Spread of Thermal Energy and Heat Sinks: Implications for Nerve-Sparing Robotic Prostatectomy

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ABSTRACT

Background and Purpose: During nerve-sparing robot-assisted laparoscopic prostatectomy, nerve injury caused by thermal energy is a concern. Using a porcine model, we studied thermal spread and queried whether vessels such as the prostatic pedicle may act as a heat sink, reducing the spread of thermal energy.

Materials and Methods: Monopolar (MP) and bipolar (BP) cautery was applied laparoscopically on the anterior abdominal wall surface of six pigs with the da Vinci robot. Using fiberoptic thermometry (Luxtron Inc., Santa Clara, CA), temperatures were recorded with and without the interposed inferior epigastric vessels to evaluate the heat sink effect.

Results: Interposition of the inferior epigastric vessels definitively demonstrated a heat sink phenomenon: at 7 mm from the MP/BP energy source, temperatures rose 10.7°C to 13.8°C without interposed vessels versus only 1.9°C to 2.5°C when vessels were interposed (P < 0.001).

Conclusion: The heat sink phenomenon suggests that the prostatic vascular pedicle should be protective of the neurovascular bundle during transection of the bladder neck during laparoscopic prostatectomy.

INTRODUCTION

The objective of nerve-sparing radical prostatectomy is complete removal of the prostate without injuring or transecting the delicate neurovascular bundles (NVBs), which are intimately and variably related to the lateral, posterolateral, and posterior surfaces of the prostate. Electrocautery (monopolar [MP], bipolar [BP], harmonic energy) causes thermal injury to nearby neural tissue and is associated with a decreased erectile response to cavernous-nerve stimulation. Ahlering and colleagues showed remarkable improvements in sexual function within the first postoperative year if the use of electrocautery near the NVBs was eliminated in preoperatively potent men aged ≤65 years. As such, avoidance of thermal energy is emphasized during prostatic vascular-pedicle transection and NVB release when performing nerve-sparing procedures.

Whether performed with purely laparoscopic instruments or the robot, we are witnessing a paradigm shift from open to laparoscopic prostatectomy as the procedure of choice at many centers worldwide. Meticulous hemostasis is crucial to the laparoscopic surgeon, as even small amounts of bleeding are not well tolerated. Therefore, most surgeons using laparoscopic and robotic techniques utilize some form of thermal energy for hemostasis when dividing the bladder neck. Division of the bladder neck (posterior and laterally) approaches the NVBs; however, the prostatic vascular pedicle is a constant anatomic fixture interposed between these two structures (Fig. 1). Hence, we queried whether intervening blood vessels could act as protective heat sinks and dampen the spread of thermal energy to the NVBs during bladder-neck transection.

MATERIALS AND METHODS

The study was conducted in the urology research laboratory on six Yorkshire pigs, each weighing 40 to 45 kg, as part of Institutional Animal Care and Use Committee protocol No. 2002-2354. To study the potential for vessels (arteries and veins) to act as heat sinks, we approached the inferior epigastric vessels intra-abdominally using the da Vinci robot (Intuitive Surgical Inc., Sunnyvale CA). After the animals had fasted for 8 hours, anesthesia was induced by intramuscular injection.
of xylazine (2 mg/kg) and Telazol® (tiletamine-zolazepam, 6 mg/kg). Each animal was then intubated and kept under general anesthesia with isofluorane 1% to 2.5% throughout the experiments. The skin and abdomen were draped, and a pneumoperitoneum of 15 mm Hg was achieved. Three port sites similar to those used for standard laparoscopic radical prostatectomy were placed, with the camera port just above the umbilicus. The right and left arm ports were symmetrically placed lateral to the rectus muscle, each 10 cm from the camera port. The da Vinci robot was docked. A 20-gauge 6-inch spinal needle was placed percutaneously to facilitate optimal placement of the temperature probe.

To apply MP cautery, we used standard 13-mm “hot” curved scissors. To apply BP, we used standard robotic Maryland BP instruments. These instruments were selected in order to simulate the actual clinical scenario. The average size of the inferior epigastric vessels was 3 to 4 mm. Figure 2 demonstrates the application of cautery relative to the inferior epigastric vessels. We applied 20 W of MP and BP cautery (Valley Lab.) for 30 seconds. The thermal probes were placed 5 to 7 mm from the cautery tip with (x distance) and without (y distance) intervening inferior epigastric vessels (Fig. 2). Temperatures were recorded continuously for 20 seconds prior to the application of cautery, then for 30 seconds during cautery application, and lastly until the tissue temperatures returned to baseline after application of MP or BP cautery. At the conclusion of the experiments, the pigs were euthanized according to the standard protocol.

To simulate the clinical scenario in humans, 20 W of MP/BP electrocautery was used. All temperatures were measured using a fluoroptic thermometry system (Model 3100: Luxtron, Santa Clara, CA) to avoid the limitations of conventional temperature measurement techniques in electromagnetic environments.4–7 The accuracy and resolution of the fluoroptic system is 0.1°C operating at 20 samples per second. This temperature-monitoring technique, considered the industry standard, uses fluorescent sensors that eliminate the electromechanical interference encountered with standard thermocouples and thermistor sensors.8 The Luxtron device uses a nonmetallic, electrically nonconducting probe (diameter 0.5 mm) that responds rapidly to temperature changes. This technology is based on the fluorescence decay time of a heat-sensitive phosphorescent sensor at the tip of the probe. The fluoroptic thermometry system was calibrated according to manufacturer’s specifications and calibration checked before each procedure using a waterbath and a reference thermometer. Temperatures and temperature–time data were recorded using the True-Temp software supplied with the system. Great care was taken to ensure proper alignment and contact of both the cautery tip and the fiberoptic probes with the tissue surface. In an effort to obtain consistent results, the same investigator manually controlled the contact pressure and orientation of the cautery tip and thermal probes. The same electrosurgical generator was used for all cautery applications. Temperatures were recorded prior to, during, and after cautery application. With each experiment, the maximum temperature was recorded.

All statistical comparisons of average maximum temperatures between the groups were evaluated with the Student t-test for means (SAS 8.2 statistical package). A P value <0.05 was considered statistically significant.

RESULTS

In this experimental model, the inferior epigastric vessels acted very strongly as a heat sink, preventing thermal spread from 20 W of both MP and BP electrocautery. At 5 to 7 mm from the energy source, neither MP nor BP caused significant temperature elevations above baseline if an intervening blood vessel was present (Table 1 and Figs. 2 and 3). Without the intervening vessel (y distance), both MP and BP cautery generated heat >10°C above baseline (all P ≤ 0.001).

DISCUSSION

Current techniques of laparoscopic prostatectomy rely on a variety of energy sources for hemostasis to improve the visibility of the operative field and increase operative efficiency.
The effects of temperature on tissues are well known. Coagulation occurs as tissue temperatures rise above 45°C.\textsuperscript{11} As temperatures continue to rise beyond that point, normal cells begin to die, with denaturation occurring at 57°C to 60°C and protein coagulation at 65°C.\textsuperscript{12} Donzelli and associates\textsuperscript{13} have shown that electrocautery, whether MP or BP, causes primarily thermal injury to nearby neural tissue. Temperatures as low as 41°C may cause injury to neural tissue.\textsuperscript{13} Hnatuk and coworkers\textsuperscript{14} also have stressed concerns about BP, as they showed it induces collateral damage in peripheral nerve tissue. The negative effects of thermal energy on canine NVBs with a subsequent decrease in the erectile response were well demonstrated by Ong and collaborators.\textsuperscript{1}

To prevent nerve injury while transecting the prostatic vascular pedicle and dissecting the NVBs, it is advisable to avoid thermal energy. Various cautery-free alternatives have been described to transect the vascular pedicles and dissect the NVBs without significant bleeding.\textsuperscript{9,10} However, the use of thermal energy when transecting the bladder neck is still a common practice. During transection, the cautery tip may come within millimeters of the prostatic vascular pedicle. Our findings, summarized in Table 1, demonstrate that blood vessels have the capacity to act as heat sinks. This finding could explain why the thermal transection of the bladder neck in conjunction with nonthermal transection of the prostatic vascular pedicle and dissection of the NVBs has resulted in remarkable improvements in sexual function.\textsuperscript{2,3} The prostatic vascular pedicles are likely acting as heat sinks to protect the NVBs from thermal injury during bladder-neck transection with electrocautery (Fig. 3).

A limitation of our study is that we tested only at 20 W for 30 seconds, an approximation of a thorough dissection time. Khan and associates\textsuperscript{15} showed that higher wattages may increase temperatures by 20°C to 30°C, which may overpower the heat sinking capability of a vascular pedicle. Furthermore, we acknowledge that our conclusions are based on a porcine model. The average size of the porcine inferior epigastric vessels was 3 to 4 mm. The human prostate pedicle as a whole is larger than 3 to 4 mm; however, each individual vessel is at most 1 mm. Therefore, the size and flow of the human prostate pedicle and its heat sink capability may differ. Further studies are indicated to determine the true thermal safety limits of electrocautery, especially if higher wattages are utilized routinely for bladder-neck transection.

**CONCLUSIONS**

According to our findings, vascular structures may act very effectively as heat sinks to prevent thermal spread. This suggests that the prostatic vascular pedicles prior to transection may act as protective heat sinks for the NVBs during transection of the bladder neck. On the other hand, if electrocautery is used to transect the vascular pedicles, extensive thermal energy would be expected to spread to the nearby NVBs, with potential injury.

**Note Added in Proof:** In the review processes, an editor astutely suggested that it would be interesting to know whether clamping or compressing the inferior epigastric vessels was suf-

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**Table 1. Average Maximum Temperatures with and without Intervening Inferior Epigastric Blood Vessels as Heat Sink**

<table>
<thead>
<tr>
<th></th>
<th>No heat sink</th>
<th>Heat sink</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean temp change</strong></td>
<td>13.8</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>SE</strong></td>
<td>2.0</td>
<td>0.44</td>
</tr>
<tr>
<td><strong>P value</strong></td>
<td>0.0001</td>
<td>0.0013</td>
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</tbody>
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**FIG. 3.** With interposing inferior epigastric vessels (heat sink), thermal spread is markedly reduced at 5 to 7 mm from MP or BP cautery probe.

**FIG. 4.** With the interposing inferior epigastric vessels clamped, thermal spread across the vessels is markedly increased at 5 to 7 mm from the MP cautery probe, eliminating the ‘heat sink’ effect.
ficient to eliminate the heat sink phenomenon, thereby proving that the flow through the vessels was the critical factor. In the interim, we took this suggestion back to the laboratory. Under the exact same conditions as stated in the Methods and Materials section, we applied 20 W of MP electrocautery for 30 sec and measured temperature changes across the inferior epigastric vessels with and without the vessels clipped. With the vessels not clipped, the average rise in temperature above baseline was 2.2°C (33.1°C to 35.3°C). Meanwhile, with the vessels clipped, the average rise in temperature was 12.9°C (32.6°C to 45.5°C) (Fig. 4). Indeed, this rise in temperature is similar to having no intervening vessels (13.8°C), thereby providing definitive proof that the critical factor is the blood flow through the vessels.

REFERENCES


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ABBREVIATIONS USED

BP = bipolar; MP = monopolar; NVB = neurovascular bundle.