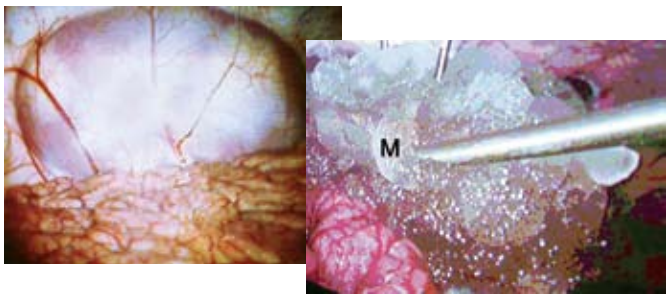
Argonne Uses ABAQUS to Guide Development and Application of Ice Slurries for Kidney Cooling

Surgeons who perform open-cavity kidney operations use hand-packed ice around the organs to delay organ damage and extend surgical times. However, doctors performing less-invasive laparoscopic surgeries do not have this option. They must clamp off major blood vessels prior to surgery, decreasing the time available before tissue damage from lack of oxygen develops. To date, many proposed cooling variations have not worked well for laparoscopic surgery. Traditional medical ice slurry does not flow reliably and clogs in surgical tubing. Surgery has thus been limited to around 30 minutes and can address only simpler scenarios, such as small tumors. An effective cooling solution would enable doctors to extend surgery times and tackle more complex problems in a less-invasive way, improving patient recovery time as well.

Innovative Ice Slurries

Argonne Labs and the University of Chicago Medical School have been developing new ice slurry cooling solutions. "We've worked on these slurries for more than ten years, first for industrial application and then, starting six years ago, with emergency room physicians, nephrologists, cardiologists, neurologists, and brain specialists," said Ken Kasza (Ph.D.), a senior mechanical engineer in the Energy Technology Division at Argonne. "With their help, we've been able to create a number of promising slurry formulations and medical applications."



Laparoscopic surgery view of kidney prior to delivery of slurry (left) and kidney covered with slurry from delivery tube M (right). *(Photos were captured from a video monitor by Argonne at U.C.)*

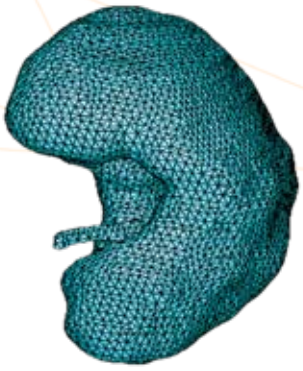
The newly developed slurries use a saline carrier solution that is biologically compatible and is much like the drip bag saline already in common medical use. Use of this coolant can extend surgical time to more than 90 minutes. One of their patented micro-particle slurries is pumped effectively through small surgical tubing. During testing it has cooled kidneys from 37˚C to below 15˚C in less than 10 minutes.

Simulation Validates Efficacy

An important task in developing and validating the efficacy of slurry cooling was simulating the cooling of a kidney using ABAQUS. "We use numerical simulation to guide development and prove out all of our medical cooling projects, which also involve cooling other organs," Kasza said.

To simulate cooling of the tissue, Kasza and his colleague, F. C. Chang, incorporated the commonly used Pennes bio-heat transfer equation into ABAQUS. This equation enables modeling of tissue metabolism and perfusion thermal behavior. They created a three-dimensional mesh model for a kidney using scanned images of thirty-six two-dimensional parallel image slices of kidneys from the National Institutes of Health Human Image databanks . They then created a three-dimensional model and mesh from the scanned slices. The finished computational mesh contained 80,426 tetrahedral heat transfer elements.

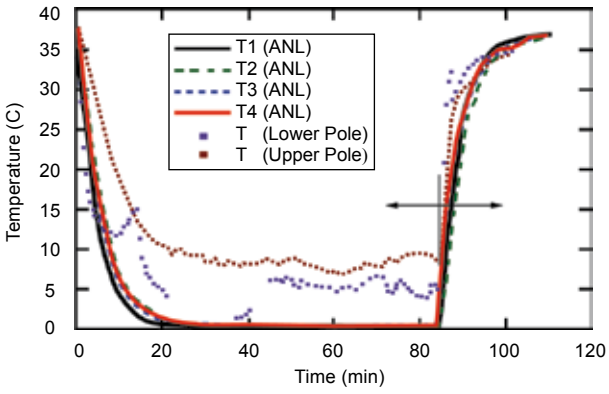
The researchers performed two kidney cooling simulations using kidney temperature data from two tests involving laparoscopic and transperitoneal surgical access to a kidney. The initial kidney temperature was 37˚C for both tests. The tests performed involved completely covering the kidney with ice slurry (applied immediately after blood vessel clamp-off). They were simulated by setting the mesh boundary temperature to 0˚C and the metabolic/perfusion rates to 0.



Meshed 3-D ABAQUS model of a kidney used to perform cooling simulations. (Model courtesy of Argonne Labs.)

Results

Simulation results were compared to physical data for cooling during minimally invasive surgeries. For all tests, the predictions agreed well with the physical measurements during the cool-down process with clamped blood vessels. They also agreed reasonably well during warmup when vessels are unclamped, perfusion resumes, and metabolic rate becomes active again.



Comparison between ABAQUS predicted kidney cooling temperature and Test 1 data obtained from experiments conducted at the University of Chicago under minimally invasive laparoscopic surgery conditions.

"A long-term goal of this research is to create a patient-specific kidney simulation that surgeons can use to plan the cooling strategy for their surgery," Kasza said. To reach this goal, Argonne is currently creating higher-resolution kidney models from CT and MRI scans to account for major blood vessels, voids, and any tumors within the kidneys of individual patients. Argonne is also expanding its development of ice slurry cooling and ABAQUS simulations to other organs where cooling provides protection from ischemia during surgery or medical emergencies such as cardiac arrest.

For More Information
Learn more about using ABAQUS for biomedical solutions at **www.abaqus.com/medical**.