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FUSE certification enhances performance on a virtual computer based simulator for dispersive electrode placement

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Abstract

Background The Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) has developed the fundamental use of surgical energy (FUSE) didactic curriculum in order to further understanding of the safe use of surgical energy. The virtual electrosurgical skill trainer (VEST) is being developed as a complementary simulation-based curriculum, with several modules already existing. Subsequently, a new VEST module has been developed about dispersive electrode placement. The purpose of this study is to assess knowledge about dispersive electrode placement in surgeons and surgical trainees in addition to describing a new VEST module.

Methods Forty-six subjects ($n = 46$) were recruited for participation at the 2016 SAGES conference Learning Center. Subjects were asked to complete demographic surveys, a five-question pre-test, and a five-question post-test after completing the VEST dispersive electrode module. Subjects were then asked to rate different aspects of the module using a five-point Likert scale questionnaire.

Results Mean pre-simulator and post-simulator assessment scores were 1.5 and 3.4, respectively, with Wilcoxon signed rank analysis showing a significant difference in the means ($p < 0.05$). Subjects were grouped by the presence ($n = 12$) or absence ($n = 31$) of prior FUSE experience and by training level. Mann–Whitney *U* testing showed no significant difference in pre-simulator assessment scores between attending surgeons and trainees ($p > 0.05$). In those with and without FUSE exposure, a significant difference ($p < 0.05$) was seen in pre-simulator assessment scores, and no significant difference in Likert scale assessment scores was seen.

Conclusions This study demonstrated a new VEST educational module. Consistently high Likert assessment scores showed that users felt that the VEST module helped their understanding of dispersive electrode placement. Additionally, the study reflected a potential knowledge deficit in the safe use of dispersive electrodes in the surgical community, also demonstrating that even some exposure to the FUSE curriculum developed by SAGES provides increased awareness about dispersive electrode use.

Keywords Simulation · Surgical education · Skills training

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Electrosurgical instruments have become indispensable in the modern operating room (OR), becoming ubiquitous in today's surgical world. First introduced in the early twentieth century, the principles behind the application of high frequency electrical energy in order to achieve hemostasis and/or tissue dissection have not changed to this day. Today's operative procedures involve a wide range of surgical energy sources [1]. However, the use of surgical energy devices has been associated with injury, OR fire, and even death. In between 1994 and 2013, a review of the Food and Drug Administration's (FDA) Manufacturer and User Facility Device Experience (MAUDE) database revealed at least 178 deaths and 3553 injury reports, including 279 OR fires [2]. While rare, these incidents have the potential to generate significant morbidity, mortality, and divert the use of healthcare resources towards preventable events.

Knowledge deficits related to the use of surgical energy have been previously identified in both General Surgeons and trainees [3]. These knowledge deficits have led to the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) to develop a curriculum, the Fundamental Use of Surgical Energy (FUSE) program in order to attempt to address some of these deficiencies [4]. This curriculum has been successfully developed and is currently available online as a free series of didactic modules. However, this curriculum is currently limited by its pure didactic form. Adding a simulation-based curriculum support the didactic FUSE curriculum has been previously shown to be an effective method to retain knowledge [5].

The dispersive electrode plays a key role in completing the circuit when using monopolar electrosurgical tools. The placement of the active and the dispersive electrodes defines the spatial region of the body where the electrical current will travel. Dispersive electrodes and monopolar electrosurgical tools are used in open, laparoscopic, and endoscopic surgery; therefore, a good fund of knowledge about dispersive electrode placement is crucial to avoiding adverse events related to dispersive electrode placement across all surgical and endoscopic procedural specialties.

The virtual electrosurgical skill trainer (VEST) is a module-based simulator that complements the FUSE didactic materials currently under development. Its objective is to train surgeons in the motor and cognitive skills that are required to safely operate electrosurgery tools during open and minimally invasive procedures. A monopolar electrosurgery module was demonstrated at the 2014 SAGES learning center and users rated the module as realistic and useful to learning the fundamentals of electrosurgery [6]. A virtual OR fire training and prevention module was demonstrated at the 2015 SAGES learning center where the simulator was highly rated for its effectiveness and usefulness for OR fire safety and training [7]. In this research, we aim to assess knowledge about dispersive electrode placement in a target audience of surgeons and surgical trainees as well as to demonstrate a new VEST module that is targeted at reinforcing the principles of safe placement of the dispersive electrodes on patients. Additionally, we would like to assess its usefulness in a target surgical audience by gathering subjective data about user experiences. The new VEST module consists of a simulator that enables visualization of current inside the human body connecting the active electrode and the dispersive electrode.

Methods

VEST simulator module design

This VEST module presents a graphical user interface where the user may explore how current travels within the human body, closing the circuit between the active and the dispersive electrodes. The dispersive electrode may be selected from a list of 15 different positions, and the active electrode may be placed anywhere within the human body. With this choice, the simulator calculates the current density distribution within the body and presents it along with the transparent body. The simulator is three-dimensional, so the user is able to rotate and zoom in the results window to better understand the shape of the region that the current occupies, as well as the power intensity at different positions (Fig. 1).

The simulator can be used for exploration or for knowledge assessment. In the first mode, the location of the active electrode is free and the user may select any dispersive electrode so that the path of the current may be observed. In knowledge assessment, a clinical case is shown on the window and the location of the active electrode is automatically determined and kept fixed in place. The user is asked to select any of the proposed dispersive electrode locations and the simulator immediately provides feedback to the user as to whether the selection was appropriate or not, giving further information for each case.

The simulator works by solving in real time the equation of current conservation within the human body. We assume that the effects of the current are purely resistive and that the input waveform is a purely sinusoidal with a frequency of 400 kHz. Under these conditions, the equation for current conservation can be written as a single equation for the amplitude of the voltage, which in this case can be represented as a real scalar field [8]. The only physical parameter involved is the value of the electrical conductivity as it changes from place to place within the body.

The data for the electrical conductivity of the body come from the AustinMan project from the University of Texas at Austin [9]. This project builds on top of the visible human body project, where a model of a human body has been digitized. For the AustinMan project, the voxels comprising the

Fig. 1 Software GUI used to interact with the simulation. The top row shows the list of possible clinical scenarios. The list of possible dispersive-electrode placements is shown on the left. The tip of the pen (blue) defines the location of the active electrode and the electric power density is displayed as the yellow cloud inside the body. The bottom left corner text box shows an example of explanatory text shown to the user. (Color figure online)

data set have been mapped to their respective organs with corresponding electrical properties. For our computations, the model with a voxel size of $8 \times 8 \times 8$ mm^3 is utilized.

The computational domain is given by a prismatic region that bounds the voxels from the data set. The computational domain extends beyond the smallest bounding box of the data set by 16 mm (2 voxels) on each face, so that the no-flux boundary condition applied on them does not interact with the boundary of the data set. The space inside the computational domain not occupied by the voxels from the dataset is labeled as air and given a constant conductivity value of 10^{-5} [S/m]. This value is much higher than the nominal value for the conductivity of air at nominal conditions, which is of the order of 10^{-15} [S/m], as it improves the stability of the computations while not affecting the final visual result or the given recommendations for the clinical cases presented.

The possible dispersive electrode locations are the chest, arm, scapula, calf, flank, hip, lower back, and thigh for both the left and right sides. For each dispersive electrode location, a corresponding surface was extracted from the AustinMan dataset boundary and was assigned a zero voltage boundary condition. For each possible placement of the dispersive electrode, a pre-computed linear system of equations was created to match all boundary conditions. The effect of the active electrode is modeled by placing a unit source at the node of the mesh that is closest to the tip of the active electrode. The resulting solution is scaled so that all solutions represent the same dissipated power. This scaling makes the visual comparison of the intensity between two different placements meaningful.

A clinical case may involve the existence of foreign metallic objects inside the patient, such as pacemakers or prosthesis. For the purpose of the simulator, these are treated as hollow metallic objects that have a constant, but unknown, electric potential that is computed along with the rest of the solution.

The clinical scenarios selected represent cases where the placement of the dispersive electrode can make a significant difference in the outcome of the procedure. The scenarios selected were: left mastectomy, cholecystectomy, left inguinal hernia, and bilateral mastectomy. For each of these cases, a reduced set of possible dispersive electrode locations was selected and the description of the cases stated if there was a foreign object present. In those cases, the foreign object was also rendered as part of the scene.

Experimental design

This study relied on opportunistic recruitment of subjects at the 2016 SAGES conference learning center in

Boston, MA. IRB approval was obtained from the Committee on Clinical Investigations (CCI), the institutional review board (IRB) for the Beth Israel Deaconess Medical Center, to conduct this study along with approval for a waiver of written consent. Subjects had a standard script read to them detailing the purpose, conduct, risks, and benefits of the study and were then asked for verbal consent; no personal identifiers were collected. Subjects who were participating in the learning center were recruited at random from attendees of the 2016 SAGES conference in Boston, MA who were passing through the SAGES learning center where the simulator was displayed. After obtaining verbal consent, subjects were asked to provide demographic information including their age, gender, handedness, level of training, and prior experience with electrosurgery, overall surgical experience, prior FUSE curriculum exposure, and video game use. Subjects were then given a five-question pre-simulator assessment including both clinical scenarios and multiple choice questions designed to assess subjects' knowledge of dispersive electrode placement. Questions were created by the authors, with senior authors having been involved in the design of the FUSE curriculum providing expert input. Once the pre-simulator assessment was complete, subjects used the VEST simulator module. The functions of the simulator were shown to subjects by research staff, and subjects were then allowed to manipulate both the virtual electrosurgical instrument and dispersive electrode in order to observe the changes in current flow that resulted from their actions. Once subjects had explored the functionality of the simulator, they were instructed to complete clinical scenarios that required them choose a location for dispersive electrode placement. The simulator provided immediate feedback to participants and informed them whether their choice was correct. Subjects were allowed to make as many selections as they wished until they reached a correct answer. The clinical scenarios presented in the simulator were identical to those presented in the pre-simulator assessment. Once subjects were finished with the simulator, they were asked to complete a post-simulator assessment that consisted of the same clinical scenarios presented throughout the experiment and in the pre-simulator assessment in order to assess knowledge retention. Subjects were then given a 5-point Likert scale questionnaire with response choices depending on the questions such as ''1—don't agree'' to ''5—Agree,'' ''1—not realistic'' to ''5—very realistic and ''1—not useful'' to 5—very useful.[10]" The questionnaire consisted of questions related to the utility and the realism of tasks VEST simulator. Data were analyzed using SPSS statistical software (IBM Corp).

Results

Demographics

A total of 46 subjects participated in this study; there were 42 complete sets of data. There were 10 females and 36 males, and the mean age of participants was 41.6 years. Prior surgical experienced ranged from no prior experience to surgical attending level (No surgical experience = 8, PGY1 = 1, PGY2 = 2, PGY3 = 5, PGY4 = 3, Attending = 25). 36 subjects reported having an MD degree. 13 subjects reported having at least some exposure to the FUSE curriculum, including 5 subjects that were FUSE certified. 33 reported no prior FUSE experience. 17 subjects reported personally placing a dispersive electrode on a patient, and 26 reported having never placed a dispersive electrode.

Knowledge assessment

The median score on the five question pre-simulator assessment was 1.5, and the post-simulator assessment median score was 3.0. A related samples Wilcoxon signed rank test comparing pre- and post-simulator assessment scores showed them to be significantly different ($p < 0.05$). A Mann–Whitney *U* test comparing mean pre-assessment scores between attending surgeons and all others showed no significant difference in scores, with mean scores of 1.52 and 1.43, respectively ($p > 0.05$). Mann–Whitney *U* testing comparing those with and without prior exposure to FUSE curriculum materials revealed a significant difference in scores, with a mean score of 1.28 in subjects with no prior FUSE exposure and a mean score of 2.00 in subjects with prior FUSE exposure ($p = 0.032$). These results are indicated in Table 1.

User assessment of simulator

Subjects were grouped into those with and without prior FUSE exposure ($n = 13$ and $n = 32$, respectively).

Table 1 Mean assessment scores before and after using VEST module

Group	Pre-simulation	Post simulation
Overall mean ($n = 42$)	1.5	3.4
Attending ($n = 22$)	1.5	3.3
Non-attending ($n = 20$)	1.4	3.6
Fuse Exposed (n = 6)	2	2.8
Fuse naïve ($n = 31$)	1.3	3.4
Fuse certified ($n = 5$)	2	3.6

Median scores were four or greater for all five questions. Table 2 demonstrates that Mann–Whitney *U* testing showed no significant difference in subjects' responses to questions between those with and without prior FUSE exposure.

Discussion

Electrosurgery is ubiquitous in modern surgical techniques. The use of high-frequency electrical energy to effectively dissect and provide hemostasis in a safe manner is rooted in a firm understanding of the principles involved. Electrical energy travels from electrosurgical unit (ESU) to the active electrode and then returns to the ESU from the patient via a dispersive electrode. The dispersive electrode is a potential source of injury, as the energy returning to the ESU can cause heating of tissues and create the potential for injury [11]. In addition, the dispersive electrode cord can also cause injury by heating adjacent instruments via antenna coupling [12]. Proper placement of the dispersive electrode relies on underlying tissue with good conductive properties. In addition, placement of the dispersive electrode should aim to minimize interference with implanted medical devices, such as pacemakers and defibrillators [13].

Prior research has demonstrated a general deficiency in knowledge about the safe use of surgical energy [14]. Our results indicate this as well, with attending surgeons demonstrating the same level of understanding regarding dispersive electrode placement as trainees and non-surgeons. This generalized lack of knowledge creates a barrier to the consistent safe use of surgical energy devices. We had 46 subjects take part in the experiment; however, not all subjects completed all questions and there were 42 complete sets of data. After using the VEST simulator module, research subjects had consistently higher scores on the assessment tool used in this study to evaluate knowledge related to dispersive electrode placement. However, post-assessment scores showed only a modest increase, which may be attributable to limited subject exposure to the VEST educational materials given the logistical constraints of conducting the experiment at a busy surgical conference (we did not time subjects, but most subjects seemed to spend approximately 15–20 min participating in the experiment based on our general observations). In addition, pre-simulator assessment scores were lower than we anticipated in all groups, potentially reflecting an assessment tool that was more difficult than anticipated. A more generalized and extensive assessment of dispersive electrode safety may have provided a more accurate description of dispersive electrode safety knowledge among participants; however, we felt that this would have been difficult to administer in the exhibit hall of the SAGES conference. While the long-term retention of knowledge gained through limited use of the VEST simulator as described in this study is unknown, previous randomized studies of simulation have demonstrated a lasting benefit of its use to help cement knowledge related to the use of surgical energy [15]. We believe this effect will only increase with the development of more VEST modules to supplement FUSE didactics.

The subjective experience portion of this study indicated that subjects both with and without prior FUSE experience highly rated this VEST simulator module. Median scores for all questions were 4 or above, indicating that subjects rated this simulator useful for understanding proper dispersive electrode placement, indicated it was enjoyable to use, and thought that it was appropriately realistic. Interquartile ranges were consistent with minimal variability. Since both experienced FUSE learners and FUSE naïve users highly rated this VEST module, a consensus is demonstrated for the applicability and usefulness of this simulator module. Subjects gave feedback regarding improvements to the simulator interface, more in-depth explanations to clinical scenarios, and more clearly demonstrating to subjects the calculations used by the simulator to model current flow.

Table 2 Survey results for the VEST simulator

Question	FUSE exposure		No FUSE exposure		Mann–Whitney *U* test *p* values
	Median score	Interquartile range	Median score	Interquartile range	
1. I feel I have a better understanding of dispersive electrode placement after using the VEST simulator	4.5	1	4	2	0.221
2. Using the VEST simulator to this topic is more enjoyable than just using textbooks	5	0	5	1	0.442
3. If the VEST simulator was available to me in my skills lab, I would use it	5	1	4	2	0.430
4. After using the VEST simulator, I will change my practices in the OR	5	1	5	1	0.436
5. Please rate the degree of overall realism of the VEST simulation (how it looks AND feels), compared to the corresponding surgical task	4	1	4	1	0.880

Overall, we believe that this VEST module is another step forward in development of the VEST simulator, adding to the work already done with the monopolar electrosurgery and OR fire VEST modules. As more modules are developed, the FUSE curriculum augmented with VEST modules will become an invaluable tool to promote the safe use of electrosurgical energy.

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Compliance with Ethical Standards

Disclosures Michael Dombek, M.D., Carlos Lopez, PhD, Zhongqing Han, Alyssa Lungarini, Nicole Santos, Steven Schwaitzberg, M.D., Caroline Cao, PhD, and Jaisa Olasky, M.D. have no conflicts of interest or financial ties to disclose. Daniel Jones, M.D. is a compensated Medical Advisory Board member at Allurion Technologies, Incorporated. Suvranu De, PhD receives support from National Institutes of Health (NIH) and National Institute of Biomedical Imaging and Bioengineering (NIBIB) Grant # R01 EB014305 DEVELOPMENT AND VALIDATION OF A VIRTUAL ELECTROSURGICAL SKILL TRAINER (VEST).

References

1. Sankaranarayanan G, Resapu RR, Jones DB, Schwaitzberg S, De S (2013) Common uses and cited complications of energy in surgery. Surg Endosc 27:3056–3072
2. Overbey DM, Townsend NT, Chapman BC, Bennett DT, Foley LS, Rau AS, Yi JA, Jones EL, Stiegmann GV, Robinson TN (2015) Surgical energy-based device injuries and fatalities reported to the food and drug administration. J Am Coll Surg 221:197–205 e191
3. Watanabe Y, Kurashima Y, Madani A, Feldman LS, Ishida M, Oshita A, Naitoh T, Noma K, Yasumasa K, Nagata H, Nakamura F, Ono K, Suzuki Y, Matsuhashi N, Shichinohe T, Hirano S (2016) Surgeons have knowledge gaps in the safe use of energy devices: a multicenter cross-sectional study. Surg Endosc 30:588–592
4. Madani A, Jones DB, Fuchshuber P, Robinson TN, Feldman LS (2014) Fundamental use of surgical energy (FUSE): a curriculum on surgical energy-based devices. Surg Endosc 28:2509–2512
5. Madani A, Watanabe Y, Vassiliou MC, Fuchshuber P, Jones DB, Schwaitzberg SD, Fried GM, Feldman LS (2014) Impact of a hands-on component on learning in the Fundamental Use of Surgical Energy (FUSE) curriculum: a randomized-controlled trial in surgical trainees. Surg Endosc 28:2772–2782
6. Sankaranarayanan G, Li B, Miller A, Wakily H, Jones SB, Schwaitzberg S, Jones DB, De S, Olasky J (2016) Face validation of the virtual electrosurgery skill trainer (VEST((c))). Surg Endosc 30:730–738
7. Jones SB, Jones DB, Schwaitzberg S (2014) Only you can prevent OR fires. Ann Surg 260:218–219
8. Gabriel C, Gabriel S, Corthout E (1996) The dielectric properties of biological tissues: I. Literature survey. Phys Med Biol 41:2231–2249
9. Massey JW, Yilmaz AE (2016) AustinMan and AustinWoman: High-fidelity, anatomical voxel models developed from the VHP color images. Conf Proc IEEE Eng Med Biol Soc 2016:3346–3349
10. Likert R (1932) A technique for the measurement of attitudes. Arch Psychol 22:1–55
11. Edrich J, Cookson CC (1987) Electrosurgical dispersive electrodes heat cutaneous and subcutaneous skin layers. Med Instrum 21:81–86
12. Townsend NT, Nadlonek NA, Jones EL, McHenry JR, Dunne B, Stiegmann GV, Robinson TN (2016) Unintended stray energy from monopolar instruments: beware the dispersive electrode cord. Surg Endosc 30:1333–1336
13. Misiri J, Kusumoto F, Goldschlager N (2012) Electromagnetic interference and implanted cardiac devices: the medical environment (part II). Clin Cardiol 35:321–328
14. Feldman LS, Fuchshuber P, Jones DB, Mischna J, Schwaitzberg SD, Force FT (2012) Surgeons don't know what they don't know about the safe use of energy in surgery. Surg Endosc 26:2735–2739
15. Madani A, Watanabe Y, Vassiliou MC, Fuchshuber P, Jones DB, Schwaitzberg SD, Fried GM, Feldman LS (2016) Long-term knowledge retention following simulation-based training for electrosurgical safety: 1-year follow-up of a randomized controlled trial. Surg Endosc 30:1156–1163