



# Development of a Model for Training and Assessing Open Image-Guided Liver Tumor Ablation

Kaled Diab, MD, Suhas Kochat, MD, James McClintic, MS, MD, Heather L. Stevenson, MD, PhD, Steven C. Agle, MD, MPH, Kelly Olino, MD, Douglas S. Tyler, MD, and Kimberly M. Brown, MD

Department of Surgery, The University of Texas Medical Branch, Galveston, Texas

**BACKGROUND:** Image-guided microwave ablation (MWA) is a technically demanding procedure, involving advanced visual-spatial perception skills. This study sought to create and evaluate a low-cost model and training curriculum for open ultrasound-guided liver tumor MWA.

**METHODS:** Simulated tumors were created, implanted into bovine livers, and visualized by ultrasound. A high-fidelity abdominal model was constructed, with a total cost of \$30. Experienced physicians in MWA performed simulated ablations and evaluated the model. Expert performance metrics were established and served as targets for our training curriculum. These included time, number of passes, number of repositionings, and percentage of tumor ablated. Next, 8 novice trainees completed our deliberate practice curriculum. Participants' performances were recorded throughout.

**RESULTS:** Physicians completed a structured feedback questionnaire rating the model's realism and training utility at 8/10 and 10/10, respectively. Tumors appeared hyperechoic and were clearly visualized on ultrasound. Trainees performed a total of 32 ablations. Our trainees' performance improved significantly in all outcomes of interest in the postcurriculum ablations compared to precurriculum ablations.

**CONCLUSION:** We have created a cost-effective, high-fidelity model of MWA, with a deliberate practice curriculum. Trainees can practice to proficiency with clear target metrics prior to participating in clinical cases (J Surg Ed 76:554–559. © 2018 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

*Correspondence:* Inquiries to Kimberly M. Brown, MD, FACS, Dell Medical School at UT Austin, Department of Surgery and Perioperative Care, 1400 Barbara Jordan Blvd, Suite 1.114, MC R1800, Austin, TX 78723; e-mail: [Kimberly.brown@austin.utexas.edu](mailto:Kimberly.brown@austin.utexas.edu)

**KEY WORDS:** ablation, simulation training, liver, ultrasound, microwave

**COMPETENCIES:** Patient Care, Medical Knowledge, Practice-Based Learning and Improvement

## INTRODUCTION

Ablation is a technically demanding procedure and there is a learning curve to achieve efficiency and effective tumor destruction, specifically with mastering hands-on intraoperative ultrasound techniques and 3D tumor targeting.<sup>1</sup> Ex vivo tumor-mimic models for laparoscopic radiofrequency ablation have been used in simulation-based training, such as a laparoscopic pelvi-trainer.<sup>2</sup>

Microwave radiation is specially tuned to the natural frequency of water molecules to maximize interaction. Thus, when an oscillating electric charge from microwave radiation interacts with a water molecule, it causes the molecule to flip billions of times per second, which produces kinetic energy and in turn, heat, which induces cellular death via coagulation necrosis.<sup>3</sup>

With the introduction of image guided thermal ablation into clinical practice, it became necessary to develop efficient and effective training methods for the procedure. One example involves an electromagnetic tracking device and software elements providing 3-dimensional image processing tools, real-time navigation functions, and objective evaluation function module. The authors describe how this simulator can be used for training purposes, but a curriculum to operationalize training would further assist educators in applying their solution.<sup>4</sup>

The purpose of our study was to demonstrate the utility of a high-fidelity simulation-based microwave ablation (MWA) training model that will allow trainees to optimize their performance prior to engaging in MWA on patients.

In addition, we established performance metrics that will serve as targets for a deliberate practice curriculum, and studied the effectiveness of our curriculum in improving trainee performance of simulated liver tumor MWA.

## METHODS

### Study participants

This study was approved by the University of Texas Medical Branch Institutional Review Board. Study participants were volunteers recruited from faculty with experience in ablation (hepatobiliary surgeons proficient in MWA) and 4th year medical students, using Institutional Review Board-approved fliers. Five faculty and 8 4th year medical students comprised our study cohort.

### Simulator construction

We constructed a simulated abdomen to create a high-fidelity context with physical constraints for open liver tumor ablation (Fig. 1). Simulated tumors were created using a mixture of 3% agarose, 3% cellulose, 7% glycerol, and 0.05% methylene blue.<sup>5</sup> Tumors were created ex vivo and implanted into bovine livers. A mold was created using 2 spoons from a measuring spoon set. The spoons were sealed against one another and a hole was created through which the mixture was injected. The liquid mixture was then allowed to cool down until the

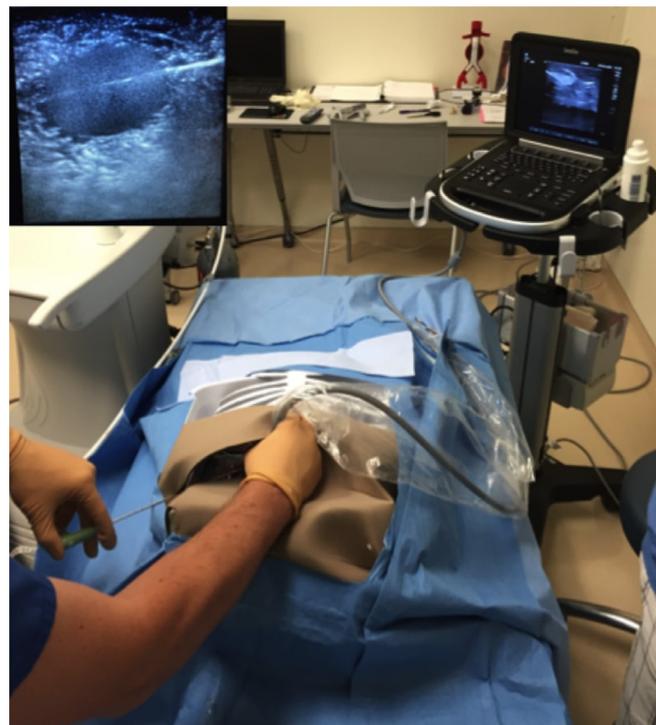
mixture solidified, to create a solid tumor. After tumors were implanted into bovine livers, we assessed the tumor visibility with ultrasound imaging. Tumors appeared hyperechoic and were clearly visualized on US as seen in the Figure 1 inset. The total cost of the model was \$30 and allowed up to 20 separate tumor ablations throughout each liver.

Physicians with experience in MWA were recruited throughout the iterative stages of the model's development and gave multiple rounds of feedback on how to improve and refine the model. Physicians completed a structured feedback questionnaire rating the model's realism and utility for training on a scale of 1 to 10.

### Establishing expert performance metrics

Five experienced physicians, defined as fellowship-trained Surgical Oncologists or Interventional Radiologists who have performed more than 50 image-guided liver tumor ablations in clinical practice, performed a total of 20 ablations using the final simulator design. Ablations were performed with recording of time from needle insertion to start of ablation, number of passes, number of probe repositionings, as well as percent of tumor ablated. Feedback on the model's realism and utility for training was collected.

Postablation analysis was then performed, where livers were cut to evaluate the ablation zone and the percentage of tumor ablated. Macro-Preparation Knives (Stat lab, McKinney, Texas; SKU: 5012) were used to cut



**FIGURE 1.** Low-cost high-fidelity open liver tumor ablation model; figure inset depicts appearance of tumor mimic with ablation probe using ultrasound.

clean slices of liver tissue in order to accurately measure the ablation zone. The ablated bovine liver specimens were sectioned in 0.5-cm-thick slices, and the zone of ablation was carefully measured accounting for percentage of tumor ablated vs. surrounding parenchymal tissue. In addition, the tumor mimics were weighed prior to ablation and the remaining tumor mimic material that was not ablated was then reweighed, and percentage of tumor ablated was determined. The protocol for measuring the percentage of tumor ablated was created in collaboration with an expert liver pathologist.

Based on literature, we considered that 5 to 10 mm was a sufficient safety margin of ablated healthy liver tissue adjacent to the lesion to eliminate microscopic foci of disease.<sup>6,7</sup> Ablations were then classified depending on the percentage of tumor ablated, using a modified tumor regression grading system as described by Rubbia-Brandt et al.<sup>8</sup>; grade 1 (<25% tumor ablated), grade 2 (25%-50% ablated), grade 3 (50%-75% ablated), and grade 4 (>75% tumor ablated).

We identified performance metrics (time, number of passes, number of repositionings, and percentage of tumor ablated) to serve as targets for our training curriculum. We then analyzed data from ablations performed by experienced surgeons to establish mastery level thresholds for each metric: time from needle to start of ablation  $\leq 300$  seconds, number of passes  $\leq 2$ , number of repositioning  $\leq 6$ , and percentage of ablation that falls under Grade 4. The statistical analysis of that data was performed and is illustrated in [Table 1](#). Both median and mean values were calculated as demonstrated in [Table 1](#); we used mean values as targets because we did not have significant outliers. Of note, even though the mean and median values for experienced physicians' time from needle insertion to start of ablation were 299 and 289 seconds, respectively, our consensus was to use  $\leq 300$  seconds as a practical cut-off value for novices to aim to perform ablation under 5 minutes (=300 seconds).

### Precurriculum assessment

Participants underwent standardized face-to-face training during which we demonstrated proficiency in the use of to the MWA apparatus as well as the US imaging system. The task to be performed (i.e., correct positioning of the ablation probe to achieve complete ablation

of the tumor with sparing of neighboring parenchymal tissue) was then clearly explained and demonstrated for the students. Participants subsequently performed a total of 2 ablations with recording of time from needle insertion to start of ablation, number of passes, number of repositionings, and percentage of tumor ablated. The data recorded served as a preassessment of the level of proficiency demonstrated by each of the 8 participants.

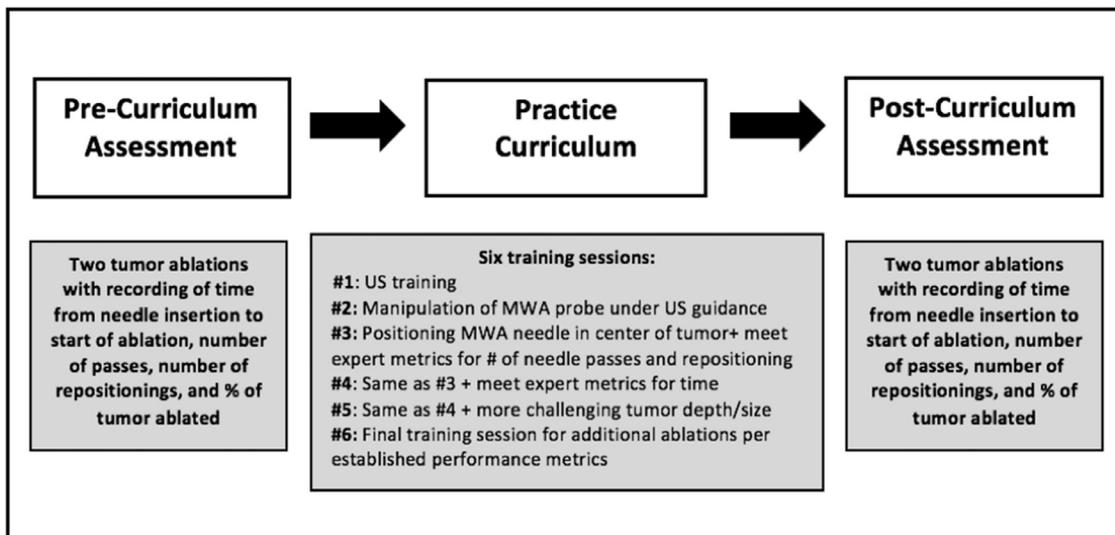
### Curriculum

Once participants had completed the precurriculum assessment phase, they were then subject to the training curriculum that we established using expert performance metrics as targets. The training curriculum consisted of a total of 6 30 minute sessions. The first session was dedicated to allowing the novice trainee to be more accustomed to the use of the ultrasound imaging system. This included demonstration of general techniques such as scanning in both transverse and longitudinal planes; identification of probe marker location on probe prior to scanning; fine tuning of the imaging controls such as gain and depth to obtain the best possible image; and illustration of the normal echogenicity scale.

The second session focused on acquainting the trainee with the MWA ablation probe. The goal of this session was for the participant to achieve a better level of control during manipulation of the MWA needle inside the liver under US guidance. The third session focused on making sure that the participants could correctly place the MWA needle in the tumor without exceeding the number of needle passes and repositionings established by the expert performance metrics. A discussion of avoiding injury to critical structures is included in these didactics, but the model does not present a tumor mimic near a structure that required preservation. The fourth training session was dedicated to allowing the participant to perform the required task without exceeding the time from needle insertion to start of ablation established by the expert performance metrics. We reminded the participants to try not to exceed the number of passes and repositionings that were mastered during the third training session. The fifth session focused on testing the participants with challenging tasks, which included having tumor mimics positioned at varying depths or ablating tumor mimics

**TABLE 1.** Statistical Analysis for the Data Recorded During Experienced Physicians' Ablations

	Time (sec)	Passes	Repositionings	Grade
Mean (SD)	299 (57)	2.0 (.56)	6.0 (1.3)	3.9 (.37)
Median	289	2	6	4
Chosen cut-off	300	2	6	4



**FIGURE 2.** Summary of curriculum, including pre- and postcurriculum assessments.

of variable sizes. The final training session was dedicated for participants to practice performing tumor ablations until they achieved the established performance metrics.

### Postcurriculum assessment

After completing the training curriculum, each participant performed 2 ablations, with recording of time from needle insertion to start of ablation, number of passes, number of repositionings, and percentage of tumor ablated. The data recorded served as a postcurricular assessment of the level of proficiency demonstrated by each of the 8 participants, as well as assisted in evaluating the efficacy of the model and the training curriculum by comparing precurriculum and postcurriculum data for each of the participants.

### Statistical analysis

Analysis was performed on 8 participants with 2 precurriculum trials and 2 postcurriculum trials. Individual trials were averaged to form precurriculum and postcurriculum values for each of the variables: number of passes, time, number of repositionings, and percent

tumor ablation. Paired *t* tests were performed to assess pre- to postcurriculum change as well as sign tests for any variables displaying a skewed distribution. Normality was assessed using Shapiro-Wilk tests and probability plots. Cohen's *d* was calculated to assess effect size. All statistical analysis was performed with the aid of SAS 9.4.

## RESULTS

The mean values obtained for each of the metrics accounted for during experts' ablations were used as targets for our training curriculum. A summarized description of the developed curriculum is displayed in [Figure 2](#).

Our novices' performance in all outcomes of interest improved significantly in the postcurriculum ablations compared to precurriculum ablations, as summarized in [Table 2](#).

Statistical analysis demonstrated significant improvement in all 4 primary outcome variables as summarized in [Table 2](#). Participants displayed an improvement in the number of passes with a mean decrease of 2.8 passes and a Cohen's *d* of 6.1 indicating a large effect size. The Shapiro Wilk test and probability plot demonstrated the

**TABLE 2.** Statistical Analysis Results of Primary Outcome Variables

Variable	Precurriculum mean $\pm$ SD	Postcurriculum mean $\pm$ SD	Mean Change	95% CI of the Mean Change	p Value	Cohen's d
Number of passes	4.7 $\pm$ 0.5	1.9 $\pm$ 0.4	-2.8	-3.2 to -2.4	<0.0001	6.1
Number of repositionings	10.9 $\pm$ 1.7	5.4 $\pm$ 1.2	-5.5	-6.4 to -4.6	<0.0001	5.3
Time (s)	373 $\pm$ 71	184 $\pm$ 40	-189	-155 to -222	<0.0001	4.7
Percent ablation (%)	24.7 $\pm$ 1.8	75.6 $\pm$ 1.8	50.9	48.8 to 53.0	<0.0001	20.2

SD, standard deviation; CI, confidence interval.

distribution was skewed violating the normality assumption. Thus, the results were verified with a sign test to instead test the median and revealed a *p* value of 0.0078 consistent with the findings of the paired *t* test. Participants also displayed a significant improvement in the number of repositionings with a mean decrease of 5.5, a mean decrease in time of 189 seconds, and a 51% increase in mean percent ablation, all with Cohen's *d* values that indicate a large effect size.

## DISCUSSION

We created a cost-effective, high-fidelity simulation model of MWA. We also established expert performance metrics using the data obtained from experienced physician ablations, which served as targets for our training curriculum. Eight novice trainees completed our deliberate practice curriculum, and demonstrated a significant improvement in performance as seen in prevs. post data analysis.

New medical procedures and technologies are continually being introduced into surgeons' practices, with a need to incorporate training in these techniques into residency or fellowship experience. Simulation-based learning exercises provide a controlled arena for learners to be able to perform deliberate tasks at a high efficiency and efficacy. What appeared to provide the greatest growth within learners was our established goal-oriented metrics as well as consistent and detailed feedback. The latter consisted of providing participants with the results of their ablations including detailed metrics achieved during the session as well as picture documentation of their postablation specimens. Ogden et al. described this as facilitation of learning through immersion minus the risks inherent in a similar real-life experience.<sup>9</sup> Thus, the approach of our curriculum is that of a high-quality model that can be taught in a reproducible and appealing manner, condenses the learning time, enhances retention from 1 training session to the next, and reduces gaps in knowledge and skills.

Our study consisted of 2 major phases. The first phase focused on constructing the model, as well as testing it by the experienced physicians; the second phase focused on establishing the training curriculum using the expert performance metrics as targets. Within the set up before each training session, the bovine livers came in different sizes and shapes. The size and depth of the liver was an important variable that the operator needed to take into consideration before ablations, as positional movements with smaller livers would create larger changes in ideal probe placement for precision ablation. The placement of the tumor mimics from session to session varied relative to the surface or edge of the liver and thus provided the ablation operator

different depths and angles to reach the tumor mimics. The experimenters' goal was to present scenarios in which the participants would be tested to perform ablations regardless of depth or difficulty of access regarding proper hand and needle positioning towards the tumor mimics. Additionally, these challenges were designed to emulate real clinical cases and further forced operators to think critically before ablations.

The obvious improvements seen in the data across the board from pre- to post-training sessions provide evidence that the model as well as the practice curriculum deliver a substantial foundation and framework for the participants to acquiesce visual and spatial content as well as construct understanding through marked improvement seen through the sessions.

It is important to note that since ablations were classified using the tumor regression grading system described by Rubbia-Brandt et al.,<sup>8</sup> we considered that a trainee achieved proficiency if he/she demonstrated a significant increase in percent ablation post-training and obtained a percentage of ablation that falls under Grade 4. Hence, although theoretically the goal is 100% ablation, the efficiency of the model can also be demonstrated if percent ablation increased significantly from pretraining vs. post-training.

In addition, the curriculum we developed was unique in that we created metrics from expert ablation operators and those metrics were tested against novice ablation operators. Again, this is different from the simulation produced by Wenbo et al. because they only tested and gained feedback from expert ablation physicians. Also, their model had more intricacies that may have made it easier for the operator to locate tumors, including electromagnetic tracking device and software elements providing 3-dimensional (3D) image processing tools, real-time navigation functions and objective evaluation function module, which are not readily available technologies used while performing MWA ablations during clinical cases.

Our study does have some limitations; our data only includes the results of testing 8 4th year medical students. Increased participation size would have provided higher statistical significance and more power to our study. Using medical students as subjects allowed for a study cohort with homogeneous knowledge and exposure to the skills being taught; however, residents or fellows are the trainees most likely to participate in ablation cases, and further validity evidence is required to demonstrate the effectiveness of this curriculum in that learner group. Also, our tumor mimics were molded into a sphere-like shape, which may not adequately represent actual tumor structure. Actual hepatic neoplasms can have various shapes, which may affect how the operator places the MWA needle for optimal ablation.

Ideally, performance on the model and training through our curriculum would be correlated to intraoperative performance. Finally, MWA is increasingly done laparoscopically, and the model described in this study was developed for open MWA. Thus, we believe it would be truly beneficial to expand this concept of training and develop a model for laparoscopic MWA.

We have created a cost-effective, high-fidelity model of MWA, which can facilitate a deliberate practice curriculum. Trainees can practice to proficiency with clear target metrics prior to participating in clinical cases. Participants reported that they experienced the technical and decision-making challenges while using the model. We also designed a practice curriculum based on the metrics established in which novices can train to achieve proficiency. The data recorded shows evident improvement in trainees' performance after completing the training curriculum using our model.

Lastly, incorporating this training curriculum into residency or fellowship could help improve the autonomy with which trainees perform ablations and could potentially allow faculty to "warm-up" prior to performing a MWA procedure if there has been a significant interval since their last procedure.

## SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.jsurg.2018.07.015](https://doi.org/10.1016/j.jsurg.2018.07.015).

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