

LAPAROSCOPIC ICE SLUSH RENAL HYPOTHERMIA FOR PARTIAL NEPHRECTOMY: THE INITIAL EXPERIENCE

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ABSTRACT

Purpose: We describe a novel technique of laparoscopic renal hypothermia with intracorporeal ice slush during partial nephrectomy as well as clinical experience with the initial 12 patients.

Materials and Methods: A total of 12 select patients with an infiltrating renal tumor who were candidates for nephron sparing surgery underwent transperitoneal laparoscopic partial nephrectomy with renal hypothermia. An Endocatch II (United States Surgical Corp., Norwalk, Connecticut) bag was placed around the mobilized kidney and its drawstring was cinched around the intact renal hilum. The renal artery and vein were occluded en bloc with a Satinsky clamp. The bottom of the engaged bag was retrieved through a 12 mm port site and opened, and ice slush was introduced within the bag to completely surround the kidney. After renal hypothermia was achieved laparoscopic partial nephrectomy was performed by duplicating open surgical techniques. Renal parenchymal temperature was measured using a thermocouple needle in 5 patients. Median tumor size was 3.2 cm (range 1.5 to 5.5), 6 tumors (50%) were central in location and an imperative indication for partial nephrectomy was present in 7 patients (58%).

Results: All procedures were successfully completed laparoscopically without open conversion. Median time to deploy the bag around the kidney was 7 minutes (range 5 to 20), the median volume of ice slush introduced was 600 cc (range 300 to 750) and the time needed to insert the ice slush was 4 minutes (range 3 to 10). Median blood loss was 200 cc, total ischemia time was 43.5 minutes (range 25 to 55) and total operative time was 4.3 hours (range 3 to 5.5). Nadir renal parenchymal temperature was 5C to 19C and the mean decrease in systemic temperature was 0.6C. Histopathology confirmed renal cell carcinoma in 11 patients (92%), of whom all had negative surgical margins. Intraoperative complications occurred in 2 initial patients, including partial bag slippage in 1 and Satinsky clamp malfunction in 1. Postoperatively renal scan confirmed a functioning ipsilateral kidney in all cases.

Conclusions: To our knowledge we present the initial clinical report of laparoscopic renal hypothermia for partial nephrectomy. By replicating standard open surgical practice our intracorporeal ice slush technique has the potential to extend the scope of laparoscopic partial nephrectomy to more complicated renal tumors.

KEY WORDS: kidney, nephrectomy, laparoscopy, hypothermia

Laparoscopic partial nephrectomy is emerging as a viable treatment alternative for select patients who are candidates for nephron sparing surgery. Initially laparoscopic nephron sparing surgery was limited to benign conditions or a small exophytic tumor.^{1–3} With increasing experience we developed a more comprehensive laparoscopic technique for performing substantive partial nephrectomy for larger or more deeply infiltrating tumors, including transient renal hilar control, controlled excision of the tumor in a bloodless field, precise suture repair of the collecting system and hemostatic renal parenchymal reconstruction, similar to open surgery.⁴ Thus, although most open partial nephrectomy steps are replicated by our laparoscopic technique, to our knowledge laparoscopic renal hypothermia has not been reported clinically. As such, renal hilar clamping has resulted in laparoscopic partial nephrectomy being performed under warm ischemia conditions. We developed a novel technique of pure laparoscopic renal hypothermia and report on the initial 12 patients undergoing this procedure.

MATERIALS AND METHODS

Between May and August 2002, 12 select patients with an infiltrating tumor underwent transperitoneal laparoscopic partial nephrectomy with intracorporeal renal hypothermia. Table 1 lists baseline demographics. Three patients (25%) had an elevated baseline serum creatinine of 1.8, 2.2 and 1.5 mg/dl, respectively (normal 0.7 to 1.4). Median tumor size was 3.2 cm (range 1.5 to 5.5). All 12 tumors were infiltrating into the renal parenchyma. The median depth of invasion on intraoperative ultrasonography was 1.5 cm (range 0.7 to 2.5). Partial nephrectomy was performed for an imperative indication in 7 patients (58%) and 2 (17%) had a tumor in a solitary kidney.

LAPAROSCOPIC TECHNIQUE

A transperitoneal laparoscopic approach is used.⁴ A 5Fr open ended ureteral catheter is inserted cystoscopically and positioned in the renal pelvis. The renal artery and vein are circumferentially mobilized en bloc without any attempt at individual dissection of the vessels. A laparoscopic Satinsky clamp is test positioned across the renal hilum to confirm

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TABLE 1. Demographic data

No. pts	12
No. males (%)	6 (50)
Median age (range)	57.5 (41–73)
Median American Society of Anesthesiologists score (range)	2 (2–3)
Median body mass index (range)	30 (20.5–40.3)
No. rt kidney (%)	10 (83.5)
Median mg % preop serum creatinine (range)	1.1 (0.7–2.2)
No. indication for partial nephrectomy (%):	
Solitary kidney	2 (16)
Bilat masses	5 (42)
Normal contralat kidney	5 (42)
Median cm tumor size on computerized tomography (range)	3.2 (1.5–5.5)
No. tumor location (%):	
Upper pole	5 (42)
Mid pole	7 (58)
Lower pole	0
No. tumor site (%):	
Anterior/anterolat	8 (67)
Lateral	2 (16)
Posterior/posterolat	2 (16)
No. tumor depth (%):	
Completely exophytic	0
Infiltrating, not abutting sinus	6 (50)
Infiltrating, abutting sinus	6 (50)
Median cm tumor infiltration depth (range)*	1.5 (0.7–2.5)

* Measured by intraoperative laparoscopic contact ultrasonography.

adequate hilar preparation. The kidney is completely mobilized within Gerota's fascia, maintaining perirenal fat over the tumor. Complete renal mobilization is essential with the upper pole mobilized away from the adrenal gland and the lower pole mobilized away from the ureter. Laparoscopic ultrasonography is performed to delineate the tumor and circumferentially score the proposed line of resection around the tumor, including an adequate margin of healthy tissue. Mannitol (12.5 gm) is administered intravenously and a Satinsky clamp is positioned around the intact, en bloc renal hilum without closing its jaws.

Sterile ice slush is created in an ice slush machine and constantly stirred manually to reduce it to a fine consistency. Five 30 cc syringes are modified by cutting off the nozzle end of the barrel. They are prefilled with ice slush in preparation for rapid injection.

The 12 mm inferior pararectal port is removed and a 15 mm Endocatch II bag is inserted through the same skin incision. The bag is opened and carefully positioned around the kidney. The drawstring is pulled, thus, detaching the bag and deploying it around the kidney. The disengaged metal ring of the bag is removed from the abdomen and the inferior pararectal port is reinserted. The drawstring is further cinched with extreme care taken to avoid any trauma to the renal artery and vein. Typically the drawstring cannot be cinched completely, requiring placement of hem-o-lock clips to snug the mouth of the bag gently around the intact renal hilum. Thus, the kidney is completely enclosed by the bag. The enclosed kidney and bag are retracted laterally and the jaws of the Satinsky clamp are securely closed around the renal hilum under direct vision with care taken not to catch any part of the bag within the clamp jaws.

The bottom end of the engaged bag is grasped with locking laparoscopic Allis forceps inserted through the inferior pararectal port. This port is removed, delivering the end of the bag outside of the abdomen, where it is secured with a hemostat. The port site skin incision is extended by only 2 to 3 mm and the peritoneal fascia is similarly incised.

Pneumoperitoneum is desufflated and the exteriorized end of the bag is cut open. Using the previously loaded syringes 600 to 750 cc of ice slush are rapidly inserted into the bag, thus, completely surrounding the kidney with ice (fig. 1). The opened end of the bag is closed with a tie, the bag is reinserted into the abdomen, a 10 mm balloon cuffed Bluntip

cannula (U.S. Surgical, Norwalk, Connecticut) is secured at this port site and pneumoperitoneum is restored.

Laparoscopic visualization confirms that the kidney is properly surrounded by ice slush within the bag (fig. 2). A laparoscopic sponge (4 × 18 inches) can be positioned around the bag to prevent bowel from coming in direct contact with the ice filled bag. After approximately 10 minutes the bag is incised and the ice slush is removed from around the tumor site only, leaving the ice in contact with the remainder of the kidney surface (fig. 3). In 5 patients a 21 gauge (0.023-inch) 17 cm thermocouple probe was percutaneously introduced into the abdomen through a 18 gauge angiocatheter sheath and inserted into the renal parenchyma for a depth of approximately 3 mm to 2 cm (fig. 4). This thermocouple was attached to a portable data recorder to measure the renal parenchymal temperature, which was digitally displayed on a laptop computer. Systemic esophageal temperature was continuously monitored by the anesthesiologist.

Laparoscopic partial nephrectomy is performed according to our previously described technique.⁴ Briefly, the operative steps include tumor excision with a margin of healthy parenchyma using endoscopic shears without electrocautery (fig. 5), pelvic-iceal suture repair as necessary, control of major visible transected intrarenal vessels with individual figure-of-8 stitches and hemostatic renal parenchymal suture approximation over prefashioned surgicel bolsters. The hilum is then unclamped, hemostasis is confirmed and the bag is removed from

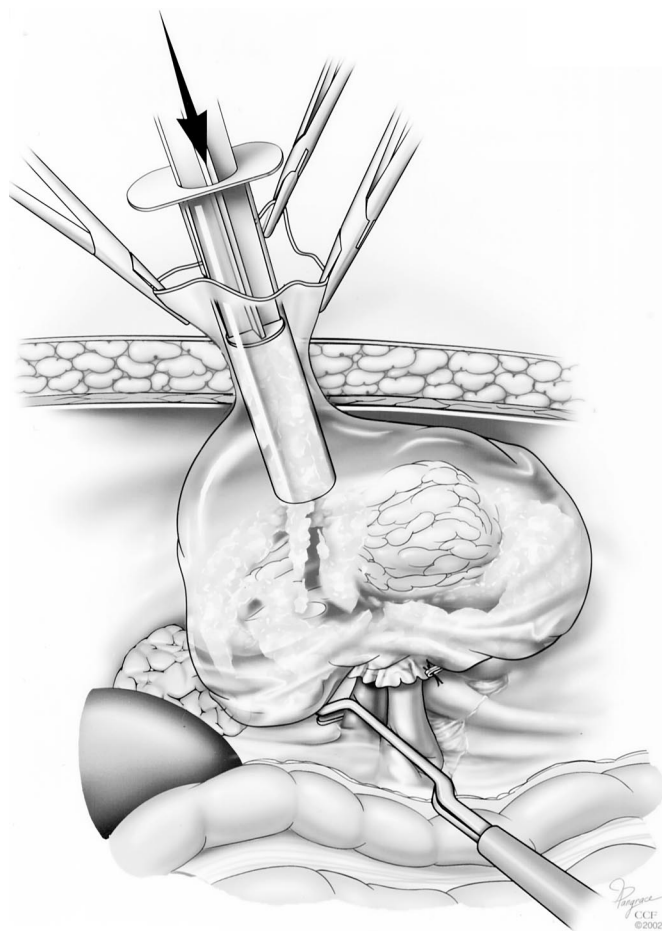


FIG. 1. Transperitoneal laparoscopic partial nephrectomy with renal hypothermia showing en bloc cross clamping of renal hilum with Satinsky clamp. Kidney is enclosed within deployed bag. Finely crushed ice slush is inserted (arrow) into bag mouth with 30 cc syringe. Syringe nozzle end is cut off to facilitate rapid injection. Port site incision is extended only 2 to 3 mm to allow easy insertion of syringe barrel.

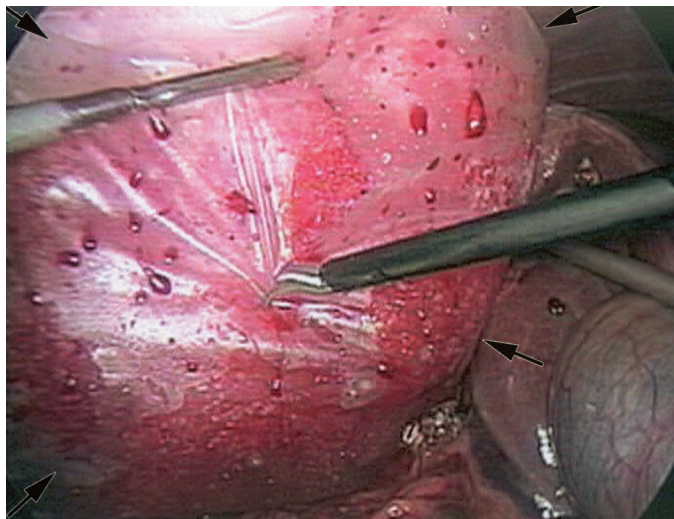


FIG. 2. Laparoscopic view of 750 cc ice slush filled bag. Arrows indicate bag outline. Kidney is not visible since it is completely surrounded with ice slush.

around the kidney. Following intact extraction of the entrapped partial nephrectomy specimen and confirmation of negative surgical margins laparoscopic exit is completed.

RESULTS

All 12 cases were completed laparoscopically without open conversion (table 2). Median time to deploy the bag was 7 minutes (range 5 to 20). A nadir renal parenchymal temperature of 5C to 19.1C was achieved in the 5 patients in whom thermocouple measurements were performed. Concomitantly median systemic esophageal temperature decreased by only 0.6C. Median total ischemia time was 43.5 minutes and total operative time was 4.3 hours (range 3 to 5.5). Pelvic/iceal suture repair was necessary in 8 patients (67%). Median hospital stay was 3 days (range 2 to 7).

The Appendix shows detailed data on serial renal parenchymal temperatures obtained by thermocouple measurements in 5 patients (fig. 6). For example, in patient 3 renal parenchymal temperature was 10.3C 13 minutes after renal hilar clamping and the introduction of ice slush. At the completion of tumor excision 7 minutes later renal parenchymal temperature was 16.4C, which increased to 19.8C at the completion of pelvic/iceal repair 8 minutes later. At the completion of partial nephrectomy 48 minutes after initial hilar clamping renal parenchymal temperature was 19.5C. At that time we maintained the thermocouple probe in position within the kidney and unclamped the renal hilum, thus, revascularizing the kidney. It required 3.5 minutes for renal parenchymal temperature to return to the patient baseline systemic esophageal temperature of 34.5C.

Intraoperative complications occurred in 2 initial patients. In 1 case the kidney was not fully mobilized, and the ice filled bag partially slipped off of the kidney. In the other case a part of the bag was inadvertently caught in the jaws of the Satinsky clamp at the time of hilar clamping. Thus, the renal vessels may have been occluded inadequately, resulting in a 500 cc blood loss during partial nephrectomy. Although thermocouple recordings were not performed, it is likely that renal hypothermia was suboptimal in these 2 cases. In these 2 patients total ischemic time was 50 and 40 minutes, and preoperative serum creatinine (0.9 and 0.7 mg/dl) was similar to postoperative serum creatinine (1.2 and 0.9 mg/dl), respectively.

Postoperative radionuclide renal scanning confirmed function of the operated kidney in each instance, although with various degrees of resolving acute tubular necrosis. For the

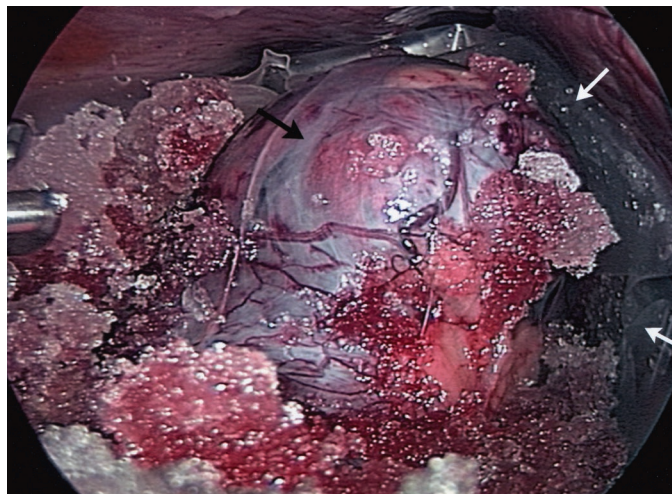


FIG. 3. Bag is cut open and renal tumor (black arrow) is exposed to begin laparoscopic partial nephrectomy. Ice was removed only from around tumor site, leaving remainder of kidney still submerged in ice. White arrows indicate cut edge of bag.

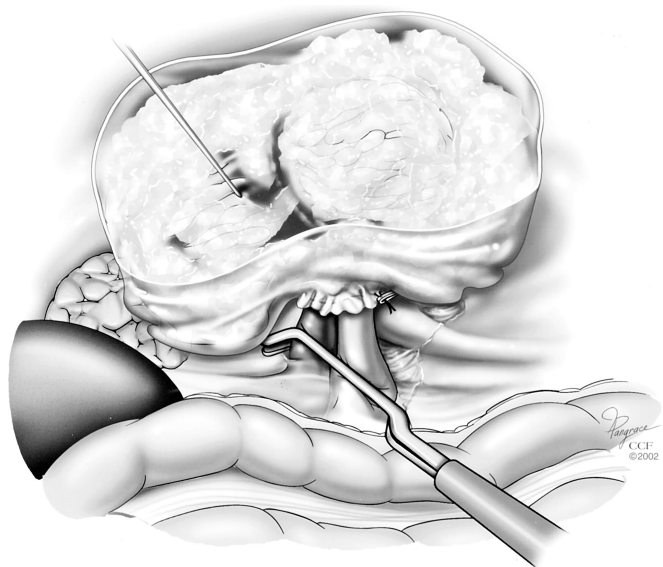


FIG. 4. In preparation for laparoscopic partial nephrectomy bag is cut open and needle thermistor is inserted into kidney to record nadir parenchymal temperature.

whole study group mean preoperative serum creatinine was 1.1 mg/dl. Mean peak serum creatinine was 1.5 mg/dl an average of 1.2 days postoperatively and mean nadir postoperative serum creatinine was 1.2 mg/dl an average 2.8 days postoperatively. Specifically 2 patients underwent laparoscopic partial nephrectomy in a solitary kidney, of which approximately 15% of the renal parenchyma were excised under hypothermia conditions. In these 2 patients preoperative serum creatinine was 0.8 and 1.0 mg/dl, and postoperative serum creatinine was 1.1 and 1.2 mg/dl, respectively. None of the patients in this series required any dialysis postoperatively. On histology renal cell carcinoma was confirmed in 11 patients, of whom all had a margin negative for cancer.

DISCUSSION

The technical success of laparoscopic partial nephrectomy depends on a bloodless operative field. Although transient renal hilar clamping achieves this goal admirably, the attendant penalty of warm ischemia is detrimental to the aerobic

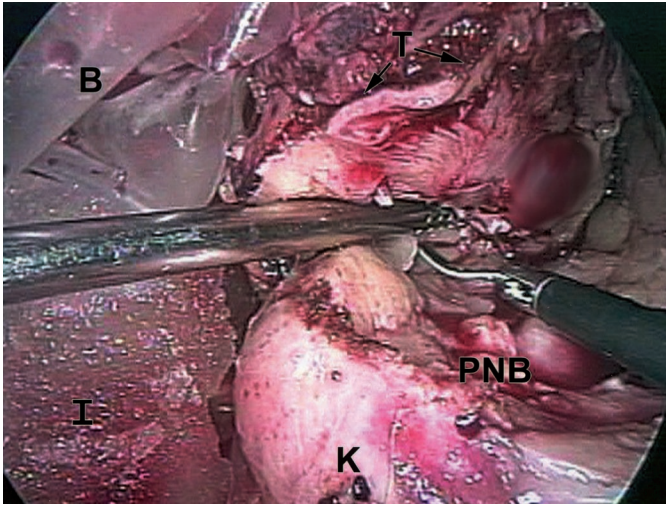


FIG. 5. Laparoscopic partial nephrectomy in progress. Excised tumor (*T*) is retracted upward and bloodless partial nephrectomy bed (*PNB*) is visible. *K*, kidney. *I*, ice. *B*, bag.

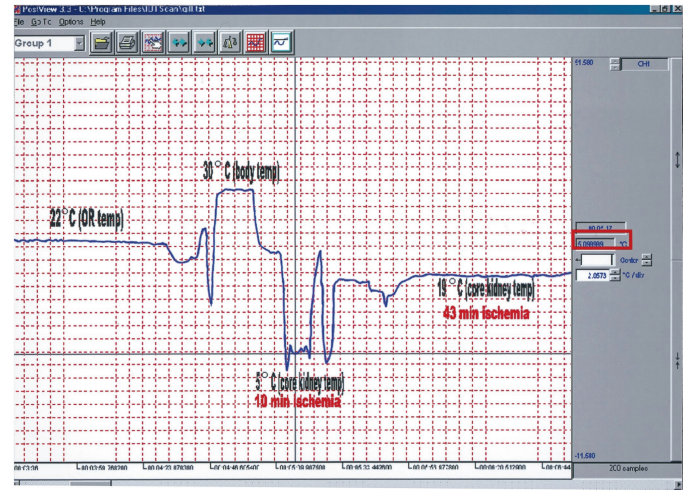


FIG. 6. Temperature graph from serial thermocouple recordings shows temperature measurements at various intervals.

metabolism of the kidney. Hypothermia induces short-term suspension of the renal metabolism, which is necessary for cellular protection and minimizing post-ischemic renal injury. Renal metabolic activity is almost completely suspended at temperatures of 5C to 20C.^{5,6} Therefore, in more complex cases in which the duration of warm ischemia is anticipated to exceed 30 minutes, renal hypothermia is established at the outset. Important adjunctive renoprotective measures used routinely include adequate intravenous hydration, avoidance of intraoperative hypotension, intravenous mannitol and furosemide, and minimizing the ischemic period by efficient preplanning.

During open partial nephrectomy surface cooling of the kidney with ice slush is the technique of choice for achieving renal hypothermia.⁷ We developed a purely laparoscopic technique of surface renal hypothermia with ice slush, similar to open surgery. Certain technical caveats deserve mention. After preparing the intact renal hilum for en bloc Satinsky clamping the kidney must be mobilized completely to allow it to be enclosed within the Endocatch II bag. If the kidney is not completely mobilized, bag slippage can occur, as in 1 case. Satinsky clamping of the hilum should be done

prior to exteriorizing the bag. Clamping the hilum after ice insertion is technically difficult and unreliable because the ice filled bag almost completely obscures the hilum. When clamping the hilum, care must be taken to ensure that no part of the bag is caught within the jaws of the Satinsky clamp, as in 1 case. This situation led to inadequate occlusion of the renal vessels, 500 cc intraoperative renal hemorrhage and presumably inadequate hypothermia. When exteriorizing the bottom of the bag, the inferior pararectal port site is carefully extended by only 2 to 3 mm to facilitate rapid insertion of the ice filled 30 cc syringe. Excessive enlargement of the skin incision leads to air leakage. The kidney should be allowed to remain completely submerged in ice slush for approximately 10 minutes to achieve adequate core cooling prior to initiating laparoscopic partial nephrectomy.

Intracorporeal ice slush surrounded the entrapped kidney adequately in each case. In the last 9 consecutive cases 600 cc or more of ice slush were inserted routinely. In the 5 patients in whom a needle thermistor was used renal parenchymal temperature decreased to a nadir of 5C to 19C. In 3 patients serial thermocouple measurements were made and terminal renal parenchymal temperature at the completion of partial nephrectomy just prior to hilar unclamping was 19C, 19.5C and 23.8C after 43, 48 and 44 minutes of ischemia, respectively. In 2 patients the needle thermistor was maintained within the kidney when the hilum was unclamped. It required 3.5 and 3 minutes, respectively, for renal parenchymal temperature to attain systemic body temperature. These data provide assurance that adequate renal hypothermia that lasts for the duration of hilar clamping can be achieved by our technique.

Various techniques of achieving renal hypothermia have been described. Transarterial hypothermic infusion by direct renal arterial puncture or by placement of a retrograde balloon catheter via femoral artery puncture can effectively lower renal parenchymal temperature.⁸ This technique has not found widespread clinical application because of the potential for renal artery injury and thrombosis, femoral artery puncture site sequelae, catheter slippage, the need to involve an interventional radiologist and the inability to use this technique in the presence of atherosclerotic, multiple, aberrant or small diameter renal arteries. Transpelvic or transureteral hypothermic perfusion, first described in the 1950s^{9,10} and more recently reevaluated at the laboratory¹¹ has been proposed. Inadequate cortical cooling of the human kidney is a potential drawback of this technique. Furthermore, during laparoscopic partial nephrectomy for an infiltrating tumor inci-

TABLE 2. Laparoscopic renal hypothermia perioperative data

No. pts	12
No. transperitoneal technique	12
No. en bloc hilum clamping	12
Median mins to deploy bag (range)	7 (5–20)
Median mins to insert ice slush (range)	4 (3–10)
Median cc ice inserted (range)	600 (300–750)
Median mins total renal ischemia time (range)	43.5 (25–55)
Median cc blood loss (range)	200 (50–500)
No. caliceal suturing (%)	8 (67)
Nadir parenchymal renal temperature (5 pts)	5–19.1C
Median systemic esophageal temperature decrease (range)	0.6C (0.3–0.9)
Median days hospital stay (range)	3 (2–7)
% Renal parenchyma excised*	15 (10–40)
Median mg % postop serum creatinine (range)	1.2 (0.9–2.4)
Median gm specimen wt (range)	32 (20–87)
No. histopathology (%):	
Renal cell Ca	11 (92)
Angiomyolipoma	1 (8)
No. neg surgical margins	12
No. intraop complications:	
Satinsky clamp malfunction	1
Partial bag slippage	1

* Surgeon subjective impression of amount of renal parenchyma excised recorded by surgeon immediately at the end of operation.

sional entry into the collecting system occurs early within 1 to 2 minutes of initiating tumor resection, which would lead to leakage of the transureteral cold perfusate, potentially compromising continued core hypothermia for most of the duration of surgery. A renal cooling jacket has been described for use during hand assisted partial nephrectomy.¹² Pharmacological agents such as inosine,¹³ captopril, and adenosine triphosphate magnesium chloride have been proposed to minimize ischemic renal damage. These techniques notwithstanding, surface hypothermia with ice slush remains the standard and most commonly used technique today during open partial nephrectomy.⁷

Certain shortcomings of our technique should be noted. Space limitations of the retroperitoneum precludes the use of our technique during retroperitoneal laparoscopic partial nephrectomy. Significant perinephric adhesions may prevent complete mobilization of the kidney, which is an essential technical prerequisite. The surrounding crushed ice and the folds of the bag may hamper operative exposure, requiring additional laparoscopic maneuvers. Renal parenchymal frostbite and general body hypothermia are theoretical possibilities, although an inconsequential decrease of only 0.6C in systemic temperature was noted in this series. While this new capability to achieve hypothermia by laparoscopic techniques certainly extends the scope of laparoscopic nephron sparing surgery, it should be noted that renal hypothermia is infrequently necessary during contemporary partial nephrectomy.¹⁴

CONCLUSIONS

A novel technique of laparoscopic renal hypothermia with ice slush that simulates open surgical practice is described. Our experience with the initial 12 patients indicates that adequate renal parenchymal cooling can be achieved by purely laparoscopic techniques. Additional studies to develop a more mechanically efficient ice slush delivery system is necessary and underway. With the incorporation of hypothermia our technique of laparoscopic partial nephrectomy now replicates the open surgical technique in all of its essential individual steps. The described technique has the potential to extend the repertoire of laparoscopic partial nephrectomy to broad based infiltrating tumors requiring complex renal reconstruction.

APPENDIX: SERIAL RENAL PARENCHYMAL TEMPERATURES RECORDED IN 5 PATIENTS

Patient 1 (8/8/02)

5C At 10 minutes (at beginning of tumor excision)

7C At 12 minutes (at completion of tumor excision)

19C At 43 minutes (upon completion of partial nephrectomy just prior to unclamping the renal hilum)

Patient 2 (8/22/02)

18C At approximately 5 minutes (prior to beginning tumor excision)

Patient 3 (8/26/02)

10.3C At 13 minutes (prior to beginning tumor excision)

16.4C At 20 minutes (upon completing tumor excision)

19.8C At 28 minutes (upon completion of pelviciceal suture repair)

19.5C At 48 minutes (upon completion of partial nephrectomy just prior to unclamping the renal hilum)

Following hilar unclamping time taken for the kidney to rewarm and reach baseline systemic body temperature (34.5C): 3.5 minutes

Patient 4 (8/26/02)

17C At approximately 5 minutes (prior to beginning tumor excision)

Patient 5 (8/29/02)

19.1C At 15 minutes (upon completing tumor excision)

17.4C At 30 minutes (upon completing pelviciceal suture-repair)

23.8C At 44 minutes (upon completion of partial nephrectomy just prior to revascularization)

Following hilar unclamping time taken for the kidney to rewarm and reach baseline systemic body temperature (35.5C): 3 minutes

Temperature was recorded with a needle thermocouple probe inserted into the renal parenchyma to varying depths of approximately 3 mm to 2 cm and each time period was calculated from the time of initial renal hilar clamping.

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