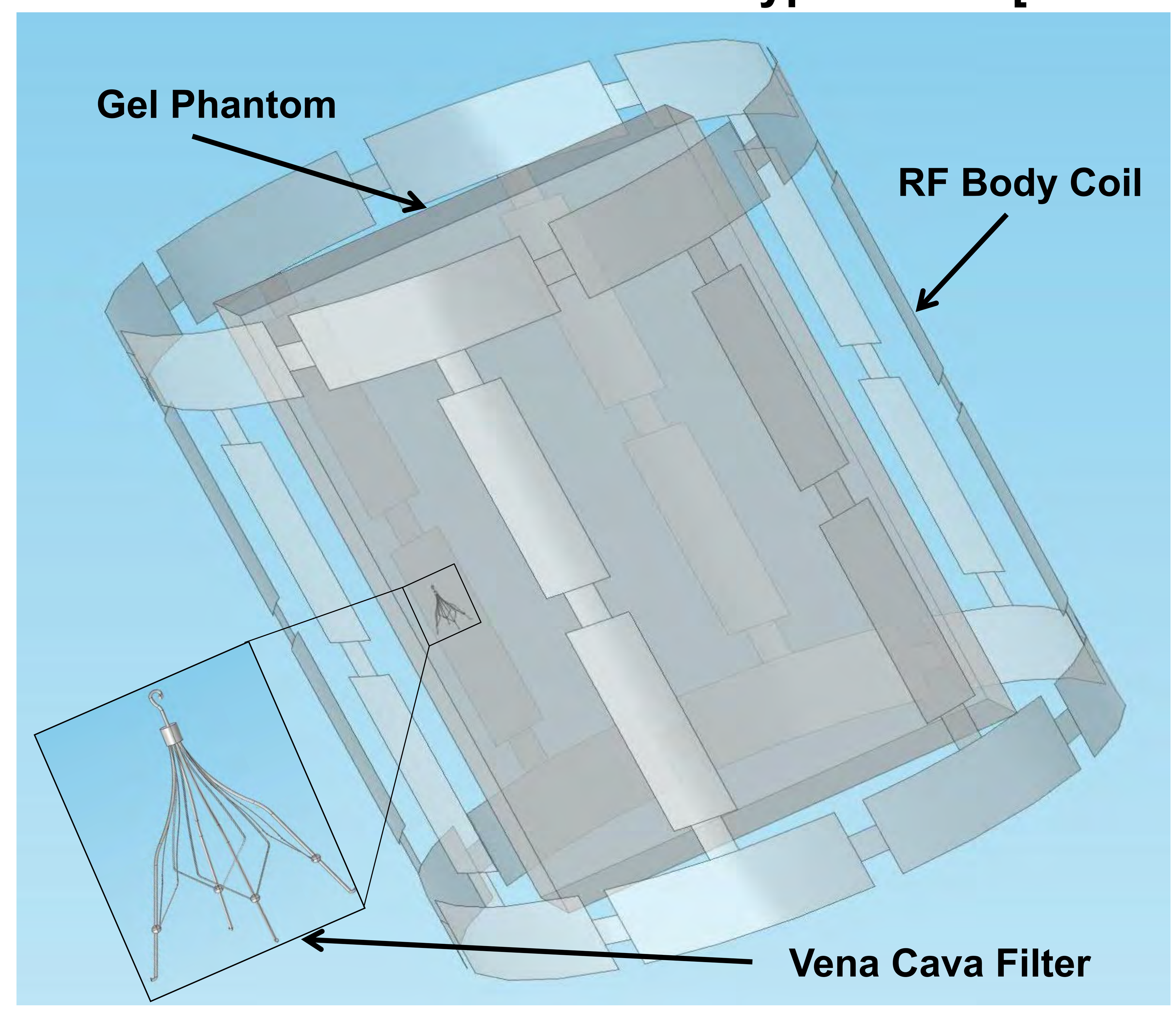
B1 Field: High Bypass Coil [128 MHz]



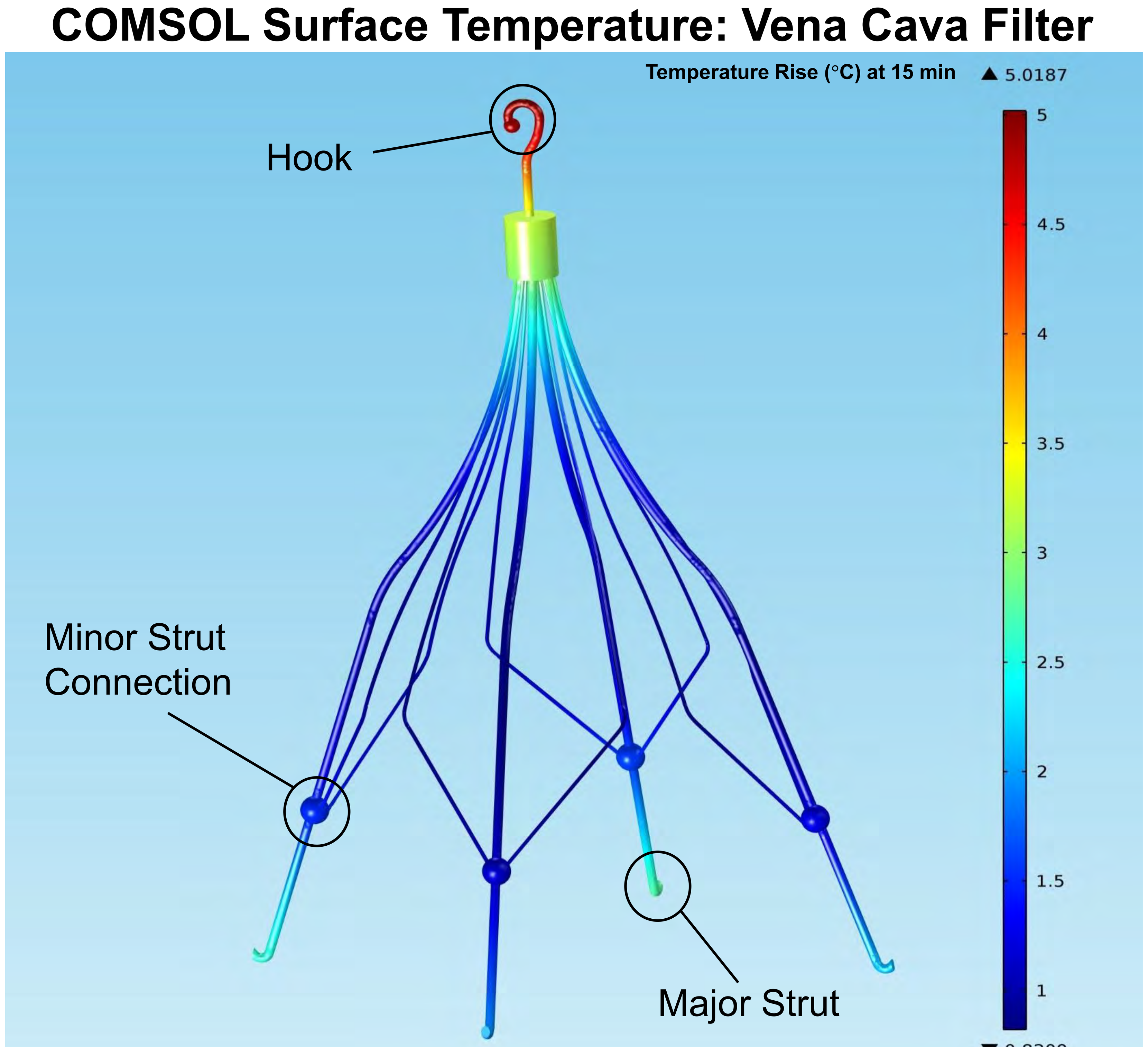
A 3.0T MR system contains a RF body coil with 16 legs and a high bypass design with lumped capacitors positioned on the top and bottom rungs of the coil. The RF body coil was powered with quadrature type excitation; the voltage ports were physically positioned 90 degrees apart with the driving voltage 90 degrees out-of-phase. This figure shows that the simulated birdcage coil was properly tuned to 128 MHz; the birdcage coil produced a circularly polarized field resulting in a relatively uniform magnetic field at the isocenter of the scanner bore. The circularly polarized time varying magnetic field produces a corresponding orthogonal electric field (Faraday's Law of Induction).

ASTM Saline Gel Phantom: Low Bypass Coil [64 MHz]



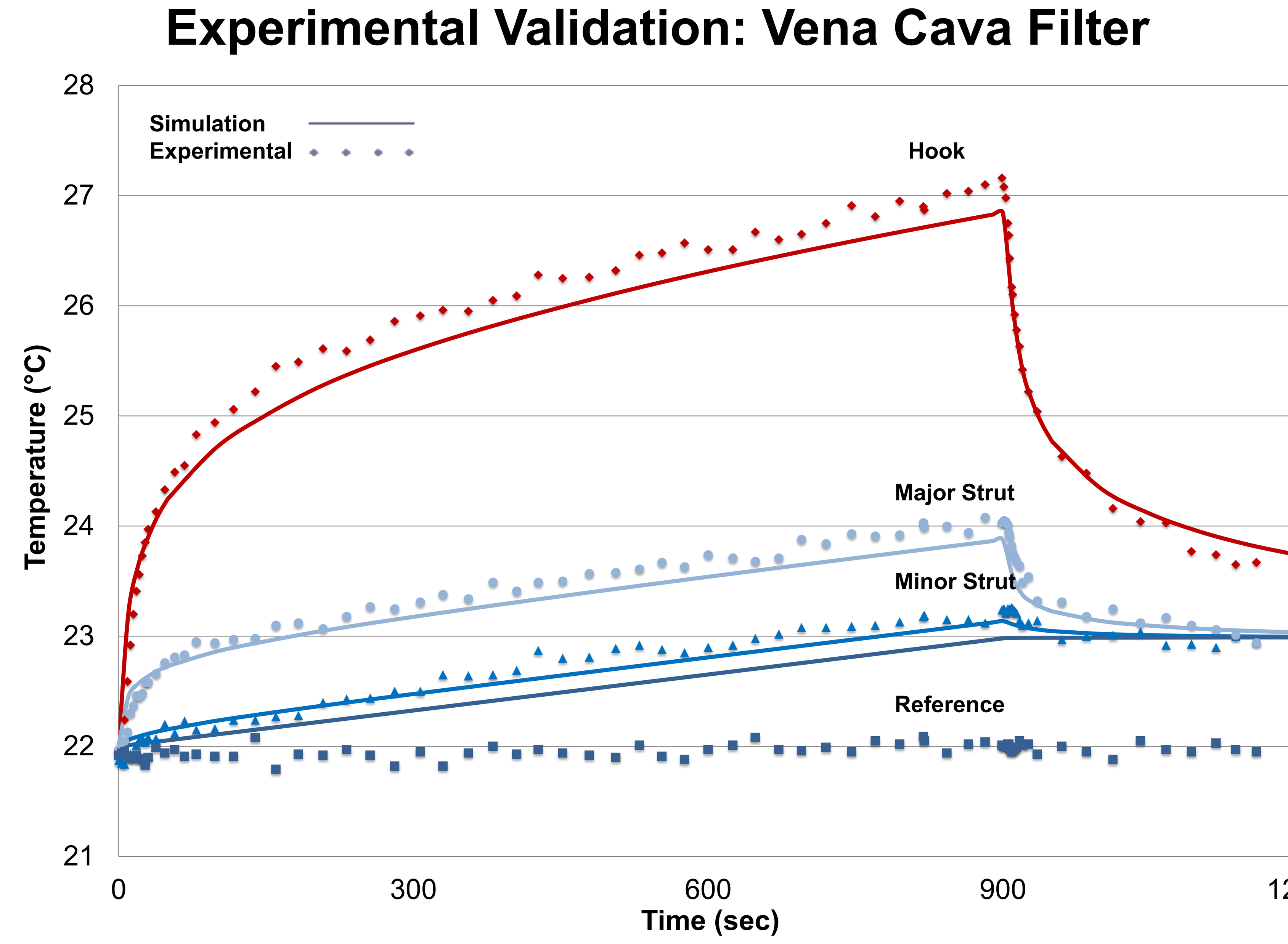
A vena cava filter shown above was modeled "submerged" in a gelled phantom placed at isocenter within a low bypass RF body coil tuned to 64 MHz, typical of a 1.5T MR system. The filter was positioned at the middle (thickness) of the phantom, centered about the isocenter of the bore and laterally approximately 2 cm from the edge of the rectangular phantom. The gelled saline contained in the phantom had electrical and thermal properties specified in ASTM F2182 typical of human tissue. The "viscous gel" performs the function of mitigating most convective heat transfer. The vena cava filter is manufactured from Cobalt Chrome, an excellent bio-compatible material.

COMSOL Surface Temperature: Vena Cava Filter



A surface temperature contour plot at the time of maximum heating is plotted on the vena cava filter. A COMSOL Multiphysics® simulation was conducted using the RF module to model the frequency response of a high bypass RF coil tuned to 128 MHz (appropriate for the 3T MR scanner) and coupled to a transient heat transfer analysis. The RF coil was powered for 15 minutes and then turned off; the transient analysis was allowed to continue for an addition 5 minutes allowing the vena cava filter to cool. The x-y plot to the left demonstrated quite clearly the maximum temperature on the filter predictably occurs at the moment of coil power down. The contour plot clearly shows the maximum temperature will occur at the hook at the top of the filter.

Experimental Validation: Vena Cava Filter



The plot above shows the local transient temperatures at specific locations on the vena cava filter (left) immersed in a gelled saline phantom placed at the isocenter of a 3.0T MR system. Experimentally, temperatures were measured at these same locations and laterally opposite the filter in the gelled phantom. COMSOL Multiphysics® was used to conduct a coupled electromagnetic transient thermal simulation and the corresponding temperatures were extracted at the same locations for the purpose of direct validation of the approach. The spatial gradient and temporal correlation between the analytical and experimental results are remarkably good.

Summary

The purpose of this work was to establish a reliable radio frequency (RF) heating simulation which directly provides transient temperatures for medical devices with high geometric fidelity. These temporal results of localized temperatures can be used to determine conditions for safety of medical devices in the magnetic resonance (MR) environment. Information from this work will directly benefit the regulatory evaluation process, medical device manufacturers, MR scanner manufacturers, physician practitioners and MR technologists.

A robust methodology for analytical simulation of electromagnetic transient heat transfer is presented. Strong correlation of predicted global and local temperature fields with experimental results in a commercial MR system is shown. In particular, the use of the COMSOL Multiphysics® was used to solve for the stationary full field electromagnetic response of the RF coil coupled with the transient heat transfer response in an ASTM F2182 phantom containing a cobalt chrome vena cava filter.

Temperatures were experimentally measured with Fluoroptic® thermometry probes secured on the vena cava filter in the ASTM F2182 phantom and then directly compared to the COMSOL Multiphysics® predictions over the entire MR scanning interval. The correlation is shown to be quite strong between the simulated predictions and experimentally measured values for both the local temperature in the vicinity of the filter as well as in the far field of the phantom.

Temperature, as opposed to the more commonly discussed local specific absorption rate (SAR) is obtained with simulation using COMSOL Multiphysics® leading to more pertinent safety conclusions. Cell death is more directly determined by, among other factors, the maximum cell temperature or the integration of cell temperature over a specific time (i.e., usually the scan time) within a defined volume of tissue. The COMSOL Multiphysics® program approach illustrated in this poster demonstrates that direct calculation of the maximum temperature can be obtained in a reliable fashion.