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# LAPAROSCOPIC RENAL PARENCHYMAL HYPOTHERMIA WITH NOVEL ICE-SLUSH DEPLOYMENT MECHANISM

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## ABSTRACT

**Objectives.** To report the development of a novel, simple-to-use method for laparoscopic deployment of fine-quality saline ice slush by way of a 10-mm end-effector for laparoscopic parenchymal hypothermia.

**Methods.** A mechanism for making fine ice slush was created, and a 10-mm laparoscopic end-effector was designed and constructed for deployment of the ice slush. The novel ice slush deployment system was tested in a porcine model and compared with that of standard open ice slush cooling. After atraumatic hilar clamping, the cortical and medullary temperatures in the upper, middle, and lower poles were measured with thermocouples.

**Results.** Six pigs were evaluated in each group. In all cases, the kidneys were successfully cooled to our goal temperature of 15° to 25°C within 10 minutes and were maintained at the target temperature for 1 hour. The core body temperature for the slush group was decreased by 3°C but did not change in the open group. The renal temperatures quickly returned to normal on unclamping of the renal hilum. One pig in the open group died of acidosis and another in the same group experienced thrombosis of the renal artery. No complications occurred in the laparoscopic group.

**Conclusions.** We describe a novel, simple-to-use mechanism for producing and delivering fine ice slush in a laparoscopic setting. The technique achieves optimal parenchymal hypothermia expeditiously. UROLOGY **66:** 33–37, 2005. © 2005 Elsevier Inc.


Nephron-sparing surgery has gained acceptance as a means to preserve renal function without compromising oncologic control of renal tumors.[1] Complex renal tumors often require transient hilar clamping to allow controlled excision of the tumor in a bloodless field, suture repair of the collecting system, and parenchymal reconstruction. However, extended renal warm ischemia times are associated with renal function impairment.[2] Adequate renal hypothermia significantly decreases renal metabolic activity and protects the kidney from ischemic insult due to hilar clamping.[3,4] Traditionally, in open surgery, renal hypothermia is obtained by clamping the renal vasculature and packing ice around the kidney.

Several groups have described their surgical technique for laparoscopic partial nephrectomy and have replicated the open technique in most respects.[5,6] However, achieving renal hypothermia has posed a challenging problem for laparoscopic surgeons. Several techniques for laparoscopic hypothermia with delivery of ice slush to the kidney have been devised. Gill and colleagues[7] reported enclosing the kidney within a bag and inserting ice slush into the bag with a 30-mL syringe. Similarly, Wakabayashi and coworkers[8] described application of a funnel insertion device to pour ice slush into the retroperitoneum. These techniques successfully produced renal hypothermia but lacked a dedicated delivery system that could be used in a consistent, simple fashion with a standard 12-mm trocar.

We developed a novel system to produce and reliably deliver fine quality ice slush around the kidney during laparoscopic procedures through a

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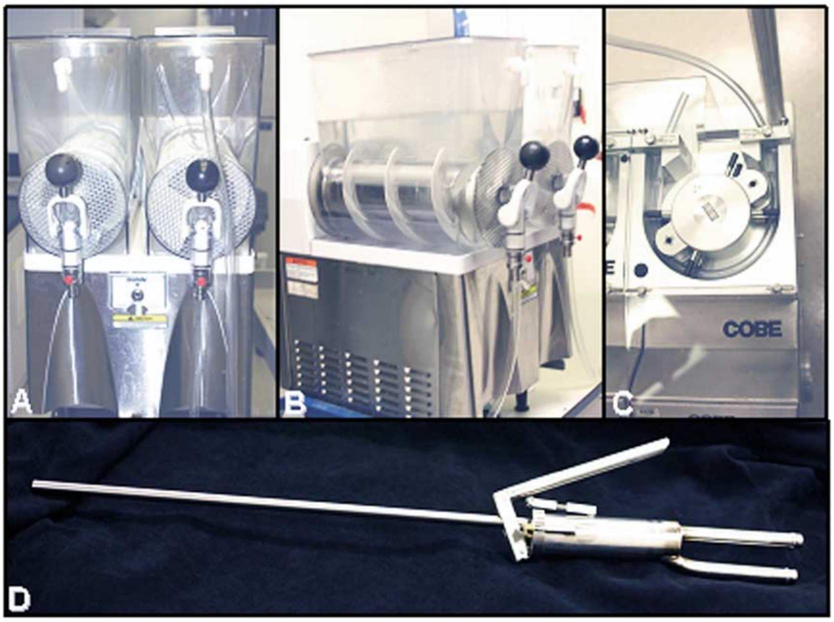


FIGURE 1. *Modified Bunn Ultra-2 Specialty Drink Machine (A,B) used to create fine ice slush from sterile saline. Ice slush propagated through vinyl tubing by peristaltic pump (C) and delivered through 12-mm laparoscopic port with specially designed end-effector (D).*

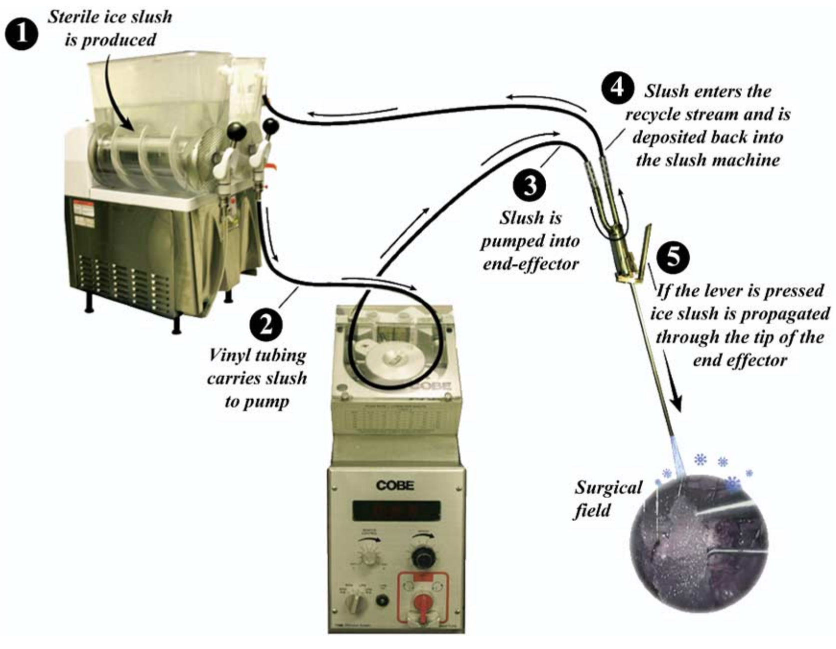


FIGURE 2. *Flow of ice slush from slush machine through peristaltic pump and end effector and into surgical field.*

12-mm trocar. We tested this mechanism in a porcine model to evaluate the effectiveness of the system.

## MATERIAL AND METHODS

The fine quality ice slush was created with a modified Bunn Ultra-2 Specialty Drink Machine (Fig. 1) to which saline was added for generation of a fine ice slush. This slush was then delivered through 0.5-in. vinyl tubing using a peristaltic pump to a custom-built, laparoscopic 10-mm end-effector. To minimize slush melting within the tubing, a slush recycle system was incorporated to circulate the slush in the tubing from the end-effector back to the generator when active deployment of ice slush is not in process (patent pending) (Fig. 2).

With the approval of the Washington University School of Medicine Animal Studies Committee, 12 domestic pigs weighing 30 to 40 kg were randomized to either laparoscopic (n = 6) or open (n = 6) renal hypothermia. After renal mobilization, five thermocouple probes were inserted into the kidney: three in the cortex of the upper, mid, and lower poles (0.5 cm deep) and two in the medulla of the upper and mid-poles (1.5 cm deep). Baseline temperature readings of the kid-

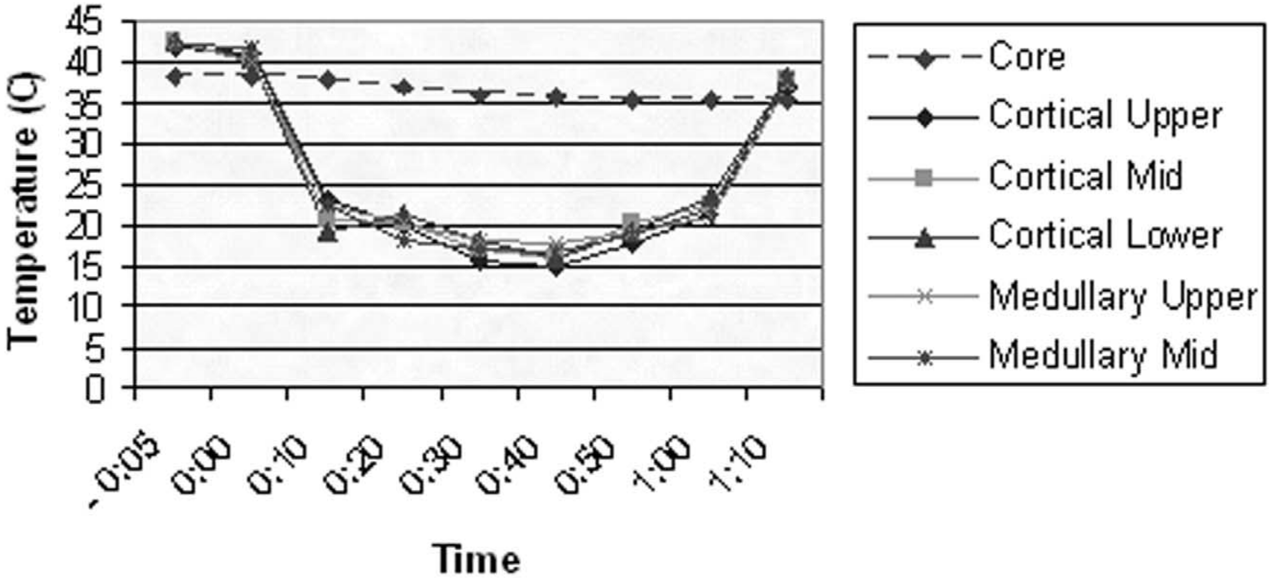


FIGURE 3. *Renal parenchymal and core body temperatures with laparoscopic deployment of novel ice slush mechanism. Goal temperatures of 15° to 25°C were consistently reached within initial 10 minutes of cooling.*

ney were recorded. Each animal's core body temperature was recorded using a thermometer in the animal's nostril. Animals were placed on a heating blanket and warmed air was applied under the surgical drapes as necessary to maintain the core body temperature.

In both groups, after clamping the renal artery using a Satinsky or laparoscopic bulldog clamp (the vein was left patent), renal parenchymal hypothermia was induced. In the laparoscopic group, ice slush produced by a modified commercial slush generator (Bunn-O-Matic, Springfield, Ill) was propelled by a peristaltic roller pump (Cobe Cardiovascular, Arvada, Colo) through 0.5-in. vinyl tubing (Tygon Flexible Tubing, Saint-Gobain Performance Plastics, Paris, France) and delivered through a specially designed 10-mm end-effector. The end-effector delivered the ice slush under laparoscopic vision and control. In the open group, ice was created using standard operating room practice and was packed around the kidney in the traditional manner.

During the ensuing 1 hour of cold ischemia, the renal parenchymal and core body temperatures were recorded every 10 minutes. After 1 hour, the renal artery was unclamped, and the ice was suctioned off the field. The renal and core body temperatures were monitored until the renal temperatures came within 5°C of body temperature or for a maximum of 1 hour, then the animals were killed. Partial nephrectomy was not performed, because the purpose of these experiments was simply to prove that our novel slush system can provide cold ischemia in a laparoscopic system.

The slush generator, tubing, and end-effector were sterilized with ethylene oxide. Samples of sterile ice slush from both the novel laparoscopic system, as well the ice slush produced in the standard method by operating room staff, were cultured to prove successful sterilization of the system.

## RESULTS

In all cases, the kidneys were successfully cooled to our goal temperature of 15° to 25°C within 10 minutes and were maintained at the target temperature for 1 hour. Figure 3 illustrates the cortical and medullary temperatures in the upper, middle, and lower poles at baseline and on laparoscopic deployment of the novel ice slush mechanism. In the laparoscopic group, the core body temperature decreased by a mean 3°C during cooling. The early animal (with the most watery ice slush) experienced a drop in body temperature to 34.3°C but the last animal (with slush that was less watery) only had a drop in body temperature to 36.4°C. After 1 hour of renal hypothermia, the renal parenchymal temperatures returned to normal within 10 minutes.

The results of the open renal cooling group are shown in Figure 4. The target renal temperatures of 15° to 25°C were obtained within 10 minutes without a change in the core body temperature. The nadir parenchymal temperature for the animals in the laparoscopic group ranged from 7° to 16°C and in the open group ranged from 5° to 8°C. These numbers were not statistically significant ($P = 0.07$). One pig in the open group died of acidosis and another developed renal artery thrombosis. No complications occurred in the laparoscopic group. Ice slush from both the novel laparoscopic system and the standard operating room method were proven to be sterile.

## COMMENT

Renal hypothermia decreases renal metabolism and thus protects renal tubular cells and minimizes ischemic renal injury. Wickman and colleagues[3] and Ward[4] elegantly demonstrated that the temperature range of 5° to 20°C induces a hypothermic state that significantly decreases renal metabolic activity. Several investigators have recently sug-

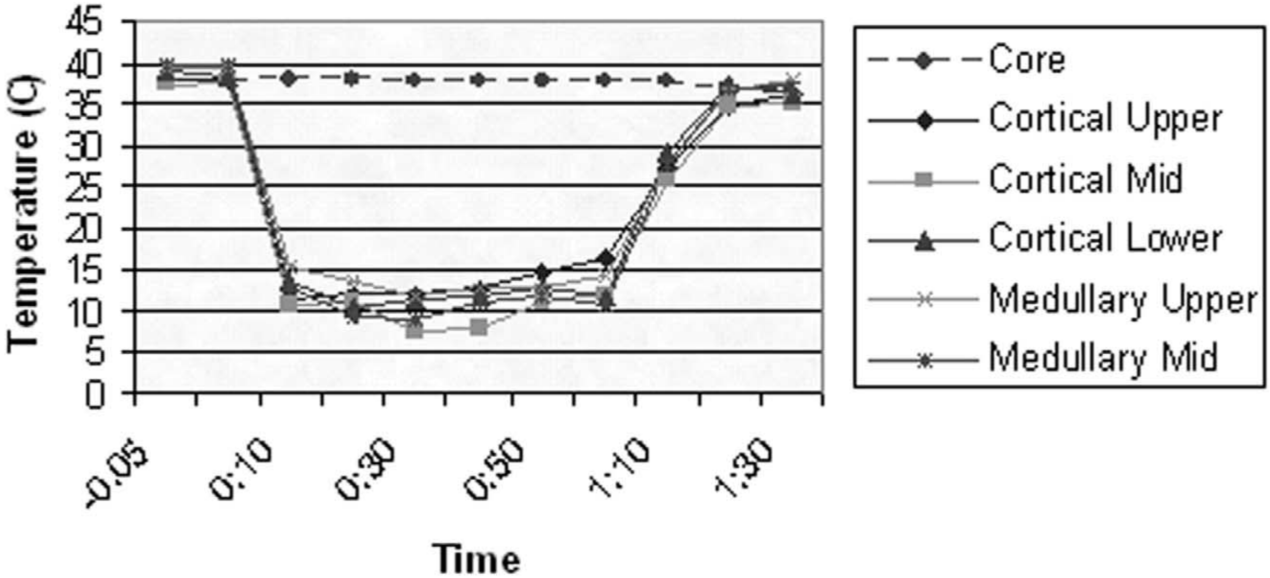


FIGURE 4. *Renal parenchymal and core body temperatures with traditional open renal exposure and packing of kidney in ice.*

gested that renal function is not impaired during short warm ischemic times.[9,10] Nonetheless, renal hypothermia has been the standard practice for complex open partial nephrectomy requiring ischemic times longer than 30 minutes.[11] As the technical success of laparoscopic partial nephrectomy mounts, larger tumors that more deeply invade the parenchyma will be approached laparoscopically with associated longer ischemic times.

Multiple techniques for inducing renal hypothermia have been reported. We have previously described renal hypothermia achieved by retrograde endoscopic cold saline perfusion through a ureteral access sheath.[12] The limitations of the "intrarenal cooling" technique included the need for postoperative stenting and that the renal cortex did not cool as efficiently as the medulla during retrograde cold saline perfusion. Despite these limitations, the intrarenal cooling technique remains our standard clinical practice when parenchymal hypothermia is required for laparoscopic partial nephrectomy.

Renal parenchymal hypothermia has also been described by way of vascular perfusion of the renal artery with Ringers lactate.[13,14] These techniques place the vasculature at risk of injury or thrombosis, subject the patient to potential volume overload, and require special skills not typically possessed by the practicing urologist. Herrell and colleagues[15] developed a novel approach for achieving renal hypothermia by applying a cooling sheath to the kidney. The sheath was efficacious but could not be deployed using a standard 12-mm trocar.

Despite the emergence of novel ideas to induce renal hypothermia, the application of ice slush around the kidney remains the most reliable and efficacious technique. With our novel system, a fine ice slush is generated that can be propelled through tubing using a roller pump from the generator to the end-effector. The surgeon has the ability to control the flow rate of slush easily and conveniently by depressing the handle of the end-effector.

The advantages of this technique include the recycle system that ensures ice slush at a near perfect consistency, the capability of the surgeon to control the placement and flow rate of the slush, and a purely laparoscopic delivery system without the need for trocar site enlargement. The paste-like consistency of the slush and the presence of the pneumoperitoneum, which separates the kidney from the bowel, preclude the need for a bag, which is occasionally used in open surgery to contain the slush around the kidney. Such a bag is cumbersome to deploy laparoscopically (as suggested by the fact that most laparoscopists still use warm ischemia for partial nephrectomy despite the description of other ice systems). Finally, that a bag is not necessary in our system will make laparoscopic cold ischemia a more simple undertaking for the surgeon. Although cooling of the bowel is a potential problem, no interruption to arterial perfusion of the mesentery occurs and, therefore, any ice that reaches the bowel melts immediately. Bowel loops remained pink throughout the experiment.

Ice slush can be easily added during the case if melting occurs. We noted a small amount of melting on first application of the slush; however, once the ischemic kidney was cooled, additional application was unnecessary. The animals involved in the early experiments had a drop in core body temperature; however, this problem was reduced by using a machine with greater control over the slush consistency. By creating a slush that had a consistency of toothpaste, the run off around the peritoneal cavity was less, and, therefore, less systemic cooling occurred.

All components of this design were sterilized. Currently, design modifications are in progress to optimize the function of the system and allow for commercial development. Because the novel ice slush machine and deployment mechanism are highly efficacious and easy to use, it is anticipated that the device will have applications outside of urologic surgery and that it will have application in both open and laparoscopic procedures that require parenchymal hypothermia.

## CONCLUSIONS

The results of our study have indicated that renal parenchymal hypothermia with the ice slush generator using a 10-mm end-effector is feasible and achieves excellent hypothermic effect expeditiously. In the in vivo porcine model, the system resulted in only a minimal decrease in core body temperature without the need for a bag, which is cumbersome to place laparoscopically.

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