

MEDTRONIC ADVANCES ABLATION TECHNOLOGY WITH MULTIPHYSICS SIMULATION

The new technology will enhance physicians' abilities to plan and implement ablation procedures, potentially leading to better patient outcomes.

By **GARY DAGASTINE**

ABLATION, OR THE USE OF HIGH-FREQUENCY electromagnetic (EM) energy to destroy soft-tissue tumors, has been in existence for a few decades, but in recent years its underlying technology has evolved.

The benchmark of minimally invasive tissue treatment has long been the application of electrical current to kill abnormal tissues. This is done by heating tissues until they break down, a process called thermal ablation. Energy is delivered at 500 kHz, within the radio frequency (RF) range of the EM spectrum, hence these systems are called RF ablation systems.

In recent years, microwave (MW) ablation technology has also become commercially available and increasingly popular. At MW frequencies, oscillating EM fields are utilized to perform thermal ablation. Medtronic, one of the world's premier medical technology and services companies, is a leader in both RF and microwave ablation technologies.

With both RF and MW systems, the energy for ablation is applied using one or more needle-like probes.

Medtronic's latest innovation, the Emprint™ abla-

tion system with Thermosphere™ technology, offers more predictable and repeatable results than other techniques and devices (Figure 1). These advantages come from the fact that Thermosphere™ technology enables precise control of an EM field independent of the surrounding tissue environment.

» **STRIVING FOR BETTER PREDICTABILITY** ACCORDING TO RESEARCH, physicians rate predictability as their number one concern with ablation performance. The higher the

level of predictability, the easier it is for a physician to plan a treatment procedure that will be safer, more effective, and less time-consuming.

Because of its nature, it's challenging to be certain that RF ablation procedures will achieve the desired results. Given their different electrical conductivities, some tissues are less amenable to effective RF heating than others. Moreover, as the temperature in targeted tissue approaches 100°C, water in the tissue begins to vaporize and electrical conductivity rapidly decreases. This can make it difficult to generate temperatures high enough to cause cell breakdown.

MW ablation technology attempts to overcome these limitations by using an EM field radiated into the tissue (Figure 2). However, in practical application, tissue type and the vaporization of water during ablation cause the size and shape of the EM field to vary.

The Emprint™ ablation system with Thermosphere™ technology realizes the promise of predictability. It gives physicians the ability to easily control the thermal energy delivered by allowing precise control of the EM field across tissues and temperatures. This allows clinicians to accurately predict the boundaries and characteristics of the ablation zone.

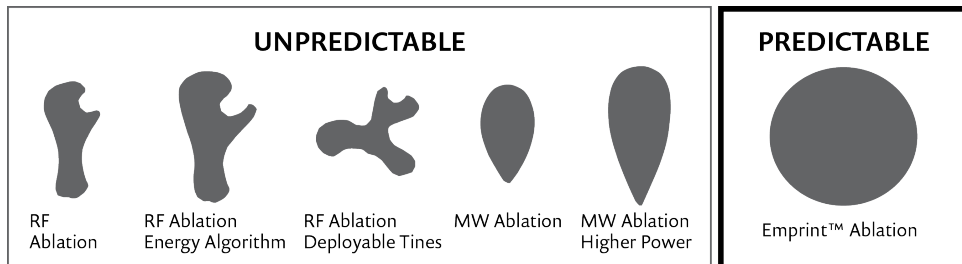


FIGURE 1: At left, shapes of tissue ablation zones that can result unpredictably from the use of various ablation technologies. At right, Medtronic's Emprint™ ablation system with Thermosphere™ technology yields predictable spherical ablations regardless of target location or tissue type.

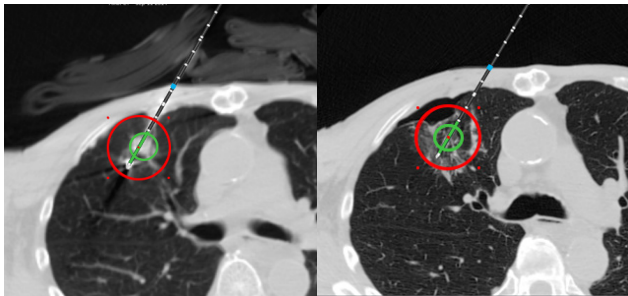


FIGURE 2: The photo at left illustrates placement of an ablation probe. The green circle delineates the target (where the lesion is located) and the red circle delineates the margin the ablation is meant to achieve. The image at right shows the site after ablation has taken place.

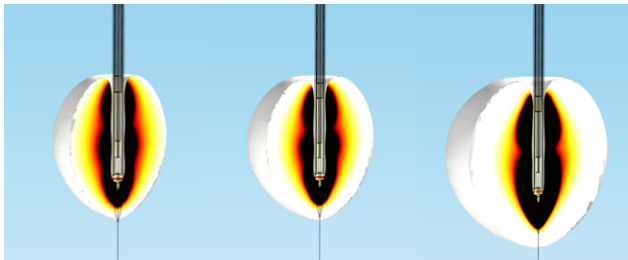


FIGURE 3: These results from a COMSOL® software simulation show the power dissipation density, or the extent of the ablation, as determined by the thermal damage calculation. The antenna and the surrounding tissue are initially well-matched, and the match (i.e., the antenna pattern) changes over time as tissue temperature increases during the procedure (left to right).

» **REAL-TIME MONITORING OF ABLATIONS**

“THE CHALLENGE NOW is to monitor the ablation performance in real-time,” said Casey Ladtkow, principal engineer in the Early Technologies unit of Medtronic’s Minimally Invasive Therapies Group (MITG). “At present, when performing ablations, physicians don’t have continuous real-time feedback on the effectiveness of their procedure. If they could know exactly what is hap-

pening in real-time from start to finish, the effectiveness of ablation treatment would increase,” he said.

With some 40 staff members focused on interventional oncology, the mission of his unit is to deliver procedural solutions that alleviate pain, restore health, and extend life. He and his team are using COMSOL Multiphysics® software to develop new ablation probes in order to achieve even higher levels of predictable perfor-

mance and effectiveness.

One development-stage project is to optimize the design of these probes so they can both create a more precise ablation zone and also provide real-time feedback using radiometers.

Radiometers measure EM radiation and enable the characterization of the spatial distribution of an EM field. Ladtkow’s team is incorporating radiometers into Medtronic probes in order to give clinicians real-time feedback about the ablation zone. This will enable a clinician to fine-tune the zone as needed during the procedure, and to make sure the radiation destroys the targeted tissues while minimizing effects on the surrounding healthy tissue.

The team uses COMSOL Multiphysics and its RF Module to help them model the probes and better understand and optimize their emitting/radiating and receiving/monitoring properties. “The performance and accuracy of MW ablation systems are affected

by a number of dynamic factors that arise simultaneously in multiple physics domains. COMSOL® software gives us the ability to perform the relevant complex modeling quickly and easily, to help us understand these coupled effects and improve our design,” Ladtkow said.

» **SIMULATION ENABLES FAST AND SAFE DESIGN, OPTIMIZATION, AND PROTOTYPING**

FOR SUCH A COMPLEX device, the traditional approach of building and evaluating a series of physical prototypes is all but out of the question because of the complexity and relationships among the many physics-based factors that impact device performance.

The team used COMSOL to model the energy radiator and test designs that incorporated radiometric sensing in the same device. They simulated coupled thermal and electromagnetic effects around the radiative probe hardware to determine radiometric performance under different conditions (Figure 3).

Ladtkow analyzed heat transfer in living tissue using a bioheat equation, which included a perfusion term, to account for blood flow cessation once the tissue coagulated (Figure 4). This helped his team understand heat transport to cells around the tumor and predict the temperature distribution to ensure efficient and predictable energy delivery.

“ Multiphysics simulation enabled the rapid development, evaluation, and optimization of our design, which would not have been possible otherwise.”

—CASEY LADTKOW, PRINCIPAL ENGINEER, MEDTRONIC

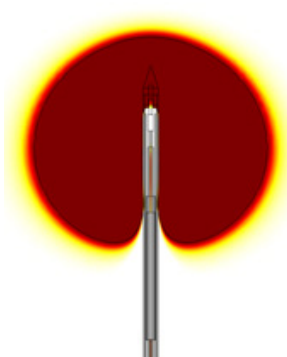


FIGURE 4: A COMSOL plot showing a cross section of the predicted ablation volume, or predicted tissue damage. This information is used to modify the bioheat equation and thereby to modify perfusion conditions in the tissue. Red areas represent coagulated tissue where no perfusion is present, and white areas represent areas of normal perfusion. This makes the model more accurate by creating a realistic on/off condition for the perfusion term in the bioheat equation.

He performed other studies as well: investigations of temperature dependence of reaction rates (to understand the size of the ablation zone); radiometry modeling to determine how much energy enters the tissue and how much is reflected back into the radiator; and liquid-to-gas phase-change dynamics (Figure 5). “The latter is critical to knowing what the wave pattern will look like, because knowing how much water is in the tissue is critical to knowing how a radiometer will behave, because of the change in wavelength,” he said. “Implementing this model in COMSOL is straightforward.”

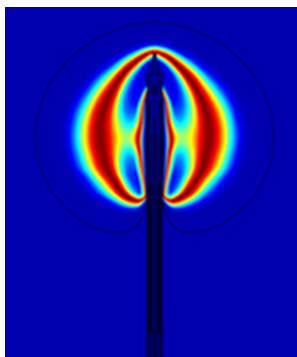


FIGURE 5: COMSOL results show the change in heat capacity in the tissue surrounding the probe, dominated by phase change of water in that tissue. Knowing where water is boiling is important because the MW radiation wavelength is dramatically different for liquid water than for vaporized water.

Simulation showed that lengthening the proximal radiating section (PRS) and shortening the distal radiating section (DRS) of an antenna would produce an efficient ablation radiator and an efficient receiver. These studies (Figure 6) resulted in versions of a prototype ablation radiator with an integrated radiometer, along with results showing the performance of the integrated probe.

» FROM IMPOSSIBLE TO POSSIBLE

“WITHOUT COMSOL to help us perform these analyses, it simply would be impossible to do enough experiments to find an optimum solution that integrates an emitter and a receiver. COMSOL helps us see that certain architectures—which we’d never have investigated otherwise—might make an

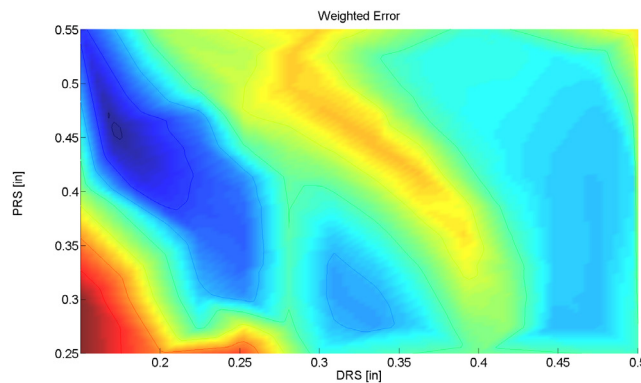


FIGURE 6: A COMSOL weighted error plot. Blue areas indicate regions where reflected power is low for delivered ablation energy and also where the receiver quality is good. They represent antenna configurations that are both good ablation devices and good radiometers.

integrated device possible,” Ladtchow continued.

His team uses COMSOL® software in conjunction with MATLAB® software, and he said that the combination gives him a powerful ability to optimize complex models with highly sophisticated algorithms quickly and easily. He also hopes to integrate the Application Builder available in COMSOL Multiphysics into their modeling workflow. This would enable the team to create simulation apps allowing partners

to test and verify different designs, while protecting their proprietary models.

“Based on our simulations, we are now realizing the potential to introduce ablation devices that will allow clinicians to not only deliver a precise energy dose, but also monitor ablations in real time,” Ladtchow said. “Multiphysics simulation enabled the rapid development, evaluation, and optimization of our design, which would not have been possible otherwise.” ☺



From left: The Medtronic team consists of Morgan Hill, Casey Ladtchow, and Robert Behnke.