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Safe energy use in the operating room☆

Introduction

"First do no harm" seems a simple and easy enough principle to which to agree. Yet, in this issue of Current Problems in Surgery, we tell you that most surgeons are unaware of what they do not know. In many cases, what we have done in the past may not be safe. In fact, we may be placing patients at unnecessary risk from the energy settings we choose, devices we use, and our operative approach.

There are approximately 40,000 burns by electrical surgical devices every year.[1] During laparoscopy, 70% of these burns may go undetected.[1] A survey of the American College of Surgeons showed that 18% of surgeons reported an insulation failure or capacitive coupling injury, and 54% of surgeons knew of a colleague who faced an electrical injury.[2]

In 1999, nearly $600 million was paid out for injuries related to misuse of energy devices.[1] approximately 550-650 of these injuries occur each year, the same number as that of wrong-site surgery.[3] Most injuries are minor and result in minimal injury, but several of these are significant, disabling, and completely preventable.

The aim of this publication is to provide an insight into thermal injuries, review common errors, review the basics of radiofrequency (RF) energy, and hopefully, motivate the reader to learn more about the safe use of energy in the OR.

Monopolar instruments

RF electrosurgical devices are ubiquitous in operating rooms (ORs) and endoscopy suites. It is difficult to imagine performing procedures without monopolar devices like the "bovie" pencil, endoscopic snare, or RF ablation (RFA) devices. RF devices are effective, inexpensive, and versatile and surgeons use them every day. However, surgeons are not specifically trained in their optimal use, knowledge gaps are common,[4] and electrosurgical injuries are not rare.[5] Increasing understanding of how these devices work contributes to safer OR conditions by enabling clinicians to make reasoned choices about the devices and power settings, and how they use these devices with other equipment. We review how RF energy causes effects in cells and tissue, the basic function of an electrosurgical generator or unit (ESU), differences between monopolar and bipolar instruments, and the basics of application of RF energy to surgery.[6-8]

☆ Dr. Jones has conflict with Allurion.

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How does RF electrosurgery create tissue effects?

An electrosurgical device applies high-frequency alternating current to cells, with the polarity alternating from positive to negative approximately 500,000 times per second. Cellular cytoplasm contains electrically charged particles such as electrolytes and proteins. The alternating polarity causes those ions to rapidly oscillate back and forth, resulting in frictional forces that increase the cellular temperature. This is used to create a cellular and tissue effect or a combination of cellular and tissue effects including vaporization (manifested as cutting), desiccation or coagulation (used to seal tubular structures), and fulguration (used for larger surface hemostasis).

Understanding the surgical applications of RF electricity requires a basic understanding of the effects of temperature on cells and tissue (Fig 1).[7]

The normal body temperature is 37°C. Temperature can go into the 40°C range, as seen with fever, without damaging the structural integrity of our cells and tissue. Once cellular temperature reaches 50°C, cell death occurs over a period of approximately 6 minutes. When the local temperature is 60°C and higher, cellular death is instantaneous through the occurrence of desiccation and coagulation. Desiccation occurs as the cell loses water through the thermally damaged wall. As water leaks out, the cell starts shrinking and becomes progressively smaller. Protein denaturation occurs at temperatures as low as 60°C as hydrogen cross-links between proteins rupture. With subsequent cooling, the cross-links reform randomly, ideally creating a homogenous coagulum. If enough energy is transmitted to rapidly raise the temperature to 100°C, intracellular water turns to steam, with massive expansion of intracellular volume. The result is cellular vaporization as the cell explodes in a cloud of steam, ions, and organic matter. When temperatures are more than 200°C, organic molecules are broken down, leaving carbon molecules that create a brown or black appearance.

The use of proper terminology reinforces principles that support safe use of energy devices. The term “cautery” is often used to refer to monopolar electrosurgical devices. However, cautery denotes a passive transfer of heat, that is, heating of an instrument, which then heats the tissue. A branding iron is an example of a cautery. But with electrosurgical devices, it is the RF energy that causes the temperature rise in cells and tissues, without any passive heat transfer. So electrosurgery is *not* cautery!

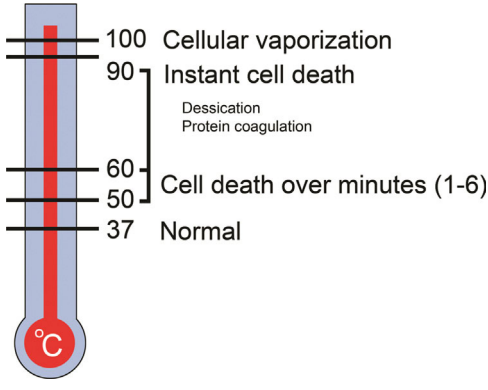

Fig. 1. Effect of temperature on cells and tissue. Normal temperature is 37°C. Once cellular temperature reaches 50°C, cell death occurs over a period of approximately 6 minutes. When the local temperature is 60°C and higher, cellular death is instantaneous through the occurrence of desiccation and coagulation. If enough energy is transmitted to rapidly increase the temperature to 100°C, intracellular water turns to steam, and cell vaporization occurs. (Adapted with permission from Munro.[6]) (Color version of figure is available online.)

Electosurgical generator

The ESU performs 3 functions.[7] First, it converts the low-frequency alternating current from the wall from 60 Hz to a very high frequency, approximately 500,000 Hz. This is called "radiofrequency" because the frequency is similar to that of amplitude-modulated radio waves. Although 60 Hz is a frequency that depolarizes muscle and nerve cells, at frequencies more than 100,000 cycles per second muscles and nerves essentially function normally. Furthermore, these frequencies affect the cells and tissue in a dramatically effective fashion. The second function of the ESU is to enable adjustment of the voltage of the output through adjusting the power setting. Recall that power (W) = voltage × current. If we increase or decrease the power setting on the ESU, the voltage is increased or decreased to maintain this relationship. The third function of the ESU is control of the "duty cycle." The term duty cycle is used to describe the proportion of time over which ESU produces a waveform. Generators produce different waveforms that, in part, allow the surgeon to change the effect of the RF electricity on the tissue. Waveforms can be depicted on an oscilloscope. Most North America – made ESUs have 2 outputs labeled "cut" and "coag." However, these terms do not accurately reflect the appropriate use of the energy and this labeling has added to confusion regarding the properties of the different waveforms. "Cut" is not used just for cutting and "coag" is not used just for coagulating.

These concepts are best illustrated with an example (Fig 2). If we start with a setting of pure "cut," at a power setting of 30 W, and view the ESU output on an oscilloscope, we would see a continuous, relatively low-voltage waveform, with a sine wave shape. If we then increase the power setting to 100 W, we still have a continuous output but at a higher voltage. If we switch to the "coag" setting, without the power setting remaining at 30 W, the oscilloscope would show a waveform that is only intermittently produced, with the current "on" only approximately 6% of the time (a 6% duty cycle). This very short duty cycle is associated with a much higher voltage than that of the same power setting used on "cut" mode because if the current is reduced, the voltage must increase to maintain the wattage (power = voltage × current). The relatively high voltage of the "coag" setting has important implications for the safety and effectiveness of electrosurgery, including the potential for interference with a pacemaker, the risk of capacitance or antennae coupling, and the quality of the vessel seal created.

A third setting is "blend." Although many surgeons think blend is a combination of cut and coag, in fact it is a modulated form of the cut output (Fig 3). Compared to pure cut, the blend setting uses an interrupted current, resulting in higher voltage compared with pure cut at the same power setting.

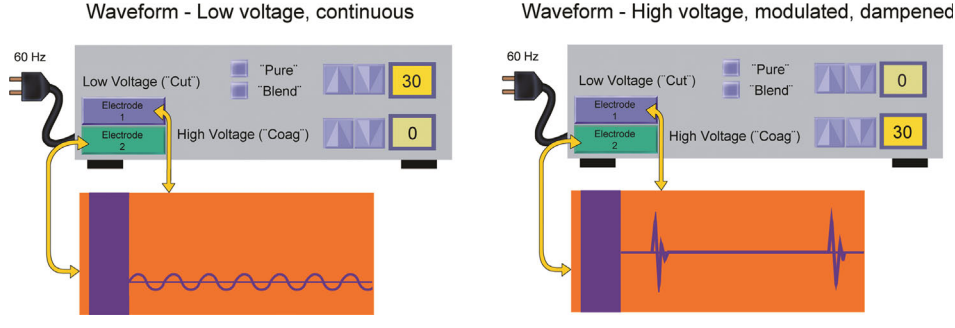

Fig. 2. Examples of "cut" and "coag" waveforms as would be seen on an oscilloscope. (A) When the ESU is set to pure "cut" at a power setting of 30 W, there is a low-voltage, continuous output with a sine wave shape. The term "cut" is misleading as it gives the false impression that this waveform is designed to cut tissue. (B) At the "coag" setting at the same power, we see a high-voltage, intermittently produced waveform (typically only 6%). (Adapted with permission from Munro.[6] (Color version of figure is available online.)

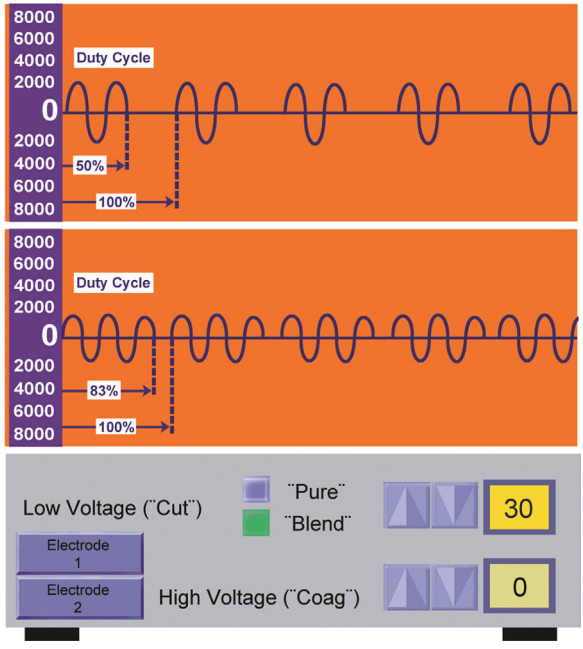

Fig. 3. "Blended" currents are NOT a combination of coag and cut. In fact, it is a modulated form of the "cut" waveform. The duty cycle refers to the proportion of time the ESU produces current. On the top image, with the power set to 30 W, there is output 50% of the time, whereas in the lower image, there is output 83% of the time. To preserve the power equation ($P = V \times I$), with the increase in current seen with the higher duty cycle, there is a concomitant decrease in voltage. (Adapted with permission from Munro.[6]) (Color version of figure is available online.)

Monopolar and bipolar devices

There are always 2 electrodes involved with electrosurgery. What differentiates monopolar and bipolar instrument setups is the function of the second electrode. With a monopolar device (eg, "bovie" pencil, laparoscopic hook, and endoscopic snare) an active electrode with a small surface area is used by the surgeon to concentrate the current and create the desired tissue effects, whereas a second large electrode is placed remotely on the patients and used to disperse the current to prevent changes in tissue temperature at that site (Fig 4). The entire patient is in the circuit, which creates the opportunity for current diversion to other parts of the patient.

With bipolar systems, both electrodes are in the same device and are generally small enough to be "active." Again, both electrodes are attached to the generator. Only the very small amount of the tissue between the electrodes or immediately adjacent to them is included in the circuit, which essentially eliminates the risk of current diversion inherent with monopolar systems. But monopolar devices are extremely versatile, as tissue cutting, sealing, and fulguration are all easily achieved.

A common misnomer is the term "grounding pad." This suggests that this pad is connected to the ground and the circuit is completed through the ground. This type of system increases the risk of current diversion and has not been sold for OR use in North America for decades. In contrast, modern electrosurgical units create isolated circuits, where both electrodes are attached to the generator. In a monopolar system, there is 1 electrode with a small surface area in the surgical field to concentrate current and create tissue effects and 1 with a large surface area electrode attached to the patient to disperse the current over a large area. As ground-referenced generators are no longer used, a better term for this second electrode that describes its purpose is "dispersive electrode."

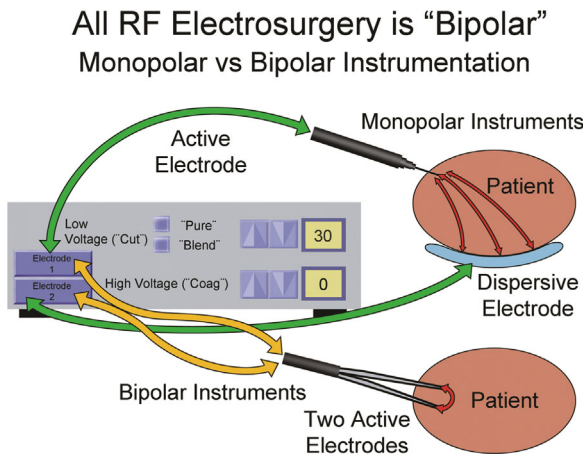

Fig. 4. Monoplar and bipolar instrumentation. There are always 2 electrodes involved with electrosurgery. What differentiates monopolar and bipolar instrument setups is the function of the second electrode. With a monopolar device (eg, "bovie" pencil, laparoscopic hook, and endoscopic snare) an active electrode with a small surface area is used by the surgeon to concentrate the current and create the desired tissue effects, whereas a second large electrode is placed remotely on the patient and used to disperse the current to prevent changes in tissue temperature at that site. With monopolar systems, the whole patient is in the circuit, which creates the opportunity for current diversion. With bipolar systems, both electrodes are in the same device and are generally small enough to be "active." Again, both electrodes are attached to the generator. Only the very small amount of the tissue between the electrodes or immediately adjacent to them is included in the circuit, which essentially eliminates the risk of current diversion inherent with monopolar systems. (Adapted with permission from Munro.[6]) (Color version of figure is available online.)

From principles to practice

There is a science and an art to electrosurgery. Understanding that electrosurgery is about the control of current density, defined as the amount of current per unit area of the electrode in contact with or near the tissue, allows the user to increase safety and versatility. Current density is determined by the shape and size of the electrode as well as the power settings and output of the generator. The size of the electrode is very important because thermal change (ΔT) is proportional to current density squared ($\Delta T\alpha$ current^2/area^2). As area $= \pi r^2$, a small change in radius results in a large difference in the thermal effect. Conceptually, reducing the radius by half would result in a 16-fold increase in the thermal effect. Surgeons recognize this effect from using the "bovie" pencil. High current density concentrated at the tip or edge of the blade vaporizes the tissue, whereas turning the device to use the flat edge of the blade at the same power setting results in slightly lower current density that would cause desiccation and coagulation. The same current spread over a much larger area may have no effect on the cells at all, which is the situation created by the size of the dispersive electrode. Hence, when the tissue effect is not what is desired, instead of first increasing the power, with the associated increased risks of thermal spread or current diversion, maximize concentration of current by decreasing the area of the electrode surface.

Thermal change also increases proportionally with tissue resistance. Resistance can be increased by removing conductive fluid (eg, blood), compressing vessels, or putting the tissue on stretch. Finally, thermal change increases in a linear fashion with the time of application. Surgeons who understand how to manipulate electrode area and tissue tension would be able to achieve excellent hemostasis and tissue transection at very low power settings (ie, 20 W). In addition to the power setting and waveform, whether the electrode is in contact with the tissue also influences the surgical effect achieved. Tissue cutting occurs through linear vaporization, accomplished by advancing a narrow tipped electrode without direct tissue contact, using a continuous, low-voltage waveform ("pure cut"). The high current density results

in a very rapid rise in intracellular temperature to more than 100°C and cell vaporization with little collateral thermal damage. Effective coagulation resulting in vessel sealing requires contact with the tissue, squeezing the vessel walls together with a forceps or against adjacent tissue. The power density must be high enough to result in instantaneous coagulation and desiccation (ie, temperatures of 60°C-95°C), without resulting in vaporization. Compressing the vessel also prevents blood flowing through to decrease the temperature. Although any waveform setting can achieve this result, it may be surprising to many surgeons that the "cut" or "blend" waveforms achieve higher quality vessel seals than that of the "coag" setting, and at lower voltage. The low duty cycle (6% "on"), high-voltage coag waveform causes brief episodes of temperature elevation, resulting in superficial coagulation, desiccation, and carbonization. This superficial zone has high tissue impedance and blocks subsequent current bursts from penetrating the deeper tissue. The area of carbonization also results in the electrode sticking to tissue, pulling off the eschar, and disrupting the seal. Tissue fulguration is achieved with the coag setting, allowing for high-voltage current bursts to achieve superficial coagulation, desiccation, and carbonization, with the resulting high tissue impedance precluding deeper current penetration. The electrode is held a few millimeters away from the tissue, and the high-voltage current is arced to the tissue. Fulguration is used to control oozing over a larger surface area such as the liver surface. This is also used with devices such as the argon beam coagulator, with argon as a medium between the electrode and tissue to facilitate current arcing.

Although electrical experts may find the above simplifications lacking precision, the goal is for the concepts to be used to avoid situations that increase the risk of injury. Understanding how RF electrosurgery works, reenforcing knowledge through correct terminology, understanding the differences in waveform duty cycle and voltage, and applying these concepts clinically may help increase the effective use of monopolar devices, while reducing harms like current diversion and electrical interference with implanted devices.

Reproducible patterns of surgical energy-based device complications

Surgical energy is used in nearly every operation. Although injuries from energy-based devices are uncommon, they typically lead to catastrophic and sometimes fatal complications. Despite the nearly ubiquitous usage of energy in the modern OR, surgeons have a poor understanding of the patterns by which these devices cause complications. Here, we describe several of the mechanisms by which common surgical energy-based devices cause complications in a clinically relevant context.

Surgical energy is essential in the modern OR, yet the basic principles, applications, and patterns of complications remain poorly understood.[4] Increasing public awareness following the death of Pennsylvania Congressman John Murtha in 2010, likely secondary to an electrosurgical injury,[9] as well as articles in the lay press [10] has prompted a renewed interest in both research and education in the safe use of surgical energy-based devices. Complications from surgical energy-based devices occur in reproducible patterns. If surgeons can recognize the patterns by which these complications occur, they can modify how energy-based instruments are used in their OR with the goal of avoiding high-risk scenarios for surgical energy-based device – related complications.

Patterns of energy-based device complications

A total of 6 dominant patterns of surgical energy-based device complications are described (Table 1). The patterns are listed in order of the most clinically relevant to the least clinically relevant. For each complication pattern, the discussion includes[1] the definition of the mechanism of injury,[2] a clinical example of OR scenario highlighting the complication pattern, and[3] practical steps that a surgeon can take to minimize or eliminate the risk of this complication occurring.

Table 1
The 6 most common patterns of surgical energy-based device complications.

Direct Application
Insulation Failure
Antenna Coupling
Residual Heat
Direct Coupling
Capacitive Coupling

Direct Application

Direct application injury results from unintended thermal injury to tissue adjacent to the tip of the activated energy-based device. In other words, thermal heat spreads beyond the tissue that the surgeon intends to dissect with the energy device (Fig 5).

If vulnerable tissue is too close to the active instruments' tip, this nearby tissue faces increase in temperature and potentially burns. The clinical consequence of this thermal injury depends on the type of tissue burned. Thermal injury to bowel leading to perforation or an adjacent blood vessel leading to hemorrhage can have devastating clinical consequences. In a review of more than 3000 energy-based device complications, the direct application injury pattern was the most common of all types of energy-based device complications observed.[11]

The distance that thermal heat travels from the activated devices tip is called thermal spread. Thermal spread varies based on how high the energy devices' temperature reaches, the amount of time the device is activated, the thermal mass of the device, and the thermal conductivity of the tissue. Thermal spread is found to be histologically up to 5 mm from an advanced bipolar instrument and up to 4 mm from an ultrasonic device.[12,13]

Clinical example

A tissue sealing device divides the mesentery adjacent to the small bowel. While dissecting adjacent to the bowel there is blanching of the bowel wall but no perforation or injury of the serosa is identified intraoperatively. The patient recovers uneventfully until the third postoperative day, when abdominal sepsis occurs due to bowel perforation.

Preventative strategies

First, avoid close proximity of the activated energy device on tissue immediately adjacent to vulnerable tissue such as bowel, ureter, and blood vessels. This prevents injury from thermal spread to tissue that might result in perforation or hemorrhage. Second, if the surgeon activates an energy device in close proximity to vulnerable tissue, a shorter activation dwell time results

Fig. 5. Direct application. The distance of thermal injury from the instrument tip following an activation represents direct application. In this graphic, the orange area adjacent to the device's jaw represents the distance of thermal spread resulting from energy application. Direct application has been recognized as the most common energy-based device complication pattern. (Adapted with permission from Thomas N. Robinson.) (Color version of figure is available online.)

in less thermal spread. Third, securing hemostasis adjacent to vulnerable tissue is more appropriately achieved with sutures, clips, or staples rather than a surgical energy-based device.

Insulation Failure

Insulation failure is a defect in the insulating material that covers the laparoscopic instrument's shaft or the active electrode's cord[14,15] (Fig 6). Breaks in insulation occur on 13%-39% of laparoscopic instruments.[14,16-18] Breaks in insulation are found most commonly at the tip of the instrument[14] and occur more commonly in robotic compared with laparoscopic instruments.[17]

Clinical example

While using the monopolar "bovie" instrument to dissect the gallbladder off the gallbladder fossa, inadvertent energy arcs from a break in the insulation along the shaft of the instrument flowed to nearby bowel. This electrosurgical burn happens outside the view of the camera and is therefore not recognized by the surgeon at the time of the operation. What results is a full-thickness bowel burn. The patient is discharged home following the ambulatory laparoscopic cholecystectomy procedure. The patient presents with abdominal sepsis and shock on the second or third postoperative day due to perforation of the transverse colon.[10] Additional insulation failure injuries have been reported from robotic instruments[19] and from defects along an electrosurgical instrument's cord on the surgical field.[20]

Preventative strategies

First, a surgical team member can inspect the laparoscopic instruments before the operation for any defects in insulation, with particular attention to the active electrode. Second, porosity detectors (a device that is passed over the insulation of the laparoscopic instrument and alarms when an insulation defect is present) can be used in sterile processing before instrument sterilization to detect insulation failure. Third, laparoscopic ports should be placed so that the shafts of instruments do not lie adjacent to vulnerable tissue such as the bowel. By avoiding the shaft of an instrument contacting bowel, energy would not be able to escape through an insulation defect along the shaft of the instrument and burn the bowel tissue.

Antenna Coupling

Antenna coupling occurs when an electrically active wire transfers energy without direct contact to nearby conductive material.[21] In the OR, the transmitting antenna is the active electrode's cord that emits energy into air through the cord layer of insulation.[22,23] The receiving antenna is any conductive material in close proximity to the active electrode cord. Factors that promote increased energy transfer are parallel orientation, increased length of parallel wires, and closer proximity of parallel wires.[21-23] The clinical relevance of antenna coupling is that stray energy transfer to the electrically inactive receiving antenna can result in thermal injury to tissue in contact with receiving antenna.

A recent randomized clinical trial tested the hypothesis of antenna coupling in the OR.[24] The hypothesis tested was whether unbundling (complete separation) the active electrode and camera cords would reduce stray energy in comparison with bundling (parallel orientation) the

Fig. 6. Insulation failure. Insulation failure is the break of the insulation material along the shaft of an instrument. In this graphic, a laparoscopic L-hook active electrode is depicted with a defect in its insulation. This defect allows stray energy transfer to burn unintended tissue. Of 5 laparoscopic instruments, 1 has been shown to have 1 or more insulation defects. (Adapted with permission from Thomas N. Robinson.) (Color version of figure is available online.)

active electrode and camera cords. This clinical trial found decreased stray energy with separation of the active electrode and camera cords, thus confirming antenna coupling as a clinically relevant pathway for stray energy transfer.

Clinical example(s)

The monopolar's active electrode cord is oriented parallel and in close proximity to the laparoscopic camera cord as they are draped off of the sterile field in an integrated OR. The laparoscopic telescope tip inadvertently comes into contact with small intestine while the active electrode is activated. Stray energy arcs from the telescope and burns the bowel outside the camera's surgical view. The burn to the small intestine results in abdominal pain and septic shock on the second postoperative day due to small bowel perforation.

Antenna coupling injuries have been reported owing to multiple types of patient-monitoring devices that have wires extending off the surgical field. Examples include burns from nerve-monitoring electrodes,[25] electrocardiogram (EKG) leads,[26] esophageal temperature probes,[27] and doppler monitoring devices.[28]

Preventative strategies

First, avoid parallel orientation and close proximity of the high-voltage monopolar active electrode wire with other conductive materials. The most common OR scenario that predisposes to antenna coupling is the parallel orientation of the active electrode cord to the camera cord. This scenario can be avoided simply by placing the monopolar generator on the opposite side of the OR table from the laparoscopic camera box so that the wires are completely separated. Second, recognize that energy complications can occur off the surgery field due to inadvertent energy transfer from high-voltage wires. Thus, antenna coupling requires a paradigm shift in surgical thinking regarding energy-based device complications. All other complication patterns occur on the surgical field; in contrast, the mechanism resulting in stray energy transfer occurs with the wires that are draped off the surgical field.

Residual Heat

Residual heat is defined as the increased temperature that remains at the tip of the energy device after energy activation is completed.[29] The elevated instrument temperature is unique to each type of energy-based device but can cause injury when the tip inadvertently touches tissue before the dissipation of heat. Residual heat is clinically most relevant with ultrasonic devices, which have been found to increase by more than 200°C from baseline.[30] Ultrasonic devices heat tissue put in contact to the active blade by more than 10°C even after a 20-second period of rest following the last activation, a temperature that is higher in comparison with monopolar or advanced biopolar instruments.[29]

Clinical example

An injury from residual heat is described in the literature.[31] During a laparoscopic right colectomy, an ultrasonic device is used to mobilize the right colon off the duodenal sweep. The active blade of the ultrasonic instrument touches the duodenal sweep several seconds after activation is complete, leaving a white mark on the serosa of the duodenum. On the second postoperative day, the patient developed abdominal pain and bile leak through a drain placed adjacent to the duodenum. On reexploration, the patient is found to have a duodenal fistula. Review of the video of the operation found that the ultrasonic device had burned the duodenal sweep after activation had been completed, which burned the duodenal wall and resulted in the fistula.

Preventative strategies

First, avoid touching additional tissue immediately after the activation of any energy-based device. Pay particular attention with ultrasonic devices to allow prolonged deactivated rest

times before touching additional tissue. Second, if an energy-based device comes into contact with vulnerable tissue immediately after activation, inspect the tissue for white blanching color. If this blanching is seen, immediate corrective action of oversewing with sutures should be considered to avoid delayed perforation.

Direct Coupling

Direct coupling is when the active electrode comes into contact with another noninsulated instrument.[15,32] This scenario causes the energy to transfer from the active electrode to the noninsulated instrument. This energy then travels along the shaft of the noninsulated instrument. If this noninsulated instrument happens to be in contact with vulnerable tissue along its shaft, thermal injury to the tissue can result. Noninsulated instruments commonly used in laparoscopic sets include the suction irrigator, the 10-mm all-metal stone forceps, and the camera's telescope.

Clinical example(s)

A monopolar “bovie” L-hook instrument is activated in the pelvis while unintentionally touching an atraumatic forceps that is retracting the ureter during a low anterior resection. Energy transfers from the L-hook to the ureter, resulting in a thermal burn to the ureter.

Another example of direct coupling can be intentional and clinically useful. If a small bleeder along the gallbladder wall is grasped with Maryland forceps, the monopolar instrument can be activated while touching the conductive (metal) material of the Maryland forceps to achieve hemostasis. The surgeon must recognize in this scenario that purposefully causing thermal effect for hemostasis could result in thermal burn to additional nearby tissue as well.

Preventative strategies

First, avoid contact of the monopolar active electrode with other conductive instruments or materials while energy is being delivered to the active electrode. Second, avoid close proximity of the monopolar active electrode to instruments that do not have insulation along their shaft (eg, suction irrigator device or 10-mm stone forceps without insulation). Inadvertent contact of the active electrode to these noninsulated instruments burns any tissue that lies along the shaft of this instrument. Third, ensure that port placement does not allow the shafts of instruments to touch vulnerable tissue such as the bowel. Low port placement along the abdominal wall in conjunction with steep angling of the table puts laparoscopic instrument shafts at high risk for touching the bowel, a scenario that should be avoided.

Capacitive Coupling

Capacitive coupling is defined as the current transferred from the active electrode, through intact insulation, into adjacent conductive material without direct contact.[15,33] Capacitive coupling is difficult to intuitively grasp without understanding what the 2 conductors in the definition are (Fig 7).

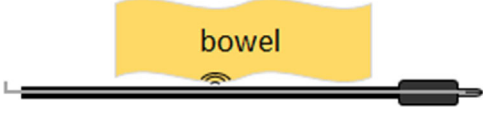

Fig. 7. Capacitive coupling. Capacitive coupling is defined as 2 conductors surrounded by intact insulation. In the operating room, the first conductor is the metal material, which intentionally leads current down the laparoscopic instrument's shaft and is surrounded by intact insulation. The second conductor is the patient's tissue. In this graphic, a segment of bowel is the second conductor, which can be burned by energy transmitted via capacitive coupling. (Adapted with permission from Thomas N. Robinson.) (Color version of figure is available online.)

The first conductor is the metal wire that travels down the center of the laparoscopic active electrode. This is the conductive material that intentionally facilitates the flow of energy down the active electrode and is surrounded by insulation. The second conductor in the capacitive coupling definition is the patient's tissue. Energy is transferred from the active electrode, across the intact insulation, and heats up the tissue that is adjacent to the shaft of the active electrode. Unintentionally heating up tissue next to the active electrode can result in thermal injury to the tissue, resulting in injury. Capacitive coupling occurs almost exclusively with the monopolar instruments due to the high voltage (roughly 9000 V when used on 30 W coagulation mode).

Clinical example

While performing a laparoscopic cholecystectomy, the monopolar “bovie” instrument is turned up to 60 W coagulation mode and activated for a prolonged time to achieve hemostasis in the gallbladder fossa. The shaft of the active electrode touches the transverse colon outside the camera's view. On the third postoperative day, after discharge home, the patient develops abdominal pain and septic shock due to a perforation in the transverse colon. A clinical case such as this was reported in the New York Times in 2006.[10]

Preventative strategy

Factors that minimize capacitive coupling include generator settings and surgical technique.[33] First, capacitive coupling is minimized by lowering the voltage delivered to the monopolar instrument (Table 2). Second, avoid the use of combined (or “hybrid”) metal and plastic laparoscopic trocars when using the monopolar “bovie” instrument. Third, Use of alternative energy-based surgical devices instead of the monopolar instrument such as traditional bipolar, ultrasonic instruments, and advanced bipolar devices.

Other energy-based device injury patterns

Inadvertent activation

Inadvertent activation injury is unintentional activation of the energy-based device that results in patient injury. An example of this complication is the surgeon who leans on the sterile drape and accidently presses the coagulation button on the monopolar pencil, which burns the patient's skin. Practical steps to minimize inadvertent activation injuries include using a “bovie” pencil holder, avoiding placing of energy-based devices on the drapes adjacent to where the surgical team might lean on the device, and having instrument activation tones loud enough to be heard by the surgical team to alert them to the unintended activation.

Interaction with electronic devices

RF energy devices emit electromagnetic interference (EMI), which interrupts the function of nearby electronic devices.[34,35] Disruption of electronic devices such as cardiac implantable electronic devices (CIEDs) (eg, a pacemaker) can lead to hemodynamic instability and even be life threatening. A clinical example is when a surgeon uses the monopolar instrument set on 30 W coagulation mode to create an upper midline incision in a pacemaker-dependent patient. On activation of the active electrode, the pacemaker function is interrupted, causing a heart

Table 2
Surgeon-controlled factors that minimize the risk of capacitive coupling injuries.[33]

Power setting	The lowest power setting to achieve clinical effect should be used in preference to higher generator power settings
Generator mode	Use modes with longer duty cycles (cut and blend mode reduces risk in comparison with coagulation mode)
Dwell time	Shorter active electrode activation times minimize risk in comparison with longer activation times
Surgical technique	Desiccation technique (active electrode touching tissue) should be used in preference to fulguration technique (energy crosses the short gap between active electrode and tissue) or open-air activation

block that results in hemodynamic instability. To minimize the effect of EMI, the surgeon can decrease generator power setting, use cut mode in preference to coagulation mode, employ the desiccation technique rather than the fulguration technique, orient the active electrode cord from the patient's feet to avoid proximity of the active electrode cord to the electronic device, avoid the current vector crossing between the active electrode tip and the dispersive electrode from crossing the cardiac device, and increase the distance between the active electrode and the cardiac device.[36,37] Other recommendations include using alternate energy-based devices such as ultrasonic and advanced bipolar instruments in preference to monopolar instruments.

Advanced energy devices

There are 2 primary types of energy used in surgery today: electromagnetic and mechanical. Electromagnetic radiation or RF energy can be applied in monopolar fashion with the “bovie” pencil or attached to laparoscopic instruments and is discussed in previous sections. RF energy can be used also in a bipolar fashion with basic tissue forceps or by “advanced” bipolar devices that actively measure tissue characteristics during activation to maximize the tissue effect (Table 3).

Another type of advanced device uses ultrasonic vibrations to create mechanical and thermal energy, which seals and cuts tissue. This is in contrast to advanced bipolar instruments that pass energy through the tissue to create a seal but require an additional mechanism or knife to cut the tissue. The last type of advanced device also does not pass energy through the tissue and instead creates tissue fusion through heat and compression. This device also requires an additional cutting mechanism (Table 3).

These “advanced” devices were designed to improve effective hemostasis and reduce OR time and complications. However, different techniques of use and numerous confounders can affect these outcome variables and has led most authors to compare instruments via surrogate end points: vessel burst pressure, seal time, lateral thermal spread, and visibility reduction (smoke plume). We compare and contrast the commonly available advanced energy devices to generate overall, evidence-based guidelines.

Advanced bipolar devices

In essence, all RF energy devices are “bipolar,” in that energy must pass from the instrument tip, through the tissue, and return to the generator. Bipolar devices are those that contain both the “poles” in the tip of the instrument, thereby focusing the energy delivered only into the tissue between the jaws. This reduces the energy required and allows for electronic monitoring of tissue characteristics. Every manufacturer has a slightly different monitoring system. Specifically, the LigaSure (Medtronic, Minneapolis, MN) measures tissue impedance, EnSeal (Ethicon, Cincinnati, OH) actively measures sealing temperature to maintain 100°C, and the Gyrus PlasmaKinetic System PKS (Gyrus Medical, Cardiff, UK) delivers pulsed energy, allowing for tissue cooling, which theoretically improves contact and seal. These active feedback

Table 3
Types of energy used in the operating room.

Electromagnetic	Mechanical	Heat transfer (cautery)
Electrosurgery Monopolar Bipolar	Ultrasonic	Advanced heating and cooling systems
Laser		

mechanisms have resulted in United States Food and Drug Administration (FDA) approval for these devices to seal vessels up to 7 mm in diameter.[38]

The key advantages of advanced bipolar energy are that it does not require a dispersive electrode (energy does not travel through the patient), less voltage is used (cut wave form), energy stays between the jaws, and up to 7 mm vessels can be sealed. With every surgical energy device, the thermal spread profile must be monitored carefully. Advanced bipolar devices typically have a 1-3 mm thermal spread pattern. Current leakage through the instrument cord is possible and should also be monitored.

Ultrasonic devices

Ultrasound-based devices are unique in that no energy traverses the tissue between its jaws. Instead, coagulation and cutting is effected by ultrasonic vibrations at frequencies from 23-55 kHz, creating thermal energy from tissue friction. Completion of tissue sealing is subjective for most ultrasonic devices and relies on visual and tactile cues and tissue tension. Ultrasonic devices have United States FDA approval to seal vessels up to 5 mm in diameter.

The main advantage of ultrasonic devices is the speed of dissection that can be accomplished. With every surgical energy device, the thermal spread profile must be monitored carefully. Ultrasonic devices typically have a 1-3 mm thermal spread pattern. A clear disadvantage is that the ultrasonic vibrating tip gets very hot. Temperatures can reach as high as 300°C during activation. Tissue death usually occurs at 60°C, so extreme caution should be undertaken while these devices are used. The surgeon should allow time for the ultrasonic tip to cool down before handling any tissue.

Advanced thermal or cautery devices

Advanced thermal and cautery devices seal vessels using compression, heat, and time. The main advantages are that it does not require a dispersive electrode (energy does not travel through the patient), no capacitive coupling is seen, the thermal spread pattern is 1-2 mm, it does not depolarize muscle tissue as no electromagnetic current goes through the body, and it can be used in patients with automatic implanted cardioverter-defibrillator AICDs or pacemakers. The main disadvantages are that intentional direct coupling is not possible, current leakage through the cord is seen, and it is not possible to cut tissue on your finger as compared to a monopolar pencil. Advanced thermal and cautery devices actively measure tissue temperature to ensure vessel sealing, rapidly heat and cool the end effector tip, and have been approved for vessels up to 7 mm in diameter.[39,40]

Instrument comparisons

Newcomb and colleagues compared multiple advanced bipolar devices (LigaSure, EnSeal, and Gyrus PKS) to an ultrasonic device, the Harmonic Scalpel (Ethicon, Cincinnati, OH), and laparoscopic clips on porcine arteries. Overall, mean burst pressures decreased with increasing vessel diameter and for small (2-3 mm) and large (6-7 mm) diameter vessels there was no statistical difference between burst pressures. For intermediate vessels (4-5 mm), the LigaSure device produced higher mean burst pressures (1261 mmHg) than those of the other devices (range: 295-928).[41] The smallest vessels, 2-3 mm in size, required between 600 and 1000 mmHg of pressure to rupture and there were no differences between the devices. In addition, for large vessels (6-7 mm), between 200 and 700 mmHg of pressure was required to rupture the vessel. There were no statistically significant differences between devices studied.

The active feedback provides clinicians with consistent coagulation of vessels. Measurement of mean burst pressures in sealed vessels is consistently supraphysiological, ranging from 200-600 mmHg for vessels 6-7 mm in diameter to 600-1000 mmHg for vessels 2–3 mm in size.[42]

Choosing the right tool for the right job requires understanding how RF electrosurgery works (Table 4). Increasing understanding of how these devices work contributes to safer OR

Table 4
Comparison of instrument types.

	Monopolar	Advanced bipolar	Ultrasonic	Advanced cautery
Thermal spread	1-3 mm	1-3 mm	1-3 mm	1-2 mm
Direct coupling	Yes	No	No	No
Capacitive coupling	Yes	No	No	No
Alternate-site injury	Yes	No	No	No
Inadvertent activation	Yes	Yes	Yes	Yes
Direct thermal extension	Yes	No	No	No
Current leakage through cord	Yes	Yes	No	Yes

conditions by enabling clinicians to make intelligent choices about the devices and power settings, and how they use these devices with other equipment. Evidence-based practices with energy devices in the OR help reinforce safe and effective use. Everyone who works in the OR has the responsibility to understand the key principles of RF electrosurgery so we can reduce the risk injury to our patients.

Preventing and responding to OR fires

The occurrence of a fire in the OR during surgery is a rare but potentially devastating event. The ECRI has estimated that between 200 and 240 fires occur in the ORs in the U.S. annually. These data are derived from an analysis in the state of Pennsylvania in which the incidence of OR fires between 2004 and 2011 ranged between 0.32 and 0.67 per 100,000 cases.[43] This number is not dissimilar to the number of wrong-site surgery cases that occur each year. Up to one-third of OR fires result in harm to the patient, and 20-30 of these events result in serious injuries that are disfiguring or disabling or even lead to death. The following case is 1 example of how an OR fire can develop:

A 65-year-old man was undergoing excision of an epidermal inclusion cyst of the forehead under local anesthesia with sedation. The patient was prepared with an alcohol-based preparation and administered oxygen by nasal cannula. He was draped with cloth towels and then a full drape. An elliptical incision was made around the cyst and the incision was deepened using an electrosurgical bovie pencil. As the incision extended to the inferior aspect of the wound, a spark was observed in the field with a flash beneath the drapes. This was immediately smothered and the drapes were pulled off. The patient was burned across the checks and nasal bridge with superficial second-degree burns that required further care in a burn unit.

OR fires have been the subject of a sentinel event alert by the Joint Commission.[44] It is also 1 of the 11 priority safety topics identified by the Association of Perioperative Registered Nurses (AORN) Presidential Commission on Patient Safety[45] and is a top priority for the FDA.[46] The FDA has a national fire protection week annually to highlight awareness about this problem.

Prevention of OR fires requires first an understanding of the elements that are required for a fire to form. The “fire triangle” consists of 3 key elements (Fig 8): (1) an ignition or heat source (electrosurgical unit and lasers); (2) fuel, which in the OR environment consists of the surgical drapes and alcohol-based preparations; and (3) an oxidizer such as oxygen or nitrous oxide. As no single member of the OR team is responsible for all of these variables, prevention requires coordination by the various members of the team.

Approximately 21% of OR fires occur in the airway and an additional 44% in the head, neck, face, or upper chest.[47] The electrosurgical equipment is the most common source of ignition, accounting for approximately 70% of cases and approximately 10% are due to lasers. The remainder is from various other equipment including fiber-optic light sources.

The ECRI Institute, an independent nonprofit health services research agency with a focus on patient safety, has developed a 1-page outline of how OR fires can be prevented titled “Only You Can Prevent Surgical Fires: Surgical Team Communication is Essential.”[48] One of the greatest

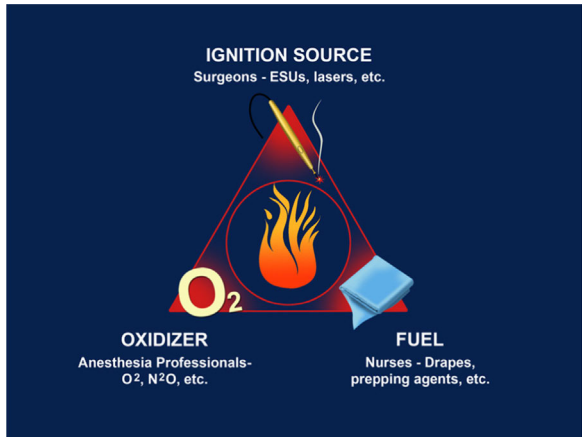

Fig. 8. Fire triangle. Three elements that cause a fire include ignition source, oxidizer, and fuel source. (Adapted with permission from Brunt.[8]) (Color version of figure is available online.)

risks for an OR fire is the use of an open oxygen source (ie, oxygen delivery via a mask or nasal cannula, particularly for head and neck procedures). If an open O_2 source is used for a head and neck procedure, the oxygen concentration should be less than 30%. For tracheostomy procedures, one should always use cold instruments and not an electrosurgical device to cut the tracheal rings and enter the airway because of the risk of an airway fire.

Alcohol-based preparations should always be allowed to dry before draping and any areas of pooling should be blotted dry. It is important to note that alcohol-based fires have a blue flame and can be hard to see until extensive damage is done. Another fire hazard is the fiber-optic light source that is used for laparoscopic and many endoscopic procedures. Precautions include making certain that the light source is on standby before the unit is turned on and connected to the laparoscope. It is also essential that the light source be turned off before it is disconnected from the laparoscope at the end of the procedure. The end of the fiber-optic cable gets extremely hot and a drape can begin to burn within 3-4 seconds of coming in contact with an activated light source. A facial burn that occurred owing to failure to take these precautions is shown in Figure 9.

Other electrosurgical safety precautions one should take include activating the electrosurgical unit only when the tip is in view and deactivating it before it leaves the surgical site. The electrosurgical bovie pencil or laparoscopic device should be put in the holster when not in

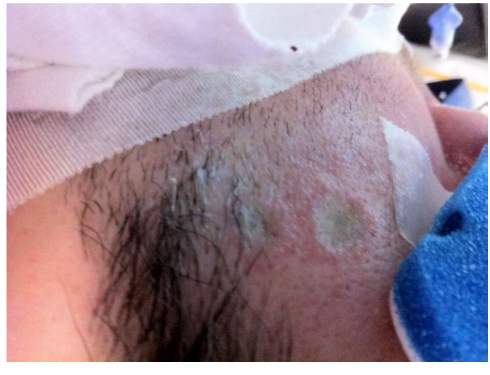

Fig. 9. Photograph of iatrogenic facial burn. (Adapted with permission from Brunt.[8]) (Color version of figure is available online.)

Table 5
Operating room fire risk assessment factors.

Open oxygen source
Surgery over chest, neck, and head
Use of a potential ignition source

use and one should never use rubber sleeves over electrosurgical electrodes because of the tendency to melt and cause flame flare-ups, especially in an O_2-rich environment.

Some groups have implemented OR fire risk assessment checklists at the beginning of procedures. The combination of surgery being done above the level of the xiphoid, open oxygen delivery, and an available ignition source should enhance awareness for the risk of an OR fire and should be integrated into the team discussions.

If an OR fire does occur, several immediate steps should be taken.[49] First, the flow of all airway gases to the patient should be stopped by disconnecting the breathing circuit. For airway fires, the breathing circuit should be disconnected from the endotracheal tube first, and then the tube should be removed. If the breathing circuit is not disconnected first, the endotracheal tube can act as a blow torch because of the presence of oxygen flowing through it. Second, all burning and burned materials should be removed immediately from the patient whether on or in the patient. Next, the fire should be extinguished on burning materials. In some case it may be necessary to use a CO_2 fire extinguisher which should be present in every OR. Finally, the patient should be cared for. This means restoration of breathing using room air and never oxygen and managing any patient injuries. It is important to note that if burned materials are not removed from the patient, the heat from them can continue to cause injury even after the fire is extinguished.

In cases of disastrous or extreme fire or smoke events, rescue, alert, confine, and evacuate (RACE) should be employed. The patient should be rescued from the room in which the fire has occurred. An alert should be given to staff, the fire alarm system should be activated, and a call should be made to the fire department. The room should be confined and isolated. Doors should be closed, medical gas valves should be shut off, automatic smoke evacuation should begin, and electrical power to the room should be stopped. Finally, the incident room should be evacuated and, if necessary, the entire surgical suite. Of note, an OR fire of this nature is an extremely rare event, and only 2 known cases have occurred over the last 30 plus years in which the OR had to be evacuated.

The FDA as a part of its national fire protection week has identified a number of things that surgeons, OR nurses, and operative allied health personnel can do to minimize the risk of an OR fire (Table 5).

Surgeons can help increase awareness about this risk by giving talks and communicating to the nurses and other OR staff and taking the appropriate precautions that are outlined in this section. Several other resources are available regarding this topic, including the The Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) Fundamental Use of Surgical Energy (FUSE) program (www.fuseprogram.org), the Anesthesia Patient Safety foundation (www.apsf.org), and others as listed in Table 6. Additional resources or additional information are listed in Table 7.

Electrical interactions with CIEDs

Patients may present for surgery with many types of implanted electronic devices. These include CIEDs, deep brain simulators, spinal cord stimulators, vagal nerve stimulators, implantable infusion pumps, and cochlear implants. CIED is the term generally used for pacemakers and implantable cardioverter defibrillators (ICDs). Whether you need to be concerned about the presence of a CIED with respect to surgical energy use is largely dependent on the type and location of the surgical procedure. For example, simple excision of a skin lesion

Table 6
Recommendations to increase awareness about operating room fires.[46]

Find out how to prevent fires (eg, FUSE Program)
Tell colleagues about the importance of using surgical fire risk assessment
Talk about surgical fires during staff meetings
Do an in-service educational program
Ask your facility what is being done to reduce operating room fire risk

from an extremity would not necessarily need the preparations discussed here. Most surgical procedures, however, do at least warrant a discussion with the perioperative team regarding the presence of a CIED, the nature of the procedure, and whether and which precautions must be taken.[50]

There are a large number of patients with CIEDs. At least 3 million patients have conventional pacemakers and approximately 750,000 more receive implants in the United States yearly. More than 300,000 patients have ICDs and approximately 10,000 are implanted per month according to the Heart Rhythm Society. By 2020, it is estimated that approximately 670,000 ICDs would be present in the American population.

Many sources of EMI exist in the OR environment. These include monopolar electrosurgical devices, monopolar endoscopic devices, RFA tools, electrocardiographic monitors, fluid and blood warmers, MRI magnets, computed tomography machines, and nerve stimulators. Most newer CIEDs are very well shielded from everyday EMI, but the amount of energy presented by surgical devices may overcome that level of shielding. Several factors determine the effects of EMI on CIED: the intensity of the energy field or source, the frequency and waveform of the signal, the distance between the source and CIED leads, and the orientation of the leads with respect to the field or source. In other words, we want to know what device is being used, what mode it is being used in, what energy level is selected, where the dispersion pad is placed on the patient, and approximately what the current path is through the patient.

There are many potential effects of EMI on a CIED, some more common than others.[36] The most common is inappropriate inhibition or triggering of a pacemaker or ICD. The pacemaker generator responds to the energy from the surgical device as a cardiac signal. For a pacemaker-dependent patient, it may be interpreted as native cardiac rhythm, inhibiting the activity of the pacemaker. For an ICD, it could be interpreted as an arrhythmia and inappropriately deliver a shock the patient. EMI can also cause unintended asynchronous pacing. This is fairly rare with current devices. Reprogramming of the device is also rare with generator models from the last decade or so, but resets and safety modes are still possible. Physical components of the generator can be damaged if the current is in close proximity or directly on the pulse generator. Current can also be conducted by the leads into the cardiac tissue, inducing ventricular or atrial fibrillation. Injury at the lead-tissue interface when energy is conducted to the tissue can create scarring. This can raise the pacing threshold and result in the patient not being appropriately paced.

Table 7
Operating room fire resources.

Anesthesia Patient Safety Foundation (APSF). Prevention and management of surgical fires (video). www.apsf.org/resource_center/educational tools/video_library.mpsx.
AORN Guidance statement: Fire safety in the perioperative setting. AORN video at www.cine-med.com.
Practice advisory for the prevention and management of operating room fires: an updated report by the American Society of Anesthesiologists Task Force on Operating Room Fires. Anesthesiology. 2013 Feb;118(2):271-90.
AORN Guidance Statement: Fire prevention in the operating room. AORN J 2005;81:1067-75.
Preventing surgical fires. www.jointcomission.org/SentinelEvent/wentineleventalert/sea_29.
www.fda.gov/Drugs/DrugSafety/SafeUSe Initiative/PreventingSurgicalFires/.
http://wwwaornorg/PracticeResources/ToolKits/FireSafetyToolKit/ 2010.

Table 8
Pacemaker codes.

Chamber(s) paced	Chamber(s) sensed	Response to sensing	Programmability, rate modulation	Multisite pacing
0 = none A = atrium V = ventricle D = dual	0 = none A = atrium V = ventricle D = dual	0 = none T = triggered I = inhibited D = dual	c R = rate modulation	0 = none A = atrium V = ventricle D = dual

When a patient presents for surgery several pieces of information must be determined. First, is a CIED present? This can be determined by history and physical examination. Once the presence of the CIED is established then more information must be sought, including the type of device. Most patients have an identification card that may assist with this. Alternatively, a chest radiograph may be obtained as devices are labeled with radiographically readable codes. The best source of information is clearly the patient's cardiologists in charge of managing the device, as they would also be able to provide information about the indication for device placement and pacemaker dependence. If it is not known whether a patient is pacemaker dependent, the device can be reprogrammed to a minimum rate to determine whether adequate ventricular activity is present. Device function should be established as well. This is most efficiently accomplished by interrogation of the device either by the electrophysiology service or remotely. The ideal situation is to obtain a “prescription” for perioperative pacemaker management from the managing physician and would include all of the above information. Physicians providing care to patients with pacemakers should be familiar with the NBG codes that are commonly used to communicate pacemaker settings.[51] Codes indicate the chambers paced, chamber sensed, response to sensing, programmability and rate modulation, and multisite pacing (Table 8).

A pertinent question is whether EMI is likely to occur. If a nonmonopolar tool can be used (eg, bipolar device or ultrasonic scalpel) then the risk to the patient is mitigated. In additional to traditional bipolar forceps, newer bipolar tools include the LigaSure and Gyrus devices. If a monopolar device is necessary given the nature of the surgical procedure, the mode of energy selected is important. Unblended cut is better than a “blend” mode, which is better than pure “coag.” Unblended cut is continuous, of low voltage, and easier for the CIED to filter out.[52]

If a patient is pacemaker dependent it is usually recommended that the pacemaker be reprogrammed to an asynchronous mode. One must be aware of the potential for R-on-T phenomenon vs risk of pacemaker inhibition. Other pacemaker modes that must be taken into consideration for reprogramming include rate-adaptive functions. These can be activated inadvertently during preparation of the chest or during mechanical ventilation by activation of bioimpedance sensors and may result in a higher heart rate than desired during surgery. ICD antitachyarrhythmia functions should be suspended to avoid inappropriate shocking of the patient and defibrillation and temporary pacemaking equipment should be immediately available.

In the case of urgent or emergent surgery, or even an elective patient presenting without prior evaluation, another question is whether or not a magnet is appropriate or safe to use in lieu of reprogramming.[53] Placement of a magnet often results in asynchronous pacing; the exact response and pacing rate vary with manufacturers and may be affected by the remaining battery life. For an ICD, a magnet typically does not alter pacemaker function but often disables tachyarrhythmia therapy. Each patient much be considered individually; using short bursts to avoid ICD oversensing or hemodynamic compromise from pacer inhibition may be safer than arbitrarily placing a magnet. If the patient is pacemaker dependent and has a combined ICD and pacemaker device it would require reprogramming. The patient should be monitored continuously until the baseline programming is reestablished.

Intraoperatively the patient should be monitored with continuous EKG per American Society of Anesthesiology standards as well as some form of continuous waveform to verify perfusion. This may be a pulse oximetry plethysmogram or arterial waveform tracing. The EKG alone is

unreliable as there tends to be “noise” interference when the monopolar device is activated. The dispersion plate (commonly and erroneously known as the “grounding pad”) should be positioned such that the current does not cross the CIED system (generator and leads). Although the thigh may be the traditional location, it may not be the best choice if the surgical site is cephalad to the CIED. The goal is to keep the current path as far away from the generator and leads as possible. If the surgical site is below the umbilicus (approximately 6 in or greater away from the leads), there is generally lower risk for interference with CIED.

The surgeon can help avoiding interference with the CIED by carefully using the monopolar tool. “Arcing,” activating the tool when distant from the tissue, should be avoided. Indirect activation (touching a metal instrument with the monopolar tool) may also cause arcing. Short intermittent bursts are preferable to longer activations. As mentioned previously, “cut” mode should be used in favor of “coag,” and the lowest effective energy levels should be selected.

The same rules apply for RFA, which is a higher energy form of monopolar surgery. The CIED should again be kept out of the current path if at all possible. RFA may be chosen as the modality for treatment vs surgery owing to the extent of patient comorbidity; thus, there may be a greater chance of CIED presence in this patient population. Unlike a monopolar tool, the energy is applied for longer intervals and at high energy, thus having higher potential for interference. All devices should be interrogated postoperatively after RFA given the heavily applied monopolar current. Until the device is interrogated, the patient should be maintained on a telemetry monitor.

In the gastroenterology suite, there are several monopolar endoscopic devices in common use. These include snares, hot forceps, endoscopic retrograde cholangio pancreatography (ERCP) sphincterotomes, the argon plasma coagulation device, endoscopic balloon array, and endoscopic submucosal dissection knives. Bipolar devices include the multipolar electrocoagulation gold probe and the RF array ablation catheter. The heater probe is a form of direct cautery. Given the proximity of the stomach to the heart, the selection of endoscopic tools must be considered in case of the pacemaker patient.

Postoperatively, CIEDs should be interrogated if at all possible. This is very important for those who are pacemaker dependent, those who were reprogrammed, or underwent hemodynamically challenging surgery with large fluid volume shifts or emergent surgery above the umbilicus. However, rare damage at the lead-tissue interface may not be apparent for 24-48 hours. Higher risk patients should be monitored continuously until the device is interrogated.[50]

To summarize, the presence of a CIED must be established preoperatively and particulars of function established. Whether a monopolar surgical device is necessary for the surgery is the next decision point; if so, the likely current path should be noted and appropriate choice of device mode selected. Postoperatively, the CIED should be examined before patient discharge to maintain patient safety.

Fig. 10. The Fundamental Use of Surgical Energy (FUSE) logo. (Adapted with permission from The Society of American Gastrointestinal and Endoscopic Surgeons [SAGES].) (Color version of figure is available online.)

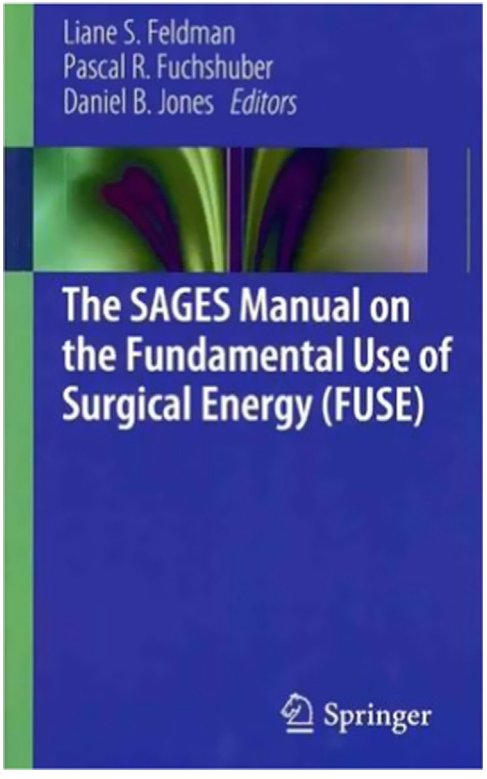

Fig. 11. Cover of the SAGES Manual on the Fundamental Use of Surgical Energy. (Adapted with permission from The Society of American Gastrointestinal and Endoscopic Surgeons [SAGES].) (Color version of figure is available online.)

The FUSE program

You have likely learned a lot from this overview. Surely, you have many questions. Consider going online to learn more with the FUSE online curriculum (Fig 10). The SAGES FUSE program is set up for nurses, residents, medical students, and practicing physicians.

There is a series of 12 modules that you go through at your own pace. This program is free, and you can learn the material and take quizzes as you go along. CME and CEU credits are awarded for a fee. The ultimate intent is for all surgeons, as leaders in the OR, to obtain FUSE certification by sitting for a written, validated, proctored multiple-choice examination. To maximize learning and one's chance of passing the test, there is the FUSE manual (Fig 11) in addition to the online modules. The manual covers everything from monopolar to bipolar to RF devices and endoscopic applications, among other topics. The examination is difficult, but those who have taken it attest to the importance of the content. There is a sense of accomplishment knowing that you have gained knowledge that would enable you to take truly better care of your patients. So, if you want to learn more, this is the time to take out your iPad and visit www.fuseprogram.org.

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