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ORIGINAL ARTICLES

Radiofrequency energy antenna coupling to common laparoscopic instruments: practical implications

Edward L. Jones · Thomas N. Robinson · Jennifer R. McHenry · Christina L. Dunn · Paul N. Montero · Henry R. Govekar · Greg V. Stiegmann

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Abstract

Background Electromagnetic coupling can occur between the monopolar "Bovie" instrument and other laparoscopic instruments without direct contact by a phenomenon termed antenna coupling. The purpose of this study was to determine if, and to what extent, radiofrequency energy couples to other common laparoscopic instruments and to describe practical steps that can minimize the magnitude of antenna coupling.

Methods In a laparoscopic simulator, monopolar radiofrequency energy was delivered to an L-hook. The tips of standard, nonelectrical laparoscopic instruments (either an unlit 10 mm telescope or a 5 mm grasper) were placed adjacent to bovine liver tissue and were never in contact with the active electrode. Thermal imaging quantified the change in tissue temperature nearest the tip of the telescope or grasper at the end of a 5 s activation of the active electrode.

Results A 5 s activation (30 watts, coagulation mode, 4 cm separation between instruments) increased tissue temperature compared with baseline adjacent to the grasper tip (2.2 ± 2.2 °C; $p = 0.013$) and telescope tip (38.2 ± 8.0 °C; $p < 0.001$). The laparoscopic telescope tip increased tissue temperature more than the laparoscopic grasper tip ($p < 0.001$). Lowering the generator power from 30 to 15 Watts decreased the heat generated at the telescope tip (38.2 ± 8.0 vs. 13.5 ± 7.5 °C; $p < 0.001$). Complete separation of the camera/light cords and the active electrode cord decreased the heat generated near the telescope tip compared with parallel bundling of the cords (38.2 ± 8.0 vs. 15.7 ± 11.6 °C; $p < 0.001$).

Conclusions Commonly used laparoscopic instruments couple monopolar radiofrequency energy without direct contact with the active electrode, a phenomenon that results in heat transfer from a nonelectrically active instrument tip to adjacent tissue. Practical steps to minimize heat transfer resulting from antenna coupling include reducing the monopolar generator power setting and avoiding of parallel bundling of the telescope and active electrode cords.

Keywords Electrosurgery · Radiofrequency · Coupling · Complications · Bovie · Antenna

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E. L. Jones (✉) · T. N. Robinson · C. L. Dunn · P. N. Montero · H. R. Govekar · G. V. Stiegmann
Department of Surgery, University of Colorado School of Medicine, 12631 East 17th Ave., MS C313, Aurora, CO 80045, USA
e-mail: edward.jones@ucdenver.edu

T. N. Robinson
e-mail: thomas.robinson@ucdenver.edu

J. R. McHenry
Covidien Electrosurgery, Boulder, CO, USA

Radiofrequency energy delivered by the monopolar "Bovie" instrument is used in virtually every laparoscopic operation. Injuries as a result of unsuspected energy transfer occur between 0.6 to 5 per 1,000 cases [1, 2]. Although rare, these injuries can lead to disastrous complications [3]. Understanding the mechanisms that lead to complications from radiofrequency energy devices can help the surgeon to avoid high-risk clinical scenarios.

Antenna coupling describes the phenomenon when radiofrequency energy emitted from a transmitting antenna couples to other conductive materials in the near-field without direct contact between conductive (galvanic) materials [4, 5]. In clinical terms, the "Bovie's" active electrode (or the "transmitting antenna") emits radiofrequency energy into the air, which is captured (or "coupled") by nonelectrically active wires in close proximity to the active electrode without direct contact.

This purpose of this study was to quantify the occurrence of antenna coupling between a monopolar instrument and other commonly used laparoscopic instruments and to determine what factors a surgeon can modify to minimize this potentially harmful phenomenon. Specific goals included: (1) determining the presence and magnitude of antenna coupling with different laparoscopic instruments; (2) comparing the magnitude of antenna coupling between laparoscopic telescope and grasper tips; (3) determining the magnitude of antenna coupling using different generator power settings; (4) comparing complete separation versus parallel bundling of the camera/light and active electrode cords; and (5) varying the distance between the tips of the active electrode and the nonelectrical laparoscopic instrument.

Materials and methods

Regulatory exemption due to designation as nonhuman research was obtained from the Colorado Multi-Institutional Review Board (COMIRB #08-1377). The laparoscopic instruments studied were the monopolar L-hook (Karl Storz, Tuttlingeon, Germany), a 10 mm 30° laparoscopic telescope (Karl Storz), and a Maryland laparoscopic grasper (Covidien, Boulder, CO). Instruments were studied in a Szabo-Berci-Sackier Laparoscopic Trainer (Karl Storz) with orientation similar to realistic operative usage during a laparoscopic cholecystectomy and were inserted through 10 mm all-plastic trocars (Ethicon, Blue Ash, OH). Monopolar radiofrequency energy (Force FX, Covidien) was delivered to the laparoscopic L-hook instrument, which was never in contact with the standard, insulated "nonelectrical" laparoscopic grasper or 30° telescope. The laparoscopic telescope had attached camera and light cords. The tips of the electrically active L-hook and the nonelectrical camera tip or grasper tip were held at a constant 4 cm separation (except as noted in Specific Aim #5). The active electrode, camera, and light cords were bundled for all experiments where temperature was measured adjacent to the laparoscopic telescope tip (except as noted in Specific Aim #4). A 20 × 5 × 5 cm section of bovine liver tissue was laid on top of the dispersive electrode pad, which rested on the floor of the box-trainer. The magnitude of antenna coupling was measured on the bovine liver tissue nearest the tip of the nonelectrical instrument (which was never in contact with the active electrode) immediately after a 5 s open air activation of the L-hook active electrode. Temperature was measured using an infrared camera (FLIR SC7600, Boston, MA) with emissivity set at 0.94. Temperature (°C) reported was the increase in temperature from baseline. This experimental setup was kept constant except for the specific variables tested, which are noted in the specific aims below. Each experimental setup was repeated tenfold.

Results were reported as mean temperature change from baseline ± standard deviation. Statistical analysis was performed by using a two-sided Student's t test for data with unequal variances for the continuous variable of temperature increase. Significance was set at $p < 0.05$.

Specific Aim #1: To determine whether antenna coupling occurs between an active electrode (laparoscopic L-hook) and the laparoscopic grasper or telescope, the L-hook was activated by using the monopolar generator in coagulation mode with 30 Watts of power. The active electrode was never in contact with the nonelectrical instruments or the tissue. The grasper or telescope tip was held a constant 4 cm distance from the active electrode tip. The camera cord and light cord were bundled together with the active electrode cord delivering energy from the monopolar generator to the L-hook. The tissue temperature recorded was that of the tissue adjacent to the tip of the nonelectrical laparoscopic instrument immediately after a 5 s activation of the active electrode (Fig. 1). Increase in tissue temperature was compared with no change in tissue temperature. Power, distance, instruments, and bundling are identical unless specifically mentioned in the following aims.

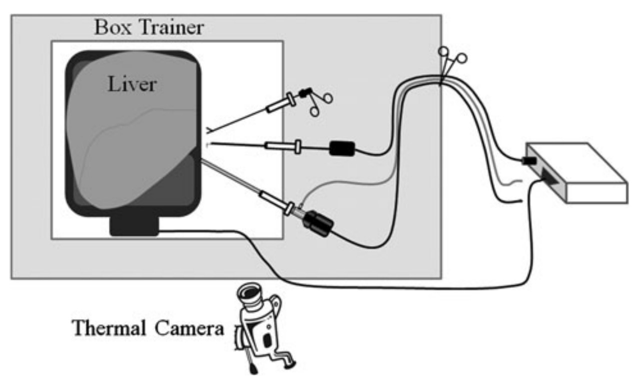

Fig. 1 Experimental setup. A laparoscopic box trainer was used with three laparoscopic instruments: a standard grasper, L-hook, and 30° telescope. The instruments were inserted through all plastic trocars placed in precut holes in the trainer box, which were triangulated to recreate clinically relevant angles between the instruments. On the floor of the trainer box, a section of bovine liver was placed on a dispersive electrode. The L-hook was the active electrode. One of the nonelectrically active instrument's tips (either the grasper or the telescope) was held adjacent to the tissue at a distance of 4 cm from the active electrode tip. Temperature was measured of the tissue adjacent to the tip of the nonelectrically active instrument after a 5 s open-air activation of the active electrode

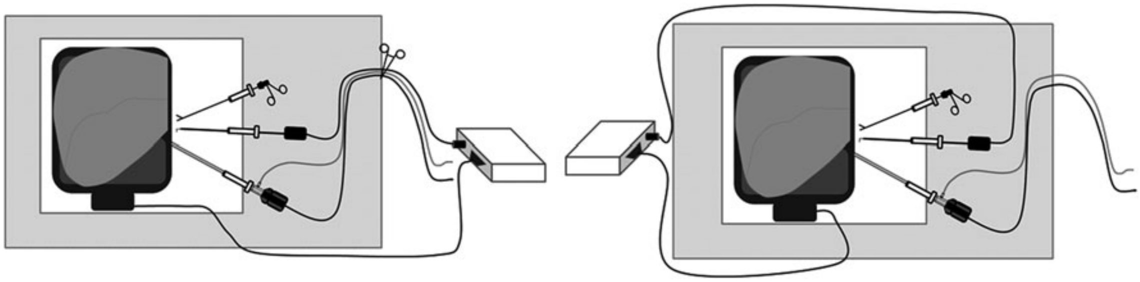

Fig. 2 The effect of bundling and unbundling the active electrode cord from the camera/light cords on heat generated at the non-electrically active telescope tip. Specific aim #4 compared the effect of bundling the active electrode cord (*left side* of figure) and separating the active electrode cord from the camera/light cords (*right side* of figure). The heat generated by the tip of the nonelectrically active telescope was lower when the cords were separated (15.7 ± 11.6 °C) compared with when the cords were bundled (38.2 ± 8.0 °C; $p < 0.001$). This practical finding suggests that surgeons should not bundle the active electrode cord with the camera cord, because the close proximity of the cords increases the magnitude of antenna coupling, which results in increased heat production at the telescope tip. The simple measure of positioning the monopolar electrosurgery generator on the side of the table opposite the camera/light boxes can avoid the parallel bundling of these cords

Specific Aim #2: To compare the heat created by antenna coupling by a nonelectrically active laparoscopic telescope tip versus the grasper tip.

Specific Aim #3: To compare the magnitude of antenna coupling at the laparoscopic telescope tip using different generator power settings (15 vs. 30 Watts).

Specific Aim #4: To compare the magnitude of antenna coupling at the laparoscopic telescope tip when the active electrode cord was bundled in parallel with the camera/light cords versus complete separation of the camera/light cords and the active electrode cord (Fig. 2).

Specific Aim #5: To compare the magnitude of antenna coupling at the laparoscopic telescope tip with the tip of the active electrode at different distances (4 vs. 20 cm) from the nonelectrical telescope tip (generator setting 30 Watts coagulation mode with bundled active electrode and camera/light cords).

Control: Control data were obtained to determine whether the increase in tissue temperature resulted from activation of the active electrode alone, without a nonelectrically active instrument being placed adjacent to the tissue. Tissue temperature 1 cm away from the nonelectrical instrument tip was measured at the end of 5 s activation and was compared to baseline tissue temperature.

Results

Specific Aim #1: The laparoscopic telescope tip increased tissue temperature 38.2 ± 8.0 °C ($p < 0.001$) from baseline. The laparoscopic grasper tip raised tissue temperature 2.2 ± 2.2 °C ($p = 0.013$) from baseline.

Specific Aim #2: The laparoscopic telescope tip increased tissue temperature more than the laparoscopic grasper tip (38.2 ± 8.0 vs. 2.2 ± 2.2 °C; $p < 0.001$).

Specific Aim #3: The laparoscopic telescope tip increased tissue temperature more when the L-hook active electrode received 30 Watts of power from the monopolar generator compared with 15 Watts (38.2 ± 8.0 vs. 13.5 ± 7.5 °C; $p < 0.001$).

Specific Aim #4: The laparoscopic telescope tip increased tissue temperature less with complete separation of camera/light cords and the active electrode L-hook cord (38.2 ± 8.0 vs. 15.7 ± 11.6 °C; $p < 0.001$; Fig. 2).

Specific Aim #5: Increasing the distance between the active electrode tip and the nonelectrically active telescope tip from 4 to 20 cm decreased the tissue temperature (38.2 ± 8.0 vs. 31.1 ± 11.1 °C; $p = 0.047$).

Control: The change in temperature from baseline of tissue 1 cm away from the tissue adjacent to the non-electrically active instrument tip was recorded for each aim's experimental parameters and is as follows: 1 cm from the laparoscopic grasper tip for Specific Aims #1 and #2: 0 °C; 1 cm from the laparoscopic telescope tip for Aims #1 and #2: −0.1 °C; 1 cm from the telescope tip for Aim #3: 0 °C; 1 cm from telescope tip for Aim #4: 0.2 °C; and 1 cm from the telescope tip for Aim #5: 0 °C. No statistical difference was found between baseline and post-activation tissue temperature 1 cm away from where the nonelectrically active instrument was held adjacent to the tissue.

Discussion

Antenna coupling exists between the monopolar active electrode and other nearby, commonly used laparoscopic instruments. The radiofrequency energy from the active electrode that couples to other nearby laparoscopic instruments has the potential to inadvertently heat up tissue that contacts the tips of these nonelectrical instruments (Fig. 3). Instruments attached to long conductive cords or antennae (e.g., the camera and/or light cords) couple more energy and create more heat at their tips compared with laparoscopic instruments not attached to conductive cords. Several factors that are modifiable by the surgeon influence the magnitude of antenna coupling. To reduce the amount of heat created by antenna coupling, the surgeon can lower the generator power setting, separate the active electrode cord from the camera/light cords (e.g., do not bundle the active electrode and camera/light cords), and increase the separation between the tips of the active electrode and other laparoscopic instruments.

Understanding the reproducible patterns of radiofrequency energy-related complications helps surgeons to avoid clinical scenarios that predispose to an electrosurgical complication. Previous studies have described five mechanisms of inadvertent energy transfer: insulation failure [6], capacitive coupling [7], direct coupling [8], residual heat [9], and direct application [10]. Antenna coupling represents a sixth mechanism of inadvertent energy transfer [11]. A recent study also documented this phenomenon during single-port laparoscopy [12]. The study reported arcing of “cold” instruments to tissue during monopolar active electrode activation and confirmed thermal injury to the tissue with histology revealing transmural injury to bowel wall.

The term antenna coupling is used in this study to describe the phenomenon of energy transferring from one transmitting wire (the active electrode) to another nonelectrically active conductor (the grasper or telescope) without direct contact. From a pure physicist’s perspective, the energy transfer in these experiments is likely a combination and sum of three distinct coupling phenomena: antenna (or radiative) coupling, inductive coupling, and capacitive coupling. Inductive coupling occurs when a magnetic field passes from one wire to another and can be exaggerated by winding wires into coils. Capacitive coupling occurs when two conductors (e.g., the wire inside the active electrode shaft and the patient’s tissue) are separated by intact insulation (e.g., the insulation along the shaft of a laparoscopic instrument), resulting in unintended current being discharged into the nonelectrically active conductor. Inductive and capacitive coupling are the more dominant mechanisms of energy transfer when the electrical and nonelectrical antennae are very close to one another. As the separation distance between the two antennae increases, the phenomena of inductive and capacitive coupling likely decrease and antenna (or radiative) coupling becomes the dominant mechanism of energy transfer.

The main reason that this study is important is because it highlights simple measures that the surgeon can take to reduce the magnitude of antenna coupling. Avoiding bundling of the active electrode cord with other conductive cords (such as the camera/light cord) is a simple, effective step to reduce the magnitude of antenna coupling. This can be achieved by locating the monopolar generator on the opposite side of the operating room table from the camera/light boxes (Fig. 2), an operating room setup arrangement that avoids the bundling of the active electrode cord and other conductive videoscopic camera cords. The findings of this manuscript may prove important to future operating room design. The current trend of integrated operating rooms locates the monopolar “Bovie” generator on a single boom accompanied by the videoscopic camera and light boxes. Future operating room design should consider locating the electrosurgery generator on the opposite side of the table from the camera box to avoid the bundling of

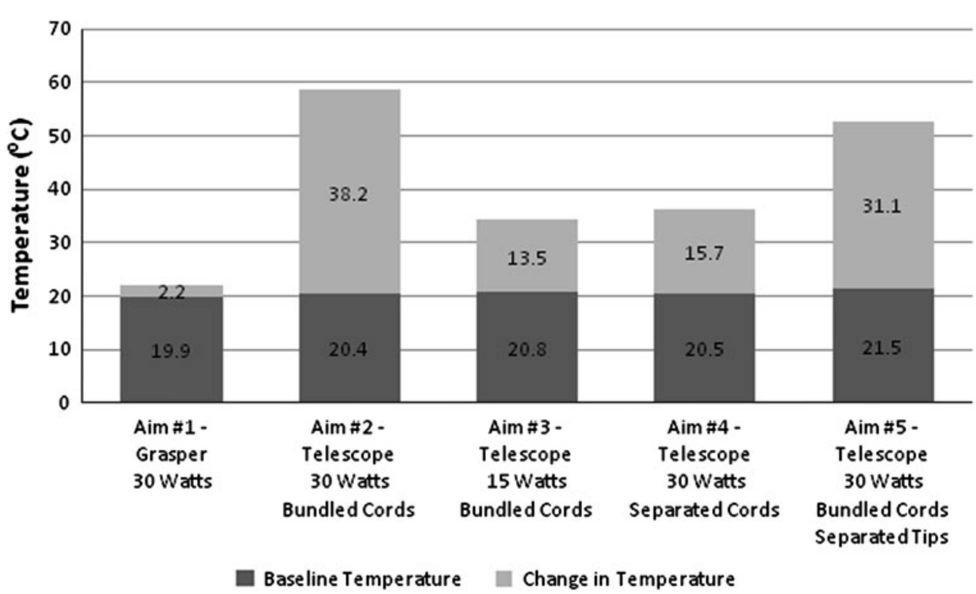

Fig. 3 Baseline and change in tissue temperature. Tissue temperature is reported on the vertical axis with the average temperature findings for each specific aim reported on the horizontal axis. Each column depicts the baseline tissue temperature (*lower dark gray area on each column*) and the increase in temperature from baseline (*higher light gray area on each column*)

the active electrode cord and other conductive cords, such as the camera cord.

There are four main limitations to our study. First, the primary outcome variable used in the study was increased tissue temperature. Histology could provide the additional information, such as depth of thermal injury. Second, all testing took place in a laparoscopic simulator ex vivo. Performing in vivo experiments would include other variables relevant to the operating room that were not achieved on the bench top (such as blood flow and pneumoperitoneum). Third, the telescope video and light cords were not plugged-in during testing. As a result, the effect of the cords plugged into the camera box and light box was not accounted for by these experiments. And fourth, the insulation along the shaft of the grasper was intact. No experiments were performed on instruments with insulation defects, and as a result, these experiments cannot determine the effect of insulation defects on the phenomenon of antenna coupling.

Conclusions

Antenna coupling results in inadvertent radiofrequency energy transfer from the active electrode to other commonly used laparoscopic instruments. Surgeons can minimize the risk of injury due to antenna coupling by separating the camera/light cords from the active electrode cord, reducing the monopolar generator power setting and increasing the distance between the active electrode and other laparoscopic instruments. Future directions of this work include moving the experimental setup into an in vivo model and examining the histology in addition to the heat generated to better understand the depth of the thermal injury.

Disclosures Edward L. Jones, Christina L. Dunn, Paul N. Montero, Henry R. Govekar, and Greg V. Stiegmann have no conflict of interest or financial ties to disclose. Thomas N. Robinson has received honoraria for teaching the topic of electrosurgery from ConMed Electrosurgery and Covidien. He has received education grants from Gyrus and Karl Storz Endoscopy, and a research grant from Medtronic, Inc. Jennifer R. McHenry is a current employee of Covidien.

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