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The Art of Electrosurgery: Trainees and Experts

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Abstract

The benefits of electrosurgery have been acknowledged since the early 1920s, and nowadays more than 80% of surgical procedures involve devices that apply energy to tissues. Despite its widespread use, it is currently unknown how the operator's choices with regard to instrument selection and application technique are related to complications. As such, the manner in which electrosurgery is applied can have a serious influence on the outcome of the procedure and the well-being of patients. The aim of this study is to investigate the variety of differences in usage of electrosurgical devices. Our approach is to measure these parameters to provide insight into application techniques. A sensor was developed that records the magnitude of electric current delivered to an electrosurgical device at a frequency of 10 Hz. The sensor is able to detect device activation times and a reliable estimate of the power-level settings. Data were recorded for 91 laparoscopic cholecystectomies performed by different surgeons and residents. Results of the current measurement data show differences in the way electrosurgery is applied by surgeons and residents during a laparoscopic cholecystectomy. Variations are seen in the number of activations, the activation time, and the approach for removal of the gallbladder. Analysis showed that experienced surgeons have a longer activation time than residents (3.01 vs 1.41 seconds, $P < .001$) and a lower number of activations (102 vs 123). This method offers the opportunity to relate application techniques to clinical outcome and to provide input for the development of a best practice model.

Keywords

electrosurgery, patient safety, surgical training, medical technology, best practice model

Introduction

Over the course of many years, there has been a great increase of the use of medical technology in hospitals all over the world.[1] The term medical technology encompasses the range from simple blood pressure pumps to very complex DaVinci robots in the operating room (OR). The main purpose for all devices is to improve patient safety, efficiency, and workflow. At this moment patient safety is a very important item on many agendas.[2-6] Safe use of medical technology represents a safe product, in the hands of a trained user, in an environment that can guarantee safe surgery. Many studies specifically focus on patient safety in the OR, since it has been recognized as a place where many incidents can occur. Baines et al found that more than 50% of all adverse events were related to surgical procedures,[7] and Wubben et al show that 15.9% of incidents during surgical procedures are equipment related.[8] In particular, the use of electrosurgical devices is often associated with hazards that may seriously influence the outcome of the procedure.[9]

More than 80% of surgical procedures performed today involve devices that apply energy to tissues. First introduced in the 1920s by Bovie,[10] electrosurgery is used for surgical cutting or to control bleeding by causing coagulation (hemostasis) at the targeted surgical site. Electrical currents and voltages are delivered through an active electrode, causing desiccation, vaporization, or charring of the target tissue.[11] Despite significant advantages for tissue dissection, hemostasis, and ablation, major adverse events can and do occur during the application of electrosurgery. The most common unwanted events include direct misapplication, capacitive coupling, direct coupling, and insulation failure, leading to damage to adjacent structures.[9]

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Furthermore, alternative site burns (eg, pads, prostheses, surgeon hand) frequently occur.[11] According to the Association of periOperative Registered Nurses, in the United States there are approximately 40 000 patient burn cases annually due to faulty electrosurgical devices, and in 1999 alone, nearly $600 million was paid in claims for those injuries.[12,13] In addition, the prevalence of bowel injuries related to electrosurgery during laparoscopic surgery is estimated at 1 to 2 per 1000 patients, with high morbidity related to unrecognized injuries.[14]

Most of the above-mentioned adverse events are considered to be preventable by ensuring a proper understanding of the technologies and their applications and an awareness of potential risks.[15] Many complications are based on the faulty use of the instruments and settings; therefore, knowledge and basic skills in operating these devices are of great importance. However, while surgeons and surgical trainees may use energy-based devices on a daily basis, they are not always familiar with their basic principles and functions. Recent studies found many gaps in the knowledge about the safe use of electrosurgical devices.[16,17] At this moment no specific guidelines about the application of electrosurgery exist. The industry suggests that in general the lowest setting possible should be used and single activations of the device should be as short as possible.[18]

With so many complications and risks associated with the use of electrosurgery, it is remarkable that there is no standardized and mandatory curriculum, teaching surgeons to safely and effectively operate such devices. Moreover, there is no procedure to certify basic skills prior to their application. The latter is mostly due to the current lack of a best practice model for electrosurgery. In fact, very little is known about the details of practical use by different surgeons. No complete training for residents can be developed, as long as the actual use of these instruments is unknown and objective assessments based on validated metrics are lacking. For these reasons, it is necessary to obtain information about the current application methods of electrosurgical devices throughout a procedure. We are not aware of other studies that investigated the use of electrosurgical devices in depth.

The aim of the work presented in this article is to get insight in the application of electrosurgical devices during surgical procedures. Our approach is to delineate ways of handling the technique by obtaining detailed registrations of the actual activations of the electrosurgical device during surgical cutting and coagulation. In this study, we evaluate the variability in activation patterns by experienced surgeons and residents. The work provides input for the establishment of a best practice model and contributes to the development of a training program focused on safe use of electrosurgery.

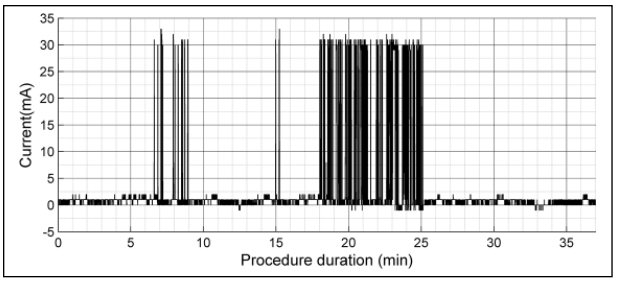

Figure 1. Example of an activation pattern of the electrosurgical device during a laparoscopic cholecystectomy. Peaks in the recorded current correspond to activations of the device.

Materials and Methods

Data Acquisition

A custom-made measurement device was used to record the magnitude of electric current delivered to an electrosurgical device (Valleylab, Force FX, or Valleylab Force triad). While plugged in between the power plug of the device and socket, it recorded the magnitude of current at a frequency of 10 Hz. The device did not interfere the procedure in any way. The recorded data were stored on a SD card for postoperative data analysis. An example of the activation pattern of the electrosurgical device during an entire laparoscopic cholecystectomy procedure is shown in Figure 1.

Recorded Clinical Procedures

For this study, elective laparoscopic cholecystectomies were chosen because of their frequent performance and relatively standard execution. A standard procedure can be divided into 3 phases. First the patient gets prepared for minimal invasive surgery, small incisions are made in the abdomen and trocars are placed. In the second phase, instruments enter the ports and the gallbladder is identified and removed from the body. In the last phase, the instruments and trocars are removed again and sutures are placed to close the incisions. Electrosurgery is mainly used in the second phase to remove the gallbladder from the liver, to establish hemostasis of the bleeding gallbladder bed, and to coagulate small vessels. A total of 91 laparoscopic cholecystectomies were recorded, performed by 5 different surgeons (>1000 laparoscopic cholecystectomies performed) and 11 different residents (100-300 laparoscopic cholecystectomies performed). The surgeons executed a total of 45 procedures and the residents covered the remaining 46, under supervision. All procedures were recorded in the OR of a Dutch teaching hospital between March 2014 and July 2015.

Patient Characteristics

Relevant patient information and perioperative details about the procedure were obtained from the hospital information system (CS-EZIS, ChipSoft, Amsterdam, The Netherlands). Surgery was performed on 30 men and 61 women, with an average age of 54 years (range 18-86 years). With an average body mass index (BMI) of 29 (range 18-44) our patients were generally overweight. Forty-five patients had abdominal surgery before, which may lead to adhesions and could make surgery more difficult. Four patients were admitted with an acute diagnosis; all others patients were scheduled on an elective basis. Spillage of gallstones and bile during the procedure was even for surgeons and residents, respectively, 14 and 10 times. Blood loss was not reported in 28 of procedures, so is excluded in this analysis. No conversions to laparotomy have occurred.

Data Analysis

The used sensor, measuring the electric current supplied to the electrosurgical device, enables accurate detection of device activation and a reliable estimate of the power-level settings. A threshold of 15 mA was selected in the data sets to detect single activations of the electrosurgical device. An activation started when the signal reaches a value higher than 15 mA and ended when the signal dropped below it. The start and end times of procedures were obtained from the hospital information system, and the current sensor data were selected manually according these timestamps.

Combining all available information, we were able to detect the following parameters:

- First moment of activation during the process
- Last moment of activation during the process
- Number/amount of activations
- Duration of separate activations
- Estimated height of activation
- Duration of total device usage

Statistics

To control for possible effects of patient characteristics on the use of the electrosurgical device we first determined whether the sex, age, BMI, and previous abdominal surgery was correlated with any of the above-mentioned parameters. Pearson product-moment correlation coefficients were obtained to see whether there was a relation between the number and duration of activations and the duration of use of the device. Student's *t* tests were performed to determine whether there were significant differences between the means of the grouped data of experts and of the residents. Analysis was done with use of MATLAB (version R2014b, MathWorks, Natick, MA).

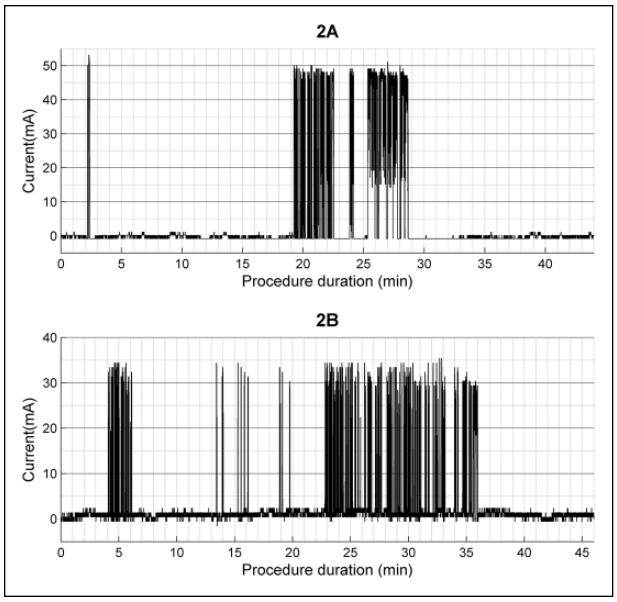

Figure 2. The activation patterns of the electrosurgical device of a surgeon (A) and a resident (B). On the horizontal axis the time in minutes is shown, starting immediately at the time of first incision and ending with the actual end-time of the procedure. On the *y*-axis the measurement data are provided.

Results

Activation Patterns

Laparoscopic cholecystectomies have a relatively standard execution. However, in this study the total procedure time varied extensively (range 9 minutes to 1 hour 44 minutes, average 44 minutes). As an illustration, Figure 2A shows that the use of the electrosurgical device was initiated about 19 minutes after the first incision, indicating that this was the time needed for placing the trocars and reaching the gallbladder. Next, the electrosurgery device was activated between the 19th minute and the 22nd minute. At around the 25th minute a second burst of activations is seen. In contrast, in Figure 2B a more frequent use of the device is seen.

With respect to the activation patterns of the electrosurgery device, several patterns were observed. Figure 2A shows the pattern of an expert surgeon, whereas Figure 2B shows the performance of a surgical resident.

Activation Parameters

Analysis showed that there were no correlations between the different patient characteristics, such as BMI, sex,

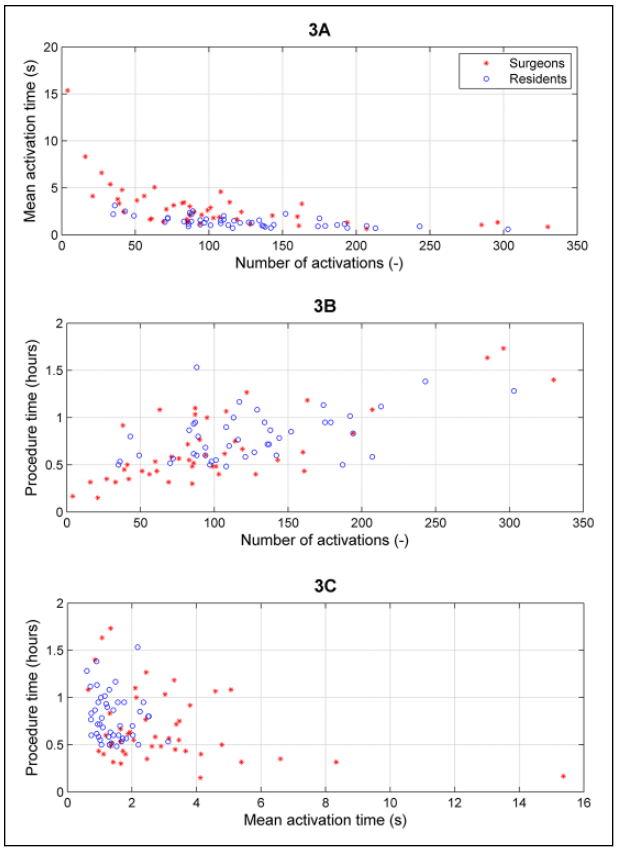

Figure 3. Number of activations (A and B) and mean activation time (C). Data obtained from surgeons (red) and residents (blue).

age, previous abdominal surgery, and the activation parameters that were measured in this study. Figure 3A shows the number of activations within a single procedure on the horizontal axis and the mean duration of activations for that procedure on the vertical axis. Combining the surgeons and residents, a correlation coefficient of $r = -0.52$ ($P < .001$) was obtained for these 2 parameters. Figure 3B shows a rise in the number of activations of both surgeons and residents when the procedure duration increases ($r = 0.66$, $P < .001$). Figure 3C shows that residents tend to use the same activation time regardless of the duration of the procedure ($r = -0.33$, $P = .002$).

Comparing the activation parameters averaged across the groups of surgeons and residents, differences between approaches in handling the device are observed. Surgeons have a mean number of activations of 102 times per procedure (median 87, interquartile range [IQR] 60.8), while residents tend to use the device more often with 123 times per procedure (median 111.5, IQR 56). This difference is not statistically significant however. The Student's t test ($t = -4.2$, $P < .001$, df = 89) does, however, show that the mean activation time of surgeons (median 2.44 seconds, IQR 1.9) is significantly higher than the residents (median 1.30 seconds, IQR 0.8); see Figure 4.

Discussion

This article presents a way to gain insight into the application of electrosurgery during a surgical procedure. In this study, we obtained detailed measurements on the use of electrosurgery in laparoscopic cholecystectomies to examine potential differences in handling techniques between operators and whether experience plays a major role in the way electrosurgery is applied. Our main findings show that different approaches in application technique can be distinguished among different operators; typically, a higher amount of activations goes along with a short activation time and vice versa. Furthermore, differences between surgeons and residents in the number of activations and the activation time of the electrosurgical device were found. All residents use a higher number of activations with a shorter activation time, while various surgeons seem to choose for the opposite approach.

Recent guidelines regarding the application of electrosurgery describe that operators should take the following parameters into account to enhance safety: the lowest power setting possible, a low-voltage waveform (cut), and brief intermittent activations.[5,18] When considering the behavior of the residents in terms of these guidelines we see clear commonalities. One could suggest that residents adhere to the guidelines better than surgeons do. However, many other factors are involved in the art of electrosurgery, such as operation speed of the surgeon and the instrument's contact area with the tissue. The final goal of electrosurgery is to develop a specific tissue effect using the appropriate instrument and wattage, furthermore causing minimal damage to the surrounding tissue.[19]

The skilled surgeon is aware of the various factors influencing the desired outcome. Thus, he or she combines basic knowledge of electrical biophysics and surgical skills to a preferred approach of the tissue. Yet it remains to be determined whether differences in the approach result in differences in clinical outcome.

It is not clear how different approaches develop in the first place. Different operators might have created their own application technique while becoming more experienced. Another interpretation of our results is that some operators are simply more careful in using energy-based devices. Furthermore, local habits of supervising surgeons are often copied by residents without further explanation.[16] This behavior could be the result of hierarchy issues, since the same supervising surgeons are responsible for the assessments. In any case, this study shows that clear differences in use of the electrosurgical device among operators exist.

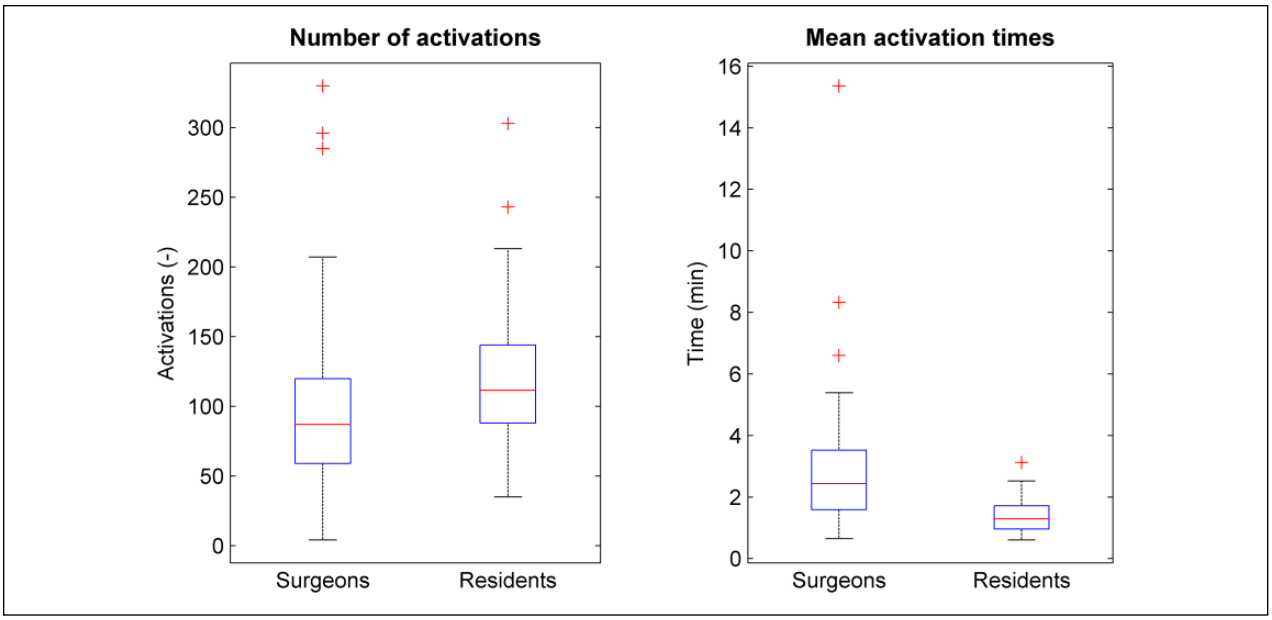

Figure 4. Boxplots of the number of activations and the mean activation time per procedure.

Possibly the apparent lack of knowledge about the theoretical background is a factor in the development of different application methods among surgeons and residents. An initiative from SAGES (Society of American Gastrointestinal and Endoscopic Surgeons) called the Fundamental Use of Surgical Energy (FUSE) program is introduced to improve knowledge among surgeons and residents about this subject.[6,14] Also other studies about knowledge-based programs show positive results.[20] However, none of the currently offered teaching programs deal with all practical aspects of safe application of electrosurgery.

In the current study, we took the first steps in obtaining data on the application of electrosurgery from a large number of procedures to eventually define the objectives for an outcome-based training program. Outcome-based education is an educational method that centers each part of an educational system on goals (outcomes). An example is the constructive alignment theory by Biggs.[21] According to this theory, the objectives, learning activities, and assessments should be in line for effective teaching and learning. For example, if students need to learn how to present, they should be given the opportunity to practice giving presentations, not only reading a book about it. If this theory is applied to the training in electrosurgery, residents in surgery should not only have theoretical education but also be offered practical skills training and assessments. In this respect, without clear knowledge of the objectives, an effective training program cannot be developed according to Biggs theory. Our approach makes it possible to gain detailed insight into the use of electrosurgery devices by surgeons of different levels of expertise.

With the availability of objective measurement techniques, we can take the next step in developing a more solid training program for surgical residents. We propose including a hands-on component in the training curriculum for electrosurgery. This could include a session in which the application technique of the resident is monitored in real-time and in which the effects of application of different settings are made explicit. This could be embedded in basic laparoscopic courses.

We conclude that differences are seen in the application of electrosurgical devices between experienced surgeons and surgical residents in terms of the number of activations and the activation times during a procedure. Detailed application measurements can offer the opportunity to relate technical approaches to clinical outcome and to provide input for the development of a best practice model.

Authors' Note

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Author Contributions

Study concept and design: Frédérique C. Meeuwsen, Annetje C. P. Guédon, Jenny Dankelman, and John J. van den Dobbelsteen
Acquisition of data: Frédérique C. Meeuwsen and Annetje C. P. Guédon
Analysis and interpretation: Frédérique C. Meeuwsen, Ewout A. Arkenbout, and John J. van den Dobbelsteen
Study supervision: Maarten van der Elst, Jenny Dankelman, and John J. van den Dobbelsteen

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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