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Three-Dimensional Printing Facilitates Creation of a Biliary Endoscopy Phantom for Interventional Radiology-Operated Endoscopy Training

Jacob J. Bundy, MD, MPH[a], William J. Weadock, MD, FACR[c], Jeffrey Forris Beecham Chick, MD, MPH[b], Rajiv N. Srinivasa, MD[a], Nishant Patel, MD, MBA[a], Evan Johnson, MD[a], Mamdouh Khayat, MD[a], Brian Jeffers, BS[a], Joseph J. Gemmete, MD, FSIR[a], Ravi N. Srinivasa, MD[d,*]

[a] *Department of Radiology, Division of Vascular and Interventional Radiology, University of Michigan Health System, 1500 East Medical Center Drive, Ann Arbor, MI*
[b] *Cardiovascular and Interventional Radiology, Inova Alexandria Hospital, 4320 Seminary Road, Alexandria, VA*
[c] *Department of Radiology, Division of Abdominal Radiology, University of Michigan Health System, 1500 East Medical Center Drive, Ann Arbor, MI*
[d] *Department of Interventional Radiology, University of California Los Angeles, 757 Westwood Plaza, Los Angeles, CA, 90095*

Purpose: To create a three-dimensional endoscopic model of the biliary tract from magnetic-resonance cholangiopancreatography imaging and to evaluate its effectiveness as a tool for training in endoscopic biliary interventions.
Materials and Methods: A magnetic-resonance cholangiopancreatography study was performed on a patient with biliary obstruction secondary to a distal bile duct cholangiocarcinoma. Using Vitrea, a three-dimensional volume-rendered image was created, and exported as a standard tessellated language file. The standard tessellated language model was then edited with MeshMixer. Three cylindrical entry ports were created. The ports were aligned and overlapped with the dominant ducts in three separate areas of the model and fused to the model. A 0.2 cm shell was created around the model and the model was hollowed. The ends of the ports were cut off, allowing access to the hollowed-out model. The model was printed at 125% scale to allow easy access with a 9.5-French (≤3.23 mm) endoscope. The model was printed using a Stratasys Dimension Elite Plus printer. After printing, the model was post-processed to remove support materials. A 10-question survey was administered to all trainees before and after use of the printed phantom to practice endoscopy skills.
Results: 11 trainees participated in the three-dimensional endoscopy simulation with most of the trainees (73%) having no prior formal endoscopy training. Using a 10-point Likert scale, the mean comfort-level of the trainees to use endoscopy alone for cholecystostomy, percutaneous biliary drainage, percutaneous nephrostomy, and percutaneous gastrostomy increased by 38.9%, 32.8%, 32.8%, and 34.3%, respectively, following the training experience.
Conclusion: The use of a three-dimensionally printed endoscopic model as a simulation tool has the potential to improve trainee comfort using endoscopy during interventional radiology procedures.

Introduction

Three-dimensional (3-D) printing has become adapted to many fields of medicine, including orthopedics, dentistry, and other surgical and nonsurgical specialties.[1] 3-D printing has been used for planning and practicing specific interventions[2] and producing patient-specific implants.[3] Of note are the advances made in producing 3-D models from two-dimensional (2-D) body images for training, planning, and education.[4,5] Specifically, the creation of 3-D models for the use of training residents in endoscopic procedures has proven both feasible and effective.[6-9] These studies provide a proof of concept of using 3-D printed models to train and evaluate residents and fellows in endoscopic procedures.

Percutaneous transhepatic cholangioscopy has been described since 1979.[10] Early procedures were performed by gastroenterologists to assist with the removal of stones. In the 1990s, interventional radiologists began performing transhepatic biliary endoscopy.[11] Nonetheless, very few interventional radiologists perform percutaneous biliary endoscopy and therefore the techniques are highly underutilized by radiologists. This likely stems from a combination of factors including lack of knowledge in the technique, lack of equipment to perform the procedures including the high costs of acquisition of endoscopy equipment as well as inadequate training in the techniques needed to perform transhepatic biliary endoscopy.

Many patients, unfortunately, are committed to having catheters for life with indwelling biliary or cholecystostomy drains due to multiple medical comorbidities precluding surgery. There are however, other options for these patients, including percutaneous endoscopic

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All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.
Informed consent was obtained from all individual participants included in the study.
Consent for publication was obtained for every individual person's data included in the study. Patient consent for the model was exempted by the institutional review board.
*Reprint requests: Ravi N. Srinivasa, MD, Department of Interventional Radiology, University of California Los Angeles, 757 Westwood Plaza, Los Angeles, CA, 90095.
E-mail address: medravi@gmail.com (R.N. Srinivasa).

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interventions to facilitate removal of stones, casts, or debris resulting in biliary obstruction and subsequently render patients with chronic indwelling tubes, tube free. A simple method to teach physicians the techniques of these procedures is greatly needed to educate and expand the use of this valuable procedure.

The creation of an inexpensive model of the biliary tract to allow physicians to practice these endoscopic techniques in a realistic, safe, and controlled environment, then, has clear and apparent potential benefits. A 3-D phantom molded from biliary tract imaging may provide an opportunity for residents and fellows to learn and practice endoscopic techniques in a technical arena that otherwise has few opportunities to gain experience.

The purpose of this study was to create a three-dimensional endoscopic model of the biliary tract from magnetic-resonance cholangiopancreatography (MRCP) imaging and to evaluate its effectiveness as a learning tool for training in endoscopic biliary interventions.

Materials and Methods

This study was conducted with institutional review board approval and complied with the Health Insurance Portability and Accountability Act.

Three-Dimensionally Printed Biliary Endoscopy Phantom Creation

An MRCP data set, in a patient with a distal common bile duct cholangiocarcinoma and severely dilated bile ducts, was selected for the model. This would provide easy access for the endoscope to the biliary system for training residents with no-to-little experience with the techniques.

Using Vitrea (Vital Images; Minnetonka, MN), a 3-D volume-rendered image (Fig 1) was created from 1.2 mm 1.5 Tesla Achieva T2 fast-recovery fast spin-echo images (Philips; Eindhoven, Netherlands) and exported as a standard tessellated language file.

The standard tessellated language model was then edited with MeshMixer (Autodesk; San Rafael, CA). The model was made into a solid model. Three cylinders were added to the model, so the cylinders would be an extension of a large dilated duct. The cylinders were then fused to the model. A 0.2 cm shell was created around the model and the model was hollowed. The model was printed at 125% scale to allow easy access with a 9.5-French ($\leq$3.23 mm) endoscope (LithoVue; Boston Scientific; Marlborough, MA). The model was printed using a Stratasys (Stratasys; Eden Prairie, MN) Dimension Elite Plus printer using red acrylonitrile butadiene styrene plastic (Fig 2).

A total of 459 g ABS plastic was used for the model and an additional 295 g of support material was used to print the model. After printing, the model was postprocessed by soaking in a thermal bath of sodium hydroxide at 70 °C for 2 days. After initial evaluation of the model showed residual support material throughout (Fig 3), consequently, it was placed in the thermal bath for an additional day.

The phantom contained three strategic entrance points from which trainees could access the interior space with an endoscope. It was attempted to fragment the residual support material with instruments (Fig 4), but that was unsuccessful.

Training Evaluation

To measure the benefit the phantom may have on endoscopic techniques, a pretest and post-test were created to gauge improvement in comfort levels with the procedure. Both tests were created using Google Forms (Google; Mountain View, CA). Demographics were collected including name, gender, year of training, and previous experience with endoscopy. Further questions included 10-point Likert scale questions ascertaining the respondent's comfort with various endoscopy procedures, the likelihood that respondents would use endoscopy in the future, and a question asking about the different resources available to learn more about endoscopic techniques. The post-test evaluated the 3-D phantom concerning its ease of use and its effectiveness as a learning tool. It also included identical questions from the pretest that measured comfort with endoscopic techniques which could be compared to results from the pretest and used to identify growth.

The 3-D phantom was presented to 11 technologists, medical students, residents, fellows, and attending physicians from January 1-31, 2018. Trainees took the pre- and post-test before and after interacting with the model, respectively.

The training sessions were conducted in an office setting. Following completion of the preprocedure survey, the trainee performed the training under the supervision of two attending interventional radiologists. The attendings assessed the subjective skill at

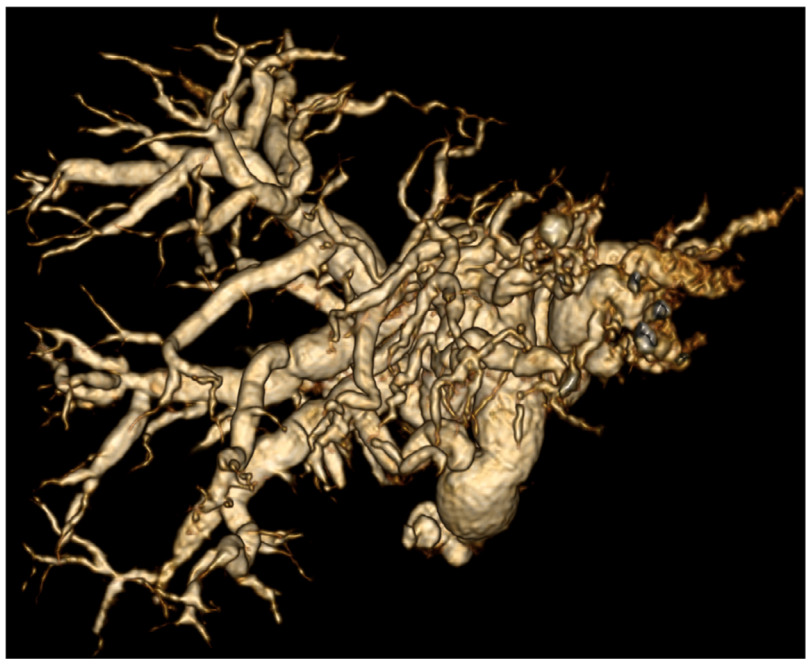


FIG. 1. Volume-rendered image from MRCP in a patient with a distal common bile duct cholangiocarcinoma.

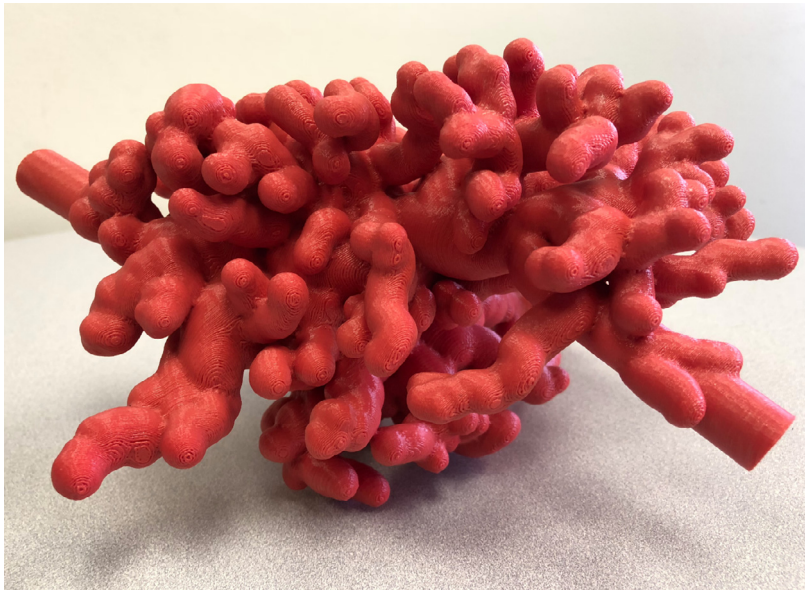


FIG. 2. External appearance of three-dimensionally printed biliary endoscopy phantom.

performing endoscopy during the training. Each trainee underwent one training session. Objectively, the operators recorded their own comfort with performing the procedure and were assessed through the survey.

Trainee Demographics

The Demographics of the 11 Individuals who participated in the endoscopy training are shown in Table 1.

Trainees currently in their interventional radiology fellowship made up the largest proportion of participants (36%), followed by integrated interventional radiology residents (18%), radiology technologists (18%), interventional radiology attending physicians (18%), and medical students (9%). The majority of trainees (73%) had no prior formal endoscopy training. Those with prior endoscopy training (27%) obtained it through residency training, workshops, or practice experience.

Results

Pre-Endoscopy Training Experience

Pretest endoscopy training results are shown in Table 2. The trainees, on average, assisted in 10.2 endoscopic procedures (range: 0-50 procedures) prior to the training exercise. The trainees had performed 3.6 endoscopic procedures (range: 0-13 procedures) prior to training on the endoscopy phantom. Although the trainees rated the benefit of endoscopy to interventional radiologists on average as a 9.1 on a 10-point scale, 82% of the trainees believed they need additional training to perform endoscopy confidently.

Post-Endoscopy Training Experience

Post-test endoscopy training results are shown in Table 3. The trainees reported that using the 3-D phantom was relatively easy,

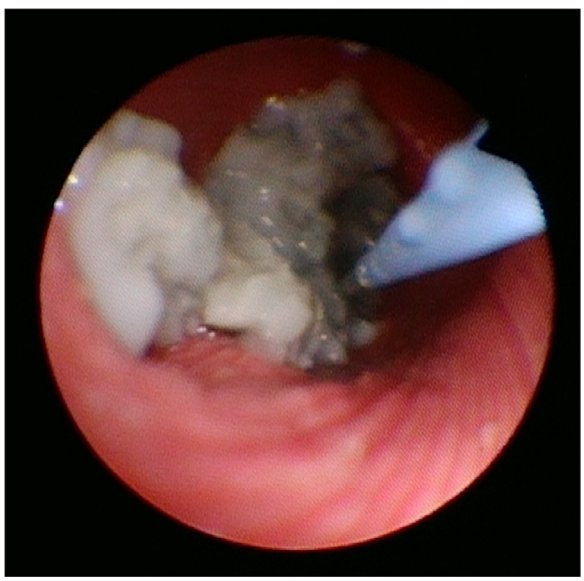


FIG. 3. Internal appearance, via an endoscopic approach, of the three-dimensionally printed biliary endoscopy phantom. Endoscopic images show substantial residual support material throughout.

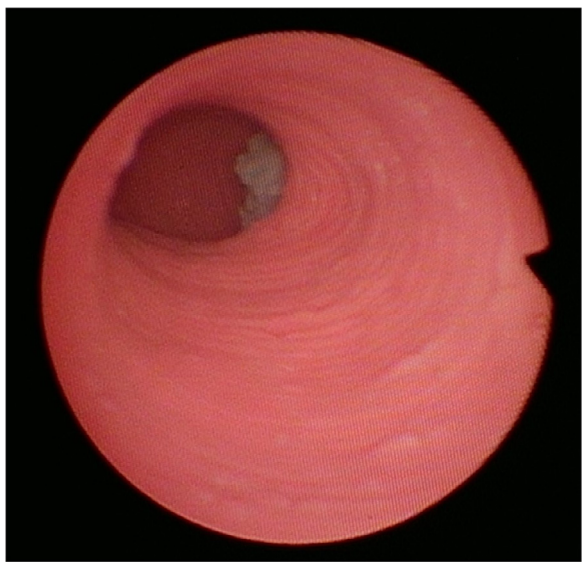


FIG. 4. Internal appearance, via an endoscopic approach, of the three-dimensionally printed biliary endoscopy phantom. Endoscopic images show substantial reduction in support material throughout.

TABLE 1
Trainee demographics

Trainee Demographics (n = 11)	
Sex	n (%)
Male	10 (91)
Female	1 (9)
Training Program	
Fellowship	4 (36)
Residency	2 (18)
Radiology technologist	2 (18)
Attending physician	2 (18)
Medical student	1 (9)
Previous endoscopy training	
No	8 (73)
Yes	3 (27)

rating it as an average of 9 on a 10-point scale. The trainees believed that their ability to use and operate an endoscope improved significantly, while their knowledge of the biliary tract improved slightly. Overall, the trainees were very likely to recommend using the 3-D phantom to others, rate the 3-D phantom as an effective learning tool, and to perceive endoscopy as beneficial to interventional radiologists, rating these beliefs on average as a 9.8, 9.6, and 9.5 out of 10, respectively following the training experience.

Trainees overall preference toward using endoscopy for common interventional radiology procedures prior to and after training using the endoscopy model is shown in Table 4.

Using a 10-point Likert scale, the mean likelihood of the trainees to use endoscopy for cholecystostomy, biliary drainage, nephrostomy, and gastrostomy increased following the training experience. There was a statistically significant increase in the likelihood of trainees to use endoscopy for gastrostomy placement increasing by 39.7% on the 10-point scale following the endoscopy training. Using a 10-point Likert scale, the average comfort level of the trainees to use endoscopy while alone for all four interventional radiology procedures increased following the training experience. There was a statistically significant increase in the comfort level of trainees to use endoscopy for cholecystostomy increasing by 38.9% on the 10-point scale following the endoscopy training.

Additional requested training is shown in Table 5. When surveyed following the training session, the trainees suggested that symposia, attending supervision, and on-the-job training were the opportunities to gain more experience with endoscopy that they would most like to have, with 8 responses for each category. Other opportunities they listed that would provide more experience with endoscopy included: practice experience, practice using physical 3-D modeling, practice using computer simulation or virtual modeling, electives, industry representation, and access to urology or gastroenterology colleagues.

Discussion

The integration of 3-D printing into the medical field has produced many advances, especially in the fields of medical education and training. Others have produced 3-D models for the purpose of training endoscopic procedures and have invariably been met with success. An endoscopic model of the stomach created by Lee et al. was viewed as realistic even among participants of varying experience levels.[6] A 3-D bronchoscopy model created for practicing foreign body removal was comparable to a porcine model in terms of accuracy and significantly increased students' confidence in both using and teaching the procedure.[7] The ampullectomy training model created by Holt et al. provided training for an uncommon procedure with limited opportunities for training.[8] Finally, a model of the middle ear produced by Barber et al. allowed students to practice and learn specific skills related to endoscopy in the ear with inexpensive, reusable materials.[9] Thus, the results from this biliary model are in accordance with results obtained from other similar models, providing a proof of concept that 3-D printed endoscopic models provide a durable alternative to live models in terms of training students with this beneficial procedure.

While not statistically significant, the 32.8% increase in the reported comfortableness in performing endoscopic biliary drainage following the training session indicates that the 3-D biliary tract model may provide a benefit to comfort and ease using endoscopic techniques with percutaneous transhepatic cholangioscopy. The data also suggests that incorporating 3-D endoscopic models into the

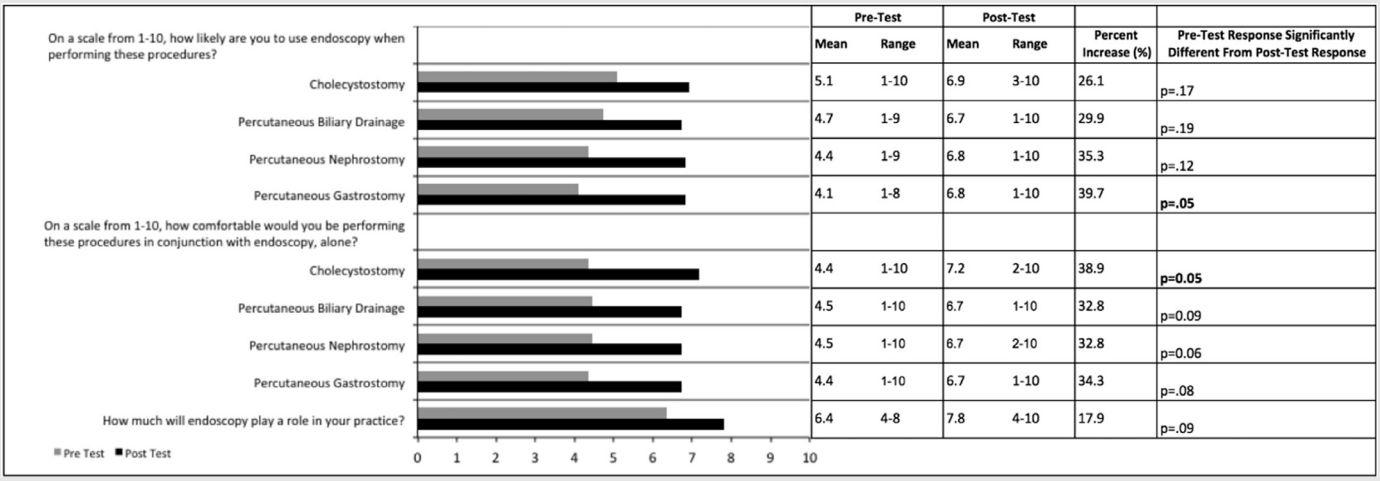
TABLE 2
Pretest endoscopy training results

Pretest Endoscopy Experience Responses (n = 11)	
Prior endoscopy experience	Mean (range)
On a scale from 1-10, how beneficial do you believe endoscopy is to interventional radiology?	9.1 (7-10)
How many endoscopy procedures have you assisted in, approximately?	10.2 (0-50)
How many endoscopy procedures have you performed, approximately?	3.6 (0-13)
Do you believe that you will need extra training in order to perform endoscopic procedures confidently?	n (%)
Yes	9 (82)
No	1 (9)
Not sure	1 (9)

TABLE 3
Post-test endoscopy training results

Posttest Endoscopy Experience Responses (n = 11)	
Experience following training	Mean (Range)
On a scale of 1-10, how easy was it to use the 3-D phantom of the biliary tract?	9 (6-10)
After using the 3-D phantom, how has your ability to use and operate an endoscope changed?	6.5 (5-7)
After using the 3-D phantom, how has your knowledge and understanding of the biliary tract changed?	5.8 (4-7)
How likely are you to recommend others to train using this 3-D phantom?	9.8 (9-10)
How would you rate the overall effectiveness of the 3-D phantom as a learning tool?	9.6 (8-10)
How beneficial do you believe endoscopy is to interventional radiology?	9.5 (8-10)
Do you believe that you will need extra training in order to perform endoscopic procedures comfortably?	n (%)
Yes	8 (73)
No	2 (18)
Not sure	1 (9)

TABLE 4
Trainees overall preference toward using endoscopy for common interventional radiology procedures prior to and after training using the endoscopy model



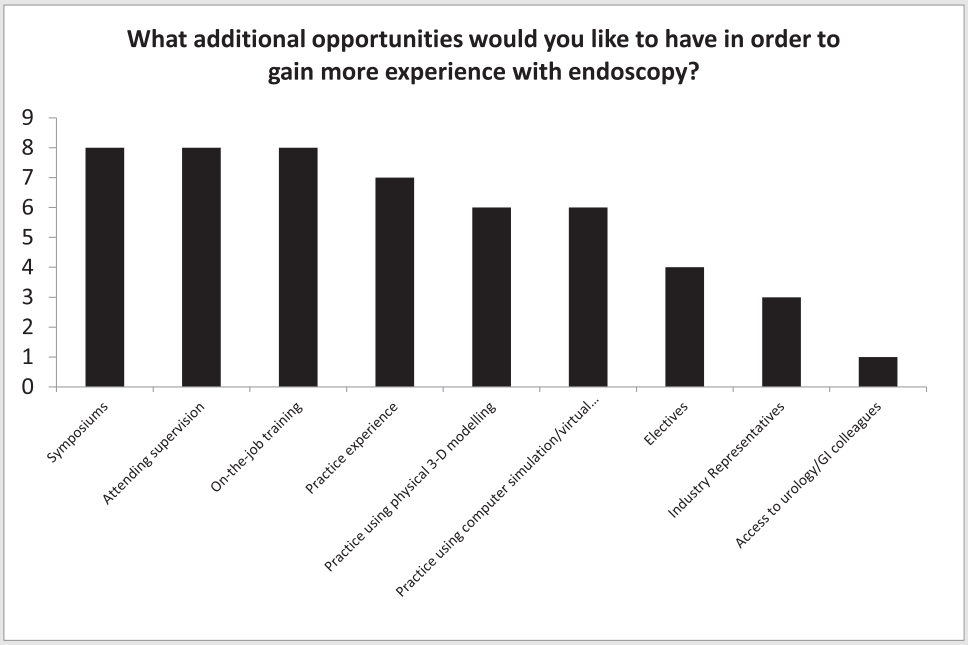
	Pre-Test		Post-Test			
	Mean	Range	Mean	Range	Percent Increase (%)	Pre-Test Response Significantly Different From Post-Test Response
On a scale from 1-10, how likely are you to use endoscopy when performing these procedures?						
Cholecystostomy	5.1	1-10	6.9	3-10	26.1	p=.17
Percutaneous Biliary Drainage	4.7	1-9	6.7	1-10	29.9	p=.19
Percutaneous Nephrostomy	4.4	1-9	6.8	1-10	35.3	p=.12
Percutaneous Gastrostomy	4.1	1-8	6.8	1-10	39.7	**p=.05**
On a scale from 1-10, how comfortable would you be performing these procedures in conjunction with endoscopy, alone?						
Cholecystostomy	4.4	1-10	7.2	2-10	38.9	**p=0.05**
Percutaneous Biliary Drainage	4.5	1-10	6.7	1-10	32.8	p=0.09
Percutaneous Nephrostomy	4.5	1-10	6.7	2-10	32.8	p=0.06
Percutaneous Gastrostomy	4.4	1-10	6.7	1-10	34.3	p=.08
How much will endoscopy play a role in your practice?	6.4	4-8	7.8	4-10	17.9	p=.09

education may increase endoscopic skills, understanding of biliary anatomy, and confidence to incorporate endoscopy into their future practice. Interestingly, the trainees perceived a statistically significant increase in comfortableness performing cholecystostomy following training. While the model was tailored to simulate biliary endoscopy, the skills used in cholecystostomy are similar to those used in biliary endoscopy. Additionally, based on the authors' personal experiences, the technical skills required to perform endoscopy within the gallbladder are lower than those required to navigate within the biliary system reflecting a lower learning curve for endoscopic interventions within the gallbladder.

The support material in the model dissolves in a warm solution of sodium hydroxide. In order to reach the deep parts of the model, it took longer than expected to dissolve the support material. Some residual support material persisted and is seen on the endoscopic image as white/gray/black material in the ducts. This had the unexpected effect of simulating biliary stones and/or tumors.

The maximum output size of a printer is defined as the build volume. In the case of the Dimension printer used, the 203×203 mm build volume was large enough to print the model as one object. Other printers with smaller build volumes may require a large model to be cut into 2 of more components and then fastened together after they are printed. An added benefit of our model printed as several separate components would be the ability to place objects into the center of the model and then reattaching the model together. The added objects (peanuts, for instance) could be used to check the trainee's ability to navigate throughout the model.

TABLE 5
Additional requested training



Because of the customizability and minimal effort needed to create or reproduce these models, these educational models may be produced and adapted to any specific situation or purpose. Models such as these could potentially increase availability and accessibility of these educational opportunities which is promising due to the current low availability of educational resources in the use of endoscopic techniques in interventional radiology. At a cost of $0.17 per gram of ABS, and $0.32 per gram for support material, the materials for the model cost $172.43.

The benefits of simulation within interventional radiology have been shown through the use of a catheter-based endovascular simulator model as a training aid for carotid stenting.[12] Dayal et al. reported improvements in procedure time and catheter manipulation following simulation. Similarly, a meta-analysis of the use of simulation-based endoscopy training for gastrointestinal fellows showed improvements in procedure time and patient outcomes.[13] The evidence supporting the benefits of simulation in medical education speaks to the necessity of pursuing research related to simulators to support medical learner's growth and improved patient safety.

There are limitations to this study. The trainees who underwent the 3-D simulation were not completely representative of physician learners. The radiology technologists incorporated into the study represent trainees with different exposures and skills than those of residents and fellows. Additionally, a small portion of the trainees had prior training and experience in endoscopy, so their preexisting proficiency may have limited their perception of growth following the training session.

Conclusion

The use of a 3-D endoscopic model as a simulation tool may improve comfort using endoscopy during interventional radiology procedures and has the potential to serve as an effective teaching platform to improve technical skills.

Disclosures and acknowledgments

None.

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