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CONTENTS

The Current State and Future of Haptics in Healthcare Simulation

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Brief Description

Haptic technology, which enables touch sensation, holds significant potential to improve fidelity in healthcare education and practice, especially when combined with extended realities (XR), such as virtual reality (VR) or augmented reality (AR). Sensations, including force, touch, and temperature, may be helpful to simulate clinical tasks such as feeling for a fever, palpating a vein, or other psychomotor skills. This paper explores current and emerging trends of haptic technology in healthcare simulation, the potential for haptics to enhance clinical education and practice, and the need for future research, technology, and investment.

Introduction

One of the primary challenges of utilizing haptic technology in healthcare simulation has been the dearth of codified terminology for understanding, assessing, and categorizing haptic sensations and their implications (Parisi et al., 2019). Definitional imprecision has stagnated scholarship, impeding research investigating capabilities and limiting haptic technology in healthcare simulation. With the maturation of a shared vocabulary for understanding haptic sensations, research into haptic techniques can flourish. Defining haptic terminology will help facilitate further research and development while enabling content creators to more easily integrate haptics into hardware and software solutions for greater effectiveness.

Definitions

The Society for Simulation in Healthcare defines haptic as “pertaining to the sense of touch” (Lioce et al., 2025), but the term haptic is often used inconsistently. For example, the International Standard Guidance on Tactile and Haptic Interactions uses tactile and haptic interchangeably (ISO, 2011). In contrast, much of the scientific literature treats tactile as a specific type of touch sensation that falls under the broader category of haptic sensation. o promote clarity, the authors propose defining haptic as an umbrella term that includes tactile sensations, such as vibration and pressure, and kinesthetic sensations, such as those produced by receptors in muscles, tendons, and joints that detect movement and tension (Haptics, n.d.). To assist with understanding the definitions and possibilities of haptic feedback, haptic sensations are defined in Table 1, and haptic simulation techniques to achieve different sensation effects are defined in Table 2. These definitions may aid healthcare educators and simulation developers to choose devices that are most aligned with their learning needs.

Table 1

Haptic Sensation Definitions

Term	Definition
Haptic	Umbrella term “pertaining to the sense of touch” (Lioce et al., 2025). Incorporates both tactile and kinesthetic sensations.
Tactile	Cutaneous sensations such as vibration or pressure.
Touch	Sensing a mechanical stimulus on the skin (Griffin Occupational Therapy, 2018; Roudaut et al., 2012; Zalta & Nodleman, Sept., 2024).
Light touch	The detection of light touches on the skin, a very responsive system designed to allow us to react to unexpected stimuli very quickly (e.g., touch a spiderweb) (Griffin Occupational Therapy, 2018; Roudaut et al., 2012; Zalta & Nodleman, Sept., 2024).
Deep touch (indentation)	The sense of pressure detected in the deeper layers of the skin (Griffin Occupational Therapy, 2018; Roudaut et al., 2012; Zalta & Nodleman, Sept., 2024).
Discriminative touch	A combination of stretch sensors, light touch sensors, and temperature sensors that give a qualitative sense of what is being touched (e.g., sticky) (Griffin Occupational Therapy, 2018; Roudaut et al., 2012; Zalta & Nodleman, Sept., 2024).
Kinesthetic	Sensation of movements of the limbs and body based on the activity of the muscles, tendons, and joints. The restrictive force sensation of gripping a solid object is an example of kinesthetic haptic feedback (Griffin Occupational Therapy, 2018; Roudaut et al., 2012; Zalta & Nodleman, Sept., 2024).
Vestibular	Relating to the sense of equilibrium detected in the inner ear. (Griffin Occupational Therapy, 2018; Roudaut et al., 2012; Zalta & Nodleman, Sept., 2024).
Proprioception	The ability to sense the position, location, orientation, and/or movement of the body and its parts (includes Kinesthesis as well as spatial sense) (Griffin Occupational Therapy, 2018; Roudaut et al., 2012; Zalta & Nodleman, Sept., 2024).

Table 2

Haptic Stimulation Techniques

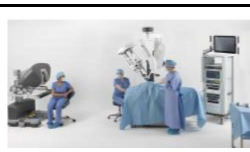
Technique	Description
Vibrotactile/Texture	The ability to stimulate the sensation of touch by creating pressure and/or vibrations on the skin, approximating surface texture (ISO, 2011). Texture sensations are used to enhance virtual objects, interactions, and environments (Hayward & Astley, 1996).
Force	The ability to simulate the solidity of objects by preventing the fingers and/or hands/tools from moving through the space that would be occupied by a solid object; the ability to simulate soft and semi-rigid pliability. Force Feedback replicates the resistance or force exerted by interacting with objects, allowing users to feel weight or resistance for tasks requiring precision or specific grip strength (Zhu et al., 2021).
Thermal	The ability to simulate hot or cold sensations on various body parts and use temperature contrast to simulate extreme heat or cold. Thermal feedback simulates temperature changes, allowing users to feel heat or cold sensations (Park et al., 2024).
Electromagnetic	Administers either an electric or magnetic pulse to stimulate the skin, usually used in haptic suits or gloves, to create the sensation of touch or the sensation of being up against an object (Kastor et al., 2023).
Ultrasonics	Uses high-frequency sound waves that exert pressure on the skin to create sensations (Jang & Park, 2020).
Other	This category is a catch-all for less common technologies that do not fit the above classifications, such as electroshock and low-frequency sound inducers.

The variability in haptic taxonomy is evident in the numerous ways haptic devices have been categorized, including by form, user interaction, wearability, and underlying technology. Examples of how different simulation techniques are incorporated into various haptic devices can be found in Table 3. Adilkhanov et al. (2022) conducted a literature review that analyzed over 90 haptic devices and subsequently created a taxonomy of haptic devices based on the extent of wearability. They defined three broad categories of devices: grounded (e.g., haptic pens), hand-held (e.g., video game controllers), and wearable (e.g., haptic gloves, exoskeletons). This differs from other reviews which focus on the techniques for providing haptic feedback, such as actuator type (Lelevé et al., 2020). For example, haptic devices may use brakes, which are passive actuators that provide a feeling of force feedback by stopping a user’s hand from moving to simulate a solid object. This differs from pneumatic actuators that use compressed air to create the feeling of force. Although both are categorized as force feedback, the underlying technology differs, each with their own benefits and limitations for implementation into healthcare simulation.

(continued on next page)

Table 3

Examples of Haptic Feedback Devices

Device name	Image	Texture	Force	Thermal	Description
Vibrotactile controllers	 (Hollins, 2021)	Y	N	N	More easily integrated into healthcare simulations because most commercial XR controllers utilize vibrotactile sensations
Haptic gloves	 (MaxboxVR, n.d.)	Y	Y	Y*	Haptic Gloves have various levels of feedback, from simple fingertip vibrations to force feedback preventing finger movement *Thermal capabilities may be available, but are not common
Ultrasonics	 (Kirby, 2024)	Y	N	N	Can create texture in the air at a distance
Haptic pens	 (3D Systems, 2014)	Y	Y	N	Provides very precise force feedback relevant to using a tool, but form factor restricts its range of operation
Exoskeleton	 (Shutterstock, 2020)	N	Y	N	Can provide resistance or assistance to simulate real-world forces
Hand exoskeleton	 (CyberGlove Systems, n.d.)	N	Y	N	Can provide resistance or assistance to simulate real-world forces
Integrated Haptics Robotically Assisted Surgical Device (RASD)	 (Intuitive Surgical, n.d.)	Y	Y	N	Incorporating trackers into the actual tool used in a healthcare task (i.e., laryngoscope, bag valve mask) can provide haptic feedback in a simulator that is realistic to performing the task.

Problems with Technology

Existing literature indicates haptic devices offer various types of tactile and kinesthetic feedback, such as vibrotactile/texture, thermal, force, or a combination of sensations (Alford et al., 2024; Zhu et al., 2024). Examples of haptic technologies and the types of feedback they provide are listed in Tables 2 and 3. Although each technique presents unique challenges, common issues across device type include high cost, bulkiness, interference with movement, high power consumption, and limited adaptability for different users. Tactile feedback, specifically, is challenging to provide complete hand coverage to meet the needs of different healthcare simulation tasks. Kinesthetic feedback also faces challenges balancing bulky, heavy active force mechanisms with lighter, passive actuators. As explained by Alford et al. (2024), emerging technologies such as “liquid metal, transcutaneous nerve stimulation, and air pressure systems,” are in development to enhance haptic feedback quality, but these technologies are not widely available.

In addition to hardware challenges, haptic devices typically rely on specialized software and application programming interfaces that are not commonly included in standard XR development pipelines. As a result, developers and educators integrating haptics into simulations must manually incorporate these tools, which presents a significant challenge for widespread adoption. As described in Alford et al. (2024), “the ideal haptic device would be lightweight, low cost, [user-friendly], and capable of delivering [multiple types of sensory] feedback” that can be utilized across healthcare tasks.

Evidence of Efficacy

Haptic research is growing, as noted by the increase in scholarly publications from 250 in 1995, 4,500 in 2015, 7,200 in 2018, and over 640,000 in 2025 (Parisi et al., 2019). Despite the growing literature on haptics, evaluating the efficacy of haptic devices for healthcare simulation remains challenging. Definitions of haptic devices in training environments vary widely, making it difficult to compare outcomes across studies when the technologies are not consistently described or categorized. At the same time, the tasks trained are highly variable. Haptic devices have been used in healthcare simulation for disparate tasks, including suturing, endoscopy, laparoscopy, palpation, ultrasound, and across specialties such as dentistry, emergency medicine, gynecology, and surgery (Coles et al., 2010; Escobar-Castillejos et al., 2016). Although there are many examples of haptics used in healthcare training, most reviews on the efficacy of haptics in healthcare simulation have focused on surgical simulations (Azher et al., 2024; Mackenzie et al., 2022).

Research on haptics is still nascent, but there are promising examples of haptics in the development of surgical skills. Rodrigues et al. (2022) found that the haptic-enhanced VR system showed high usability scores, indicating that participants found the technology intuitive and efficient, which led to improved surgical precision, confidence, and procedural outcomes in dental surgery training. Haptic feedback has also shown promise in increasing bone drilling efficacy to reduce the risks of neurovascular injury in orthopedic surgeries (Gani et al., 2022). However, literature reviews highlighted the lack of quality evidence to support conclusions on the impact of haptics in healthcare training due to small sample sizes, biased study designs, incomplete reporting practices, and a dearth of evidence on the transfer of training to clinical practice or patient outcomes. The notable conclusions from these reviews and surveys are that there is an urgent need for haptic research in healthcare simulation to standardize research protocols, incorporate larger sample sizes, validate simulators and simulation methods in various contexts and for different learners, and to ultimately measure patient outcomes.

New methods of creating and integrating sensors and actuators, along with innovative feedback strategies, are necessary to address these limitations. The call for the collaborative development of open-source haptic preprogramming underscores the importance of ongoing research and development, which are crucial to realize the full potential of this technology in healthcare education. Haptic devices present the potential for enhancing the sensation of touch during healthcare training, but technical and practical challenges must be resolved. Further research is also essential to understand how and when to best use haptic devices in healthcare simulation.

Future State

Haptics in healthcare education are considered immersion-enhancing tools within XR platforms. The use of haptics augments users' suspension of disbelief to deepen their connection to the teaching content, which generates increased agency, empathy, understanding, and a heightened sense of involvement. This is significant because increased immersion may lead to improved learning outcomes and retention (Zhang, et. al., 2019). The haptic sensorial layer is so synonymous with all immersive virtual world interactions that experiences without haptic properties may feel inadequate or low fidelity (Söderström et al., 2022). Thus, as XR hardware and software proliferate in terms of accessibility and fidelity, complementary haptic technologies should co-evolve to achieve an analogous breadth and depth of touch experiences in healthcare education.

Following a similar trajectory of integration into personal technologies (phones, vehicles, etc.), healthcare training will domesticate the haptic vocabulary within immersive environments. Additive immersion achieved through novel physical sensation will become the expectation. Just as gamers have come to expect touch as a central component of connection to the virtual world, healthcare practitioners will increasingly demand that haptics be integrated into the overarching simulation experience.

One challenge to advancing adoption of haptics is that development of hardware for XR use is extremely time- and cost-intensive. At times, this development can require exorbitant budgets and multi-year development cycles to launch iterations of previous models. Likewise, XR software development involves an investment of time and resources that must be justified through a valid return on investment. In lieu of compelling evidence that the initial investment in haptic technology is offset by an increase in the efficacy of an XR experience, healthcare educators often decide to utilize a simulation modality with known outcomes. Without a universal language for understanding haptic experiences and research to illustrate its impact, healthcare haptic technology will not achieve significant industry penetration in training or patient care.

Research evaluates results, results designate impact, and impact stimulates investment. Thus, a growing body of research around haptics in healthcare training and patient care outcomes will eventually yield results in terms of applications that create the best outcomes. This, in turn, will further technology investment and enrich the canvas of possibilities for haptic development. XR platforms will standardize the realm of possibility for enhanced immersion with haptics, which will further refine content creators' tool sets and processes for meaningful integration.

Recommendations for Future Research and Development:

1. Research is needed to establish the efficacy of haptic devices for specific clinical tasks, with careful attention to functional-task alignment (Hamstra et al., 2014).
2. Studies should clarify the educational value added by haptic devices compared to existing technologies, such as high-fidelity manikins.
3. Because different parameters of haptic fidelity may require varying levels of implementation, research should identify the degree of haptic feedback necessary to achieve specific learning outcomes.

4. Cost–benefit analyses, such as those described by Foo et al. (2020), are essential to determine whether the educational gains of haptic devices justify their investment.
5. Interdisciplinary collaborations among researchers, clinicians, and developers are necessary to evaluate device capabilities and limitations while informing industry of educational needs.
6. Healthcare simulation content incorporating haptics is currently limited, and there is a need for more simulation content incorporating haptics across a wider range of clinical domains.
7. Future development of haptic devices should prioritize affordability and accessibility to enable broad adoption across training programs.

Conclusion

Haptic technology has the potential to improve healthcare simulations; however, current limitations must be addressed to facilitate broader adoption. Standardized terminology will ensure that haptic technology groups work effectively with other collaborators in education, research, and development. Healthcare simulation professionals need to standardize terminology and frameworks to successfully integrate haptics. Unified standards for haptics between healthcare and industry can enable platform interoperability across sectors and enhance the accessibility of content creation. The future of haptics in healthcare simulation lies in overcoming these obstacles through the continued advancement of hardware, software, and interface design, which will lead to more immersive, adaptable, and effective educational tools. Further research is essential to address current challenges and fully harness haptics to meet the complex evolving needs of healthcare education.

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Evaluation of a Low-Cost, Innovative Skin Abscess Incision and Drainage Procedural Task Trainer

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Conflict of Interest Statement

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Abstract

Incision and drainage of skin abscesses is a common yet essential medical procedure that requires hands-on training. Ethical concerns around practicing on live patients highlight the need for effective simulation models. However, current commercial trainers are often costly and lack realism. We developed a low-cost, high-fidelity abscess trainer using DragonSkin™ silicone molded in a 6-well escargot tray to create realistic abscess wheals filled with food-grade materials to simulate pus. The trainer features multiple sites, enhancing skill development and cost-efficiency. Medical students and residents evaluated the trainer's fidelity across key procedural steps: anesthetization, incision, drainage, packing, and dressing. Learners reported high satisfaction with the model's anatomic realism and stepwise procedural accuracy. Comfort performing the procedure improved from a mean of 3.9 to 4.6 on a 5-point Likert scale (1 = highly uncomfortable, 5 = highly comfortable) after training. Participants strongly recommended continued use of the model for teaching this skill with a mean score of 4.6 on a 5-point Likert scale (1 = highly unlikely, 5 = highly likely). This novel trainer offers a realistic, reusable, and inexpensive solution for teaching skin abscess incision and drainage, with appropriate fidelity for all steps in the process.

Introduction

Simulation practice and training have shown to be useful and effective (Gordon et al., 2016), giving participants the opportunity to practice skills without risking harm to real patients (Sagalowsky et al., 2016). It also enables them to practice, receive feedback and practice again in rapid succession to improve competency quickly (Singh & Restivo, 2024). Procedural trainers are needed to fill a gap in surgical and procedural training that can otherwise be ethically challenging when practiced on real patients (Thyagarajan et al., 2024). Incising and draining abscesses are essential skills in many healthcare specialties (Nicka & Swanson-Biearman, 2019).

Commercially available task trainers for abscess incision and drainage (I&D) are limited, are often expensive, and have myriad drawbacks. A recent internet search revealed models range from $42 for a pack of six to over $170 for a single-incision device. Some commercial trainers require refrigeration to prevent spoilage, while others contain latex risking severe allergic reaction in sensitive participants. Others lack visual and procedural fidelity elements, only allowing for certain steps in the overall I&D process or are only available in one skin color. Commercial trainers also take time to order and deliver.

Available literature describes homemade models, each with their own set of drawbacks (Chambers et al., 2024). Heiner (2010) inserted simulated abscesses into cadaverous chicken breasts for later incision, drainage, and removal of the cystic casing. Since it contains raw meat, it requires refrigeration, has a short shelf life, meaning it cannot be made long before the training session, and carries inherent risk of salmonella poisoning (Heiner, 2010). It also has a limited number of purulent sites since it requires a valid location in the chicken breast to insert a balloon (Heiner, 2010). Several other models describe a similar preparation with a balloon and food-grade products that have varying degrees of realism and shelf life or require cadaverous tissue for implantation of the abscess (Done et al., 2020).

This novel training model is low cost and free of the limitations previously described. Our model costs approximately $7 per pad with six independent abscesses, or a little over $1 per abscess, allowing for procedural repetition. The pad can be made in as little as 4 hours. It does not require refrigeration, animal or human tissue, and is not perishable. The trainer possesses an extended shelf life up to 6 months and can be constructed with any desired skin tone.

This paper aims to evaluate if our novel training model is effective at replicating key aspects of skin abscess I&D with medical students and residents who have varying experience performing I&D. Participants can practice all steps in the process including circumferential anesthetization, incision, pus expression and complete drainage, and packing the empty wound (Pastorino & Tavarez, 2024). We predict this trainer demonstrates high procedural fidelity, indicating suitability for training any level of learner. We hypothesize that participants will recommend it for future trainings.

Methods

Model Design

A custom, low-cost abscess I&D trainer was created using three types of Platinum Cure™ silicone: DragonSkin™ 10 Very Fast, Eco-flex™ Gel, and Eco-flex™ 00-30 Fast silicone rubber (Reynolds Advanced Materials, n.d.). Simulated pus made from food grade mustard and mayonnaise replicates tactile and procedural fidelity of abscess management. It was evaluated by medical students and residents during one of two structured skills workshops. All materials used are listed in Table 1. The authors encourage visiting https://www.reynoldsam.com/product-category for further information on each of the products described; however, it should be noted that the authors do not endorse one product brand over another.

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Table 1

Supplies and Costs

Material	Manufacturer	Size	Unit cost	Amount used per pad	Cost per pad
Dragon Skin™ 10 VERY FAST	Reynolds Advanced Materials	1 pint	$36.33	~30 mL	$1.14
Ecoflex™ GEL	Reynolds Advanced Materials	1 pint	$36.72	~80 mL	$3.06
Ecoflex™ 00-30	Reynolds Advanced Material	1 pint	$33.03	~60 mL	$2.06
Silc Pig™ Flesh Tone[a] 9-pack color sampler	Reynolds Advanced Material	9 x 0.25 oz	$39.91	~1 drop per color application	Negligible
Chavant Sculptex Medium	Reynolds Advanced Material	1 lb	$5.28	~0.4 kg	Reusable
Escargot tray, 6-well stainless steel	Amazon	2 pack	$12.34	1	Reusable
Power mesh	Amazon	60x60”	$9.99	4x4”	$0.04
Mayonnaise[b]	Grocery store	15 oz	$2.12	1.5 oz	$0.21
Mustard[b]	Grocery store	8 oz	$0.68	1.5 oz	$0.05
Total materials cost, initial purchase:	**$176.40**	**Total cost, per pad:**	**$6.56**	**Total cost, per abscess:**	**$1.09**

Note. All prices were gathered on August 25, 2025. Prices may vary with time, source, and location. [a]This was purchased as part of a multi-pack which cost $39.91 for nine 0.25 oz pigments. The brown, red, and yellow pigments were used interchangeably to vary skin colors. Materials from Reynolds Advanced Material were priced from: https://www.reynoldsam.com/product-category. [b]Prices obtained from Walmart.com were the Great Value Brand and the lowest price available.

Process

This process outlines the creation of a single pad at a time. These can be multiplied when multiple escargot trays are available simultaneously; however, we recommend not working with more than 3-4 trays at one time, especially until the techniques are mastered. Silicone comes in two parts, A & B, which, once mixed, begin to cure into the desired texture of silicone. These parts need to be kept separate until ready to mix, pour, and mold. The manufacturer lists two times for each type of silicone. Pot time is the amount of time to work with the fully mixed material before it starts to become sticky marking the beginning of curing. Cure time is the time needed to achieve final texture and firmness. Both vary with each product line. Some product lines have multiple pot and cure times. Be aware of these before mixing.

General Silicone Mixing and Pouring

1. Pour parts A & B in equal quantities into separate cups, filling each cup no more than halfway.
2. If using pigment, mix a small quantity, about a single drop, into Part B. Start with a little, adding more until the desired color is achieved. Mix until uniformly distributed.
3. Pour Part A into Part B, scraping the sides to extract as possible. Mix well until color is well distributed, keeping in mind pot times as discussed above.
4. When creating layers, we recommend pouring the successive layer before the cure time has completed for the prior layer, but after the first layer has become sticky or about half of the cure time has passed. This will be something to get a feel for over time.

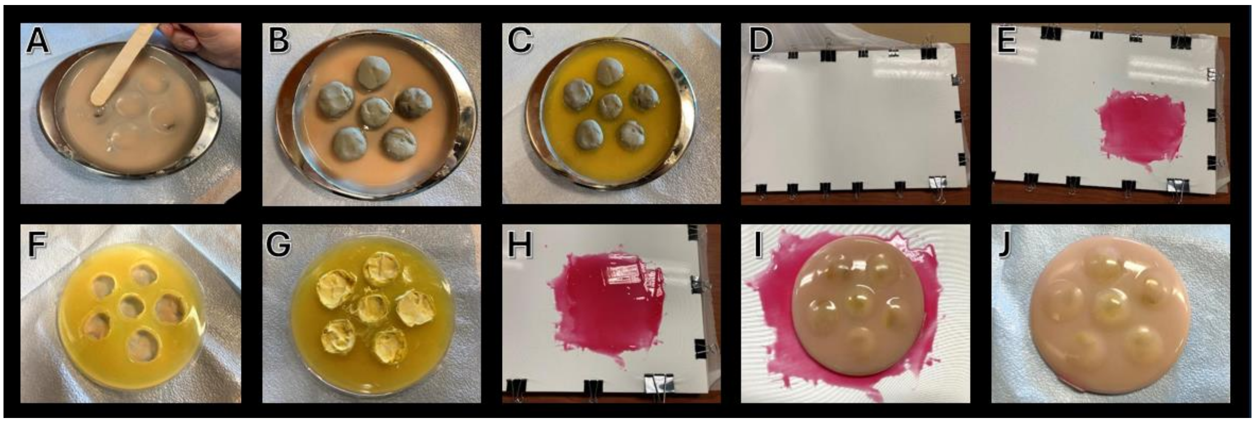
Abscess Pad Process

1. Using the modeling clay, form 6 discs about the diameter of the escargot tray well and about as deep as the tray. They should be arched on one side like the curve of the well of the tray. These will be space holders for the simulated pus. Set aside.
2. Following manufacturer guidelines, thoroughly and quickly mix approximately 15 ml each (1:1 ratio) of Dragon Skin™ with selected pigment (Silc Pig™) to create a customized skin color. Dragon Skin™ Very Fast pot time is four minutes, and cure time is about 30 minutes (Reynolds Advanced Materials, n.d.).
3. Pour the mixture uniformly throughout the 6-well escargot tray.
4. As the silicone begins to pool in the wells, use a chip brush or similar tool to minimize pooling in the wells while making sure a layer of silicone remains in the wells. The wells will form the wheal of the dermal abscess (Figure 1A).
5. Pull some silicone up the sides of the inner walls of the tray for uniform edges of the pad.
6. While allowing the silicone to partially cure for about 15 minutes, prepare the fat layer. Mix 30-40 ml each of Ecoflex™ Gel Part A & B with a few drops of yellow pigment to replicate the yellow appearance of body fat until uniformly colored. There is plenty of time to work with this product.
7. Place clay discs into the center of each well to form the cavity for simulated pus. Ensure the discs are centered and pressed lightly into the semi-cured silicone (Figure 1B).
8. Pour mixed Ecoflex™ Gel into the tray over the silicone and around the clay. The gel does not have to cover the discs but can if necessary to fill to near the top of the escargot tray. Let the gel fully cure (Figure 1C).
9. Meanwhile, stretch a sheet of Power Mesh over a flat, non-porous surface (Figure 1D).
10. Mix 15 ml each of Part A & B of either Dragon Skin™ or Ecoflex™ 00-30 with a few drops of red pigment to replicate the muscle layer until uniformly colored. Pigmenting the muscle layer is not likely to reduce the product fidelity.
11. Spread a thin, even layer of this mixture onto the mesh, ensuring the silicone is pushed through the holes in the mesh. Allow it to cure completely (Figure 1E).
12. Remove the cured silicone pads from the tray.
13. Extract the clay discs to reveal the internal voids (Figure 1F).
14. Fill each void with a mixture of mayonnaise and mustard to simulate pus (Figure 1G).
15. Repeat step 10 to create a second red layer. Spread this across the cured red layer poured in Step 11 (Figure 1H). This layer will bond the pad to the bottom layer and seal the filled abscesses.

16. Flip each filled pad upside down and press it onto the second, red-pigmented silicone layer while it is still wet, allowing it to attach. This forms the muscle layer. Let this cure thoroughly. (Figure 1I).
17. Once fully cured, cut the pad free from the flat surface and remove any excess silicone for clean edges (Figure 1J).

Figure 1

Abscess Model Process



Note. Panel A: Step 4, pulling silicone out of the wells to minimize pooling. Panel B: Step 7, placement of the clay discs. Panel C: Step 8, Fat layer poured. Panel D: Step 9, non-porous board covered with stretched Power Mesh. Panel E: Step 11, initial silicone pour for muscle layer backing. Panel F: Step 13, Pad removed from tray, clay discs removed from pad revealing abscess voids. Panel G: Step 14, abscess wells filled with mayonnaise and mustard "pus." Panel H: Step 15, second layer of for muscle backing, still wet. Panel I: Step 16, filled abscess pad placed on wet muscle layer. Panel J: Step 17, completed, filled pad with excess silicone trimmed.

Pilot Testing and Model Implementation for Participants

This project was approved as no more than minimal risk to participants by the University of Central Florida's IRB, number STUDY00007657 with modification approval number MOD00006599. This study was conducted at the University of Central Florida College of Medicine Clinical Skills and Simulation Center and the Osceola Medical Center. Twenty-two learners voluntarily and anonymously consented to participate in the survey following use of the abscess I&D procedural task trainer. Learners consisted of fourth-year medical students and first, second, and third-year emergency medicine residents during regularly scheduled simulation training. Six participants never performed the skill prior to this training, ten participants indicated they have done the skill at least once but less than ten times, and six indicated they had performed this skill more than 10 times. Learners were required to practice the skill; however, they were not required to complete the survey.

Survey Development and Data Collection

Participants were selected through a convenience sample. The survey consisted of 10 total questions across four different categories. Questions 1-6 evaluated six key aspects of the trainer's realism using a Likert-type scale from 1 (highly unrealistic) to 5 (highly realistic). Questions 7-8 evaluated the learners' comfort levels doing the procedure before and after using the trainer using a Likert-type scale from 1 (highly uncomfortable) to 5 (highly comfortable). Question 9 evaluated how likely learners would be to recommend use of the trainer in the future using a Likert type scale from 1 (highly unlikely) to 5 (highly likely). Question 10 was an open-ended response, allowing learners to provide comments. The data was summarized, and statistical analyses were done in Microsoft Excel.

Results

The mean scores and standard deviations of the survey are presented in Table 2. Based on responses to all six realism items, learners rated the trainer's fidelity as realistic (mean = 4.44, SD = 0.94). The learners' average comfort level increased significantly by an average of 0.73 (95% CI = 0.31 – 1.14), rising from an average of 3.90 before practicing to 4.60 after using the model. The learners overwhelmingly recommended continued use of this trainer (mean = 4.6, SD = 0.88). After removing one outlier, the mean fidelity rating was 4.56 (SD = 0.65) for participants without prior experience and 4.60 (SD = 0.60) for those who had performed a real abscess I&D, with no significant difference at $p = 0.05$. Comments generally praised the trainer, complementing its realism and effectiveness as a teaching tool with commenters saying the trainer was particularly useful for training medical students and was helpful for reviewing and practicing the procedure. One commenter suggested using more pus in each abscess.

Table 2

Survey Results

Category	Mean	Standard deviation
Rate the overall *look* and *feel* of the abscess.	4.36	0.90
Rate the ability to *anesthetize* the abscess.	4.36	1.00
Rate the ability to *incise* the abscess.	4.50	0.96
Rate the ability to *drain* the abscess.	4.55	0.96
Rate the ability to *insert* packaging material into the abscess.	4.41	1.05
Rate the ability to *dress* the wound with gauze and tape.	4.45	0.96
Rate your comfort level performing abscess incision and drainage *BEFORE* today.	3.91	1.11
Rate your comfort level performing abscess incision and drainage *AFTER* today.	4.64*	0.49
How likely would you be to recommend using this trainer for skin abscess incision and drainage practice?	4.64	0.90

Note. n = 22. *Significant increase in comfort, $p < 0.001$.

Discussion

This trainer can be constructed quickly with customizable skin tones by personnel with no experience working with silicone. It provides six purulent sites per trainer, allowing for repeated practice and scaling for larger training programs. It is inexpensive with consumable materials costing approximately $7 per pad with six independent abscesses, or a little over $1 per abscess. Based on feedback from medical students and emergency medicine residents, the trainer effectively replicates critical components of abscess I&D including anesthetization, incision, pus expression and drainage, packing, and dressing. The survey results indicate that users were satisfied with all aspects of realism incorporated into the trainer.

Overall, the mean ratings for fidelity-related questions indicated that participants perceived the trainer as highly realistic. Since each area was evaluated independently, this suggests that transitioning from one step of the skill to the next was smooth and replicated a real experience. Participants who had experience incising and draining real abscesses found the overall realism of the trainer to be high (mean = 4.60, SD = 0.60). This indicates that those who had experience incising and draining real abscesses found this trainer to be close to their experienced reality, further attesting to the procedural fidelity of the trainer.

In addition, two anomalies were identified in the survey results. One participant rated the fidelity of all procedural steps realistic or highly realistic; however, they indicated they were highly unlikely to recommend using this trainer. Another participant rated almost all the step fidelities as highly unrealistic; however, they were highly likely to recommend using this trainer. This represents a potential limitation in the data. Since there were only 22 participants who self-selected into the study, participation bias exists, and outliers can have a greater impact on overall averages and standard deviation.

Limitations and Opportunities for Future Research

There were several limitations to this study. To begin with, the sample size of learners was small and therefore could limit the generalizability of the results. Further research would be needed to evaluate if the results presented here are replicated in other groups. Only medical students and residents participated in the study. Providers who perform the skill frequently such as attending physicians, family nurse practitioners, and physician associates, among others, may have a different assessment of this trainer. Future studies including experienced providers is warranted.

The survey was conducted via a convenience sample, introducing potential for selection bias in participants. However, there was not a pre-test/post-test survey design to accurately capture participants anxiety, comfort, or competence with abscess I&D before and after using the trainer. Although these data indicate a significant improvement in comfort after using this trainer, more research would help further understand the benefits of the trainer, especially in novice learners.

The residents were all emergency medicine residents from a single residency program. Future participants should include residents from other specialties who are likely to need experience with abscess I&D. Additionally, the medical students included happened to be rotating in emergency medicine during the time of the skills training. Evaluating a broader swath of medical students would further enhance the generalizability of the study. This trainer would benefit from input from additional providers including physician assistants, family nurse practitioners, dermatologists, and emergency medicine physicians.

Another future research consideration would be to directly compare the fidelity and learner preference of this trainer to other trainers, including both commercial and homemade models. Although this trainer addresses several issues present in other models, this study cannot conclude that it is superior to trainers reported in the literature or available commercially.

Conclusion

Our innovative, low-cost skin abscess incision and drainage procedural task trainer created from silicone cast in an escargot tray mold was viewed as realistic in its procedural steps by medical students and residents. Simultaneously, the trainer shows distinct promise as a model which overcomes the various shortcomings present in other homemade and commercial models, including cost, perishability, and limited ability to perform all steps in the I&D procedure. The trainer was perceived as allowing realistic practice of anesthetizing, incising, draining, packing, and dressing a skin abscess. Learners increased their comfort in performing the skill in the clinical environment and encourage continued use of this model for future trainings.

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QGenda for Hospital-Based Simulation Center Scheduling: Accessibility, Transparency, and Data Management

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Abstract

Introduction: Simulation event scheduling is a key operational aspect of planning and executing simulation-based education events. This hospital-based simulation center identified the need for a more efficient, functional, and forward-facing scheduling process to ease the workload of program staff and increase the satisfaction of facilitators and users.

Methods: The IDEAL Problem-Solving Model was used to organize the project, systematically explore available scheduling options, and generate a creative and informed solution. The three options considered were: Microsoft Office Outlook, B-Line Medical (now SimCapture), and QGenda. Each option was evaluated based on simulation center priorities, including accessibility, cost-effectiveness, transparency, customizability, simulation specific, and ability to track data.

Results: This simulation center selected QGenda as the best scheduling platform option. QGenda is a hospital-based platform used for healthcare workforce management. It was already in use within the hospital system and was adapted for simulation center scheduling processes. The introduction of QGenda as the scheduling platform yielded process and operational improvements, including decreased emails, more timely event scheduling, staff and user satisfaction, and event tracking with reports generated using data management functionality.

Conclusions: QGenda has proven to be an inspired and functional option as a simulation scheduling platform. Especially for hospital-based simulation centers that already utilize QGenda for clinical-based and workforce scheduling, extending its use to simulation scheduling can be cost-effective and may result in little to no additional cost to the program.

Introduction

Scheduling is an important part of planning and executing simulation-based education events (Dongilli et al., 2015). Scheduling processes involve a variety of components, including reservation of time, space, personnel, and equipment, as well as administrative logistical coordination of approvals and assurance of resource availability across multiple events (INACSL Standards Committee et al., 2021). Ineffective scheduling increases user frustration, minimizes use of simulation space, and increases programmatic costs. Moreover, many simulation centers are located within institutions such as hospitals or universities, requiring scheduling systems that can be accessed and integrated with other institution-specific systems.

Several scheduling platforms are available; however, they can be difficult to tailor to the unique needs of individual simulation programs. Similarly, many scheduling platforms come at a high cost, are incompatible with other programs, and may be inaccessible to all users in multi-organizational simulation centers. Microsoft Office Outlook and Learning Management Systems have been used by simulation centers for scheduling (Grant et al., 2020; Wood et al., 2014). Microsoft Office Outlook can be a cost-effective scheduling system, but only if all users have access to and enable bidirectional calendar viewing (Grant et al., 2020; Wood et al., 2014). Many institutions have existing platforms available to employees for trainings and meeting space reservations. Although these platforms have scheduling operations, they are not specific to simulation scheduling, are purchased through external vendors, require additional orientation, or involve lengthy processes and costs to approve new uses or new vendors (Grant et al., 2020). This project aimed to identify and implement a transparent, easily accessible, customizable, cost-effective, and simulation specific scheduling platform for this hospital-based simulation center.

Methods

To address the issues surrounding simulation center scheduling processes, the IDEAL Problem-Solving Model was used to generate creative solutions and to organize and implement the project (Bransford et al., 1998; Bransford & Stein, 1984). The IDEAL model consists of the following steps: 1) Identify the problem, 2) Define the outcomes, 3) Explore possible strategies, 4) Anticipate outcomes and act, and 5) Look back and learn. This simulation center is located within a free-standing, quaternary care academic children's hospital in the Midwest United States. It contains five high-fidelity simulation rooms, one debriefing room, one exam room, one virtual reality room, one classroom, one conference room, and one flexible space dedicated to skills and procedures. The simulation center hosts a variety of event types, ranging from individual just-in-time training sessions to large-scale multi-institutional simulation workshops. It serves multidisciplinary participants at all levels of training with an average of 11,000 annual learner contact hours.

Results

Identify the Problem

The first step of the IDEAL model was to identify the problem: the lack of an efficient simulation scheduling process. Prior scheduling processes consisted of primarily unstructured email communication between an event facilitator and a simulation program staff member to query availability for a specific day and time. Frequently, back-and-forth messaging was required to successfully schedule a date, time, space, and equipment for each event. The event date and time was then manually entered by the staff member into the simulation center's Outlook calendar, only viewable to program staff due to institutional restrictions and associated firewalls. On average, four emails over a duration of twenty days were required to successfully schedule the various components of a simulation event. This resulted in cumbersome communication, limited transparency of facilitator availability, and increased risk of transcription errors.

Define the Outcomes

The second step of the IDEAL model was to define the outcomes in order to address the problem and inform possible solutions. The first outcome was to provide a scheduling process with well-defined procedures that were easily accessible, cost-effective, transparent, customizable, and simulation specific. The second outcome was to incorporate the ability to efficiently document, track, and report event data, such as number of events, total education time, and participant demographics. This outcome was considered important by staff, program leadership, and other key stakeholders, as it provided data-driven insights into resource use and event trends, supporting future strategic planning for program expansion and development.

Explore possible strategies

With the problem and outcomes defined, the third IDEAL step was to brainstorm all possible strategies. Simulation program staff and leaders engaged in thoughtful dialogue and consulted a variety of key stakeholders, including corporate hospital sponsors, academic medical program leadership, funding groups, event facilitators, and participants to ensure the solutions addressed the spectrum of scheduling needs. Several simulation-specific and non-simulation-specific scheduling options were identified. The strengths and weaknesses of each option were evaluated based on the identified outcomes. Scheduling options explored were Microsoft Office Outlook (Microsoft, 2025), B-Line Medical/SimCapture (Laerdal Medical, 2024), and QGenda (QGenda, LLC, 2024).

Microsoft Office Outlook is a non-simulation email and calendar platform used by many institutions. Given it is already widely accessible and used institution-wide, it is considered cost-effective and may result in no direct costs to the simulation program. Microsoft Office Outlook contains embedded and customizable scheduling features which allow users to schedule rooms for a specific date and time and generate reports for event tracking. Users can choose to share either individual calendar events or an entire transparent shared calendar, with some notable limitations. Many times, users do not have the option to share calendars across different employers and/or institutions, limiting usability. As a result, when users view the calendar, the platform may not accurately display room availability if used across multiple institutions, limiting transparency for end-users.

B-Line Medical/SimCapture is a simulation-specific scheduling platform which allows a center to customize scheduling options based on the number of simulation spaces and many other variables. This platform also provides transparent availability between the program and users. The schedule is viewable by users with a B-Line Medical/SimCapture account; however, most employees and end-users do not have an account, which limits schedule accessibility. Additionally, B-Line provides data storage of event details that can be exported for data tracking. Despite these strengths, B-Line Medical requires a significant investment of time for platform management, as well as both upfront and ongoing costs for subscribing to the specific modules needed by the program.

The third option considered was QGenda, a scheduling platform used by healthcare organizations for healthcare workforce management. Although it is not simulation-specific, it can be customized with names of simulation rooms and provide transparency into room availability. Similar to Microsoft Office Outlook, many institutions already use QGenda system-wide; therefore, users already have access, and it requires no additional direct financial investment from the simulation center. It has capacity for data collection and extraction for simulation event tracking. Finally, QGenda has the unique feature of synchronizing with Microsoft Office Outlook calendars across different institutions, eliminating the need for manual event entry. In turn, this has the potential to save staff time and minimize the risk of transcription errors.

After thoughtful review of the three possible solutions, QGenda was selected as the best option because it most closely aligned with the program’s defined outcomes (Table 1). As the hospital was already using QGenda as a scheduling platform, existing infrastructure was already in place to support the adoption of this platform. The supportive infrastructure included easy access to the QGenda application through the hospital's main internal website, IT expertise, and hospital employees' existing familiarity with the platform.

Table 1

Comparison of Scheduling Options and Alignment with IDEAL Outcomes

	Microsoft Office Outlook	B-Line Medical (SimCapture)	QGenda
Accessible	✓	✓	✓
Cost effective	✓		✓
Transparent		✓	✓
Customizable	✓	✓	✓
Simulation Specific		✓	
Data Tracking	✓	✓	✓

To begin the transition to QGenda as the simulation center's scheduling platform, staff met with a QGenda representative and discussed logistics and timeline for implementation. QGenda was customized to incorporate all simulation center rooms and spaces, which were then displayed to users as either "booked" or "available" for the date and time of interest. This created a forward-facing schedule for all users by allowing users to see if their desired room, date and time were available, while also showing alternative available options. Program staff had administrative access to adjust the availability of each room and space (Figure 1). Finally, QGenda representative support is not required on an ongoing basis, only for the initial build of the simulation center schedule or in the event of major changes, such as adding new spaces or changing room names.

Figure 1

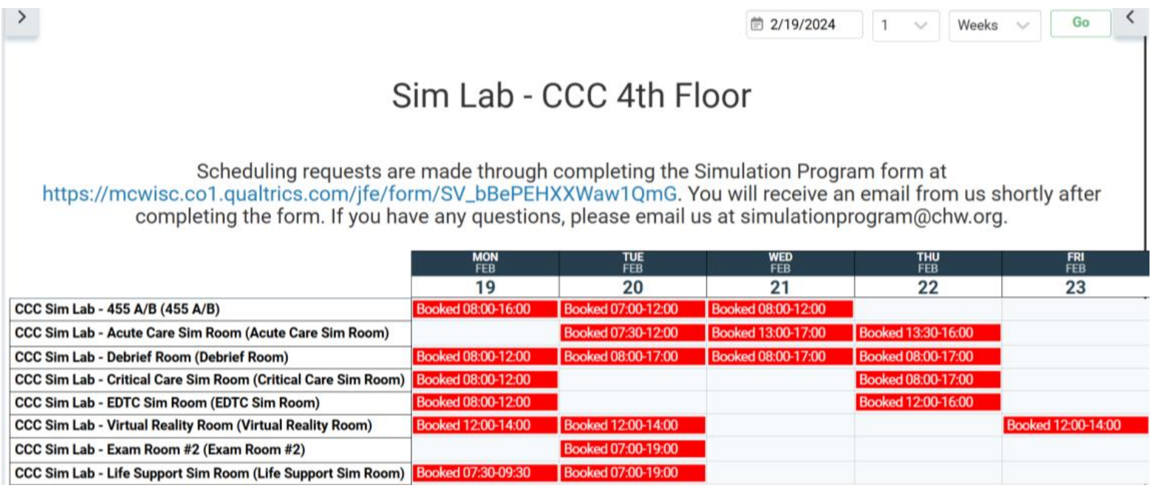
Administrative View of QGenda Simulation Schedule

Note. QGenda screen display of the calendar, space/room names, availability, booked events, and additional event details. Rooms are not available if "Booked" is shown in red. Additional details appear as tags (e.g., "Low fidelity," "High-fidelity") viewable only by simulation center staff and used to populate data reports.

Part of the first outcome was to provide an easily accessible scheduling platform across the institution. To address this, the simulation schedule was added to the institution's internal webpage. The webpage was already the designated location to access QGenda for other programs and was therefore familiar to users. It is available to any person working or training within the hospital, regardless of employer, eliminating the need for additional logins or specific access permissions. Users can apply filters to view specific simulation areas during their desired timeframe. To further augment accessibility and usability, instructions and related external links, such as the simulation program's reservation form and contact information, are located on the simulation center QGenda page (Figure 2).

Figure 2

User View of QGenda Simulation Schedule


2/19/2024 1 Weeks Go

Sim Lab - CCC 4th Floor

Scheduling requests are made through completing the Simulation Program form at https://mcwisc.co1.qualtrics.com/jfe/form/SV_bBePEHXXWaw1QmG. You will receive an email from us shortly after completing the form. If you have any questions, please email us at simulationprogram@chw.org.

	MON FEB 19	TUE FEB 20	WED FEB 21	THU FEB 22	FRI FEB 23
CCC Sim Lab - 455 A/B (455 A/B)	Booked 08:00-16:00	Booked 07:00-12:00	Booked 08:00-12:00		
CCC Sim Lab - Acute Care Sim Room (Acute Care Sim Room)		Booked 07:30-12:00	Booked 13:00-17:00	Booked 13:30-16:00	
CCC Sim Lab - Debrief Room (Debrief Room)	Booked 08:00-12:00	Booked 08:00-17:00	Booked 08:00-17:00	Booked 08:00-17:00	
CCC Sim Lab - Critical Care Sim Room (Critical Care Sim Room)	Booked 08:00-12:00			Booked 08:00-17:00	
CCC Sim Lab - EDTC Sim Room (EDTC Sim Room)	Booked 08:00-12:00			Booked 12:00-16:00	
CCC Sim Lab - Virtual Reality Room (Virtual Reality Room)	Booked 12:00-14:00	Booked 12:00-14:00			Booked 12:00-14:00
CCC Sim Lab - Exam Room #2 (Exam Room #2)		Booked 07:00-19:00			
CCC Sim Lab - Life Support Sim Room (Life Support Sim Room)	Booked 07:30-09:30	Booked 07:00-19:00			

Note. QGenda screen showing calendar dates, simulation spaces/rooms, availability, and booked events. Above the calendar are brief instructions on scheduling procedures and a link to the scheduling request form.

This simulation center is located in a hospital which was already invested in and using QGenda for healthcare workforce management. Therefore, there were no upfront or direct costs to the simulation program to implement QGenda. Additionally, there were no associated maintenance or simulation-specific subscription costs, such as those with the B-Line Medical platform.

Finally, QGenda contained features for documenting, tracking, and reporting simulation event data. It allowed simulation staff administrative access to scheduling and event data, including categorization of event types (e.g., high-fidelity, low-fidelity, space), frequency of use of rooms/spaces, and trends in frequency of use (e.g., days of the week, times of the day).

Anticipate outcomes and act

The fourth step of the IDEAL model was to anticipate outcomes and act. This step involved expecting a range of reactions, planning how to navigate them, and considering sustainability and future state of the solution. With any change comes a variety of responses, both positive and negative (Harrison et al., 2021). Simulation event facilitators expressed satisfaction with the ability to easily view room availability. This allowed self-selection of an available date and time on the front end of the scheduling process and eliminated the need for multiple emails. Many simulation center users were already familiar with QGenda as part of their clinical workflow; therefore, issues related to learning a new and unfamiliar system were minimized. To mitigate perceived barriers by individuals not previously familiar with QGenda, program staff provided tutorials regarding how to find the calendar on the internal website and navigate the various features.

One future consideration is the impact on the simulation center if the hospital decides to transition from QGenda to a different workforce management system. Currently, QGenda is highly utilized and integrated across the system; therefore, an intensive process would be required to select and implement any new system for this purpose. If this were to occur, the simulation center would undertake a similar process described here to identify a scheduling platform. Simulation staff and leadership overwhelmingly felt the benefits of adopting QGenda for simulation scheduling outweighed the possible and hypothetical risks of eventually losing access and having to again find a new platform.

Look back and learn

The final step in the IDEAL model is to look back and learn to reflect upon success and identify further areas of opportunity. The overall timeline of the project was six months, from problem identification to fully functional QGenda implementation. Once QGenda was selected as the scheduling solution, simulation staff and QGenda representatives collaborated to customize the platform and define scheduling procedures. Prior to the institutional QGenda go-live, a one-month pilot was conducted wherein select simulation center users accessed QGenda to schedule their events and provided feedback on the platform and scheduling process. Email communication was sent to frequent simulation center users to announce the transition to QGenda and provide instructions regarding access and procedures. Additional users were informed and trained on a rolling basis. Supplemental resources regarding QGenda orientation and related scheduling procedures were created, including a detailed how-to guide with screenshots and links. This was available to users via email and posted on the simulation center intranet site. Simulation staff were also available to provide direct assistance and answer questions.

QGenda was an inspired solution to the large problem of scheduling for the simulation center. It successfully addressed the programmatic goals of being easily accessible, cost effective, transparent, customizable, and allowing for data management. All limitations to the platform were anticipated regarding how people would navigate and accept a change in scheduling procedures. Constructive feedback from users was acknowledged and quickly resolved with just-in-time education, as well as thoughtful, timely, and efficient responsiveness from simulation staff to address issues as they arose.

Discussion

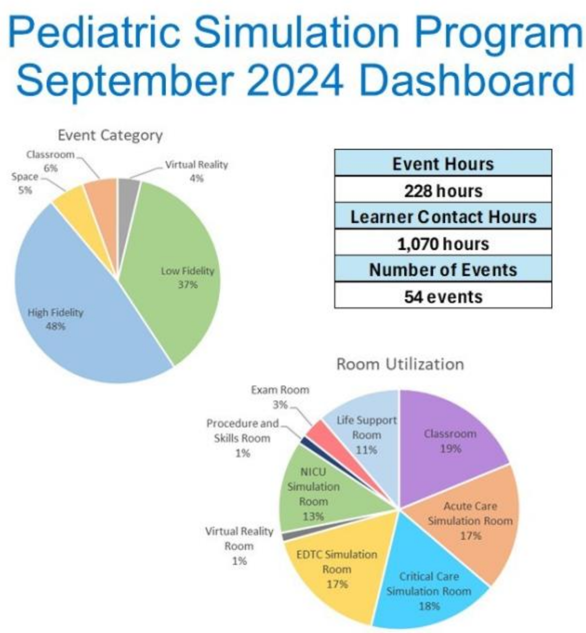
The QGenda scheduling solution was introduced within this simulation center in August 2021 and remains the current scheduling platform. Since that time, 2,217 events and 7,651 event hours were scheduled (August 2021 to December 2024) using QGenda. Prior to the implementation of QGenda, an average of four emails over a duration of twenty days was required to schedule an event, whereas now an event is scheduled after one confirmation email within two business days. Most of the time, the user can view the transparent schedule, submit a request, and receive a one-time email confirmation of their request without further communication. Additionally, program staff can synchronize QGenda with Microsoft Office Outlook calendars to eliminate the need for manual entry and associated transcription errors.

Users had the opportunity to share feedback regarding the scheduling process by using the program’s optional anonymous feedback survey. One hundred percent (n = 21) of survey participants rated the ability to view simulation space availability within QGenda as useful and helpful. Additionally, in the free text response option, participants stated it was "very easy to identify open times the simulation area was available for our use with the current scheduling methods," "much improved from previous scheduling abilities," and that the "scheduling process is very organized".

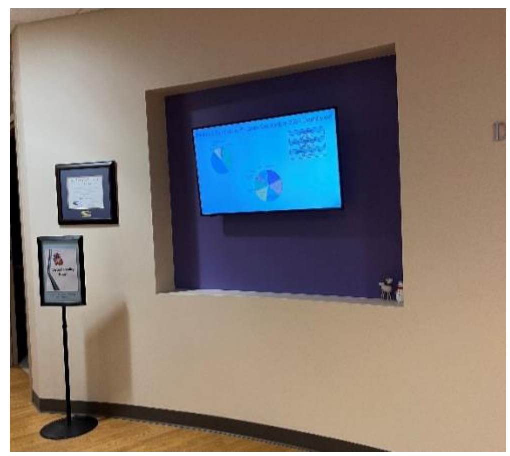
Finally, the use of QGenda to collect, organize, and report event trends has facilitated a data-driven approach to decision-making regarding simulation program development, such as equipment purchases, space allocation, and staffing requirements. Data reports can be generated and used to create informative dashboards to display user statistics, such as space, education hours, learner contact hours, and event types (Figure 3A). The data and dashboards are used in a variety of ways to demonstrate the impact of simulation, such as the generation of business plans, crafting annual reports, and demonstrating the use of philanthropic donor funds. Additionally, the dashboards are publicly displayed on a large monitor upon entrance to the simulation center, which increases awareness and highlights the various simulation events across the institution (Figure 3B).

Figure 3

A *Simulation Data Dashboard Example*



B *Simulation Data Dashboard within Simulation Center*



Note. Panel A: Informative simulation dashboard created from QGenda event data displaying room utilization, event category, and other event data. Panel B: Informative simulation dashboard posted on the monitor within the simulation center.

Conclusion

Scheduling is a vital aspect of the daily operations and management of a busy simulation center. QGenda is a cost-effective scheduling system, especially for simulation centers affiliated with a healthcare or hospital-system that is already using it for workforce management. This platform benefits users by being easily accessible and transparent, with the ability to efficiently view availability and schedule a simulation event. QGenda benefits simulation program staff and leaders through its functionality as a data management system to facilitate data-driven decisions and informed strategic planning.

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Construction of an Animal-Alternative Liver Model for Surgical Simulation Training

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Conflict of Interest Statement

The authors of this manuscript declare no conflicts of interest. Innovations were designed at the STRATUS Center for Medical Simulation when author BFQ was employed there.

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Brief Description

Traumatic liver injuries are among the most common life-threatening emergencies observed in patients worldwide, most often resulting from blunt force trauma or penetrating injuries (Coccolini et al., 2020; H. Jiang & Wang, 2012). Due to the liver's essential functions, dense vascular supply, and large surface area, poor management of these injuries can lead to severe complications and high mortality (Arık et al., 2013; Gao et al., 2003; Ozougwu, 2017; Taghavi & Askari, 2023). Given that quick and appropriate action is required to maximize favorable patient outcomes, surgical practitioners must receive efficient training to ensure they can repair these injuries competently. Medical simulation offers practitioners a psychologically safe educational space to improve their psychomotor skills. Historically, animal models have been a gold standard for surgical training in medical simulation (Cordero et al., 2011; DeMasi et al., 2016; Loh et al., 2017). However, animal products (AP) may not always be readily available and may carry ethical and practical considerations (Kadima et al., 2006; Parra-Blanco et al., 2013). In addition to ethical issues, the need to repurchase APs repeatedly can be financially burdensome. These concerns underscore the need for alternative training methods in the development of surgical skills. Using readily available materials, we designed a reusable and cost-effective model that provides realistic feel and tissue response to train surgical practitioners.

Introduction

Uncontrolled hemorrhages are one of the major causes of death amongst trauma patients. Given the liver's size, vascular supply, and relatively fragile parenchyma, it is a common source of life-threatening hemorrhage (Coccolini et al., 2020; Gao et al., 2003). Bleeding from liver injury is associated with a high mortality rate and can result from various mechanisms, with the most acute and life-threatening cases typically involving penetrating trauma or blunt force injury (Jin et al., 2012; Keizer et al., 2020; Slotta et al., 2013; Tarchouli et al., 2018). Given the time-sensitive nature of such cases, it is crucial for surgical practitioners to be thoroughly trained in the prompt management of these injuries. With medical simulation, evidence-based teaching methods can be used to improve practical skills and knowledge in managing complex injuries like liver trauma (Delingette & Ayache, 2005; Rashidian et al., 2020).

While APs are commonly used in surgical procedure training, there are associated ethical, financial, and logistical challenges (Broom, 2010; Kadima et al., 2006; Parra-Blanco et al., 2013). Firstly, specialty APs bought in bulk can be expensive due to the careful and time-demanding harvesting process. In some cases, APs can carry diseases and environmental hazards due to unhygienic shipping and handling practices. Second, as APs spoil quickly after use, multiple teaching sessions will require the purchase of new APs for each cohort, contributing to overspending. Lastly, with growing emphasis on animal welfare advocacy and cultural considerations, the use of APs may conflict with individual morals, especially if the use of APs in training is not an absolute necessity.

In recent years, technological innovations like extended reality have been introduced to shift the paradigm of medical education and surgical training (Preibisch et al., 2024; Suresh et al., 2022; Toni et al., 2024; Woodall et al., 2024). However, these new methods have limitations regarding how learners can fully refine and develop their psychomotor skills (Co et al., 2023; Woodall et al., 2024). Despite being relatively costly, three-dimensional printing and silicone modeling in medical simulation has enabled learners to hone surgical skills using anatomically precise models (Jiang et al., 2024; Tenewitz et al., 2021; Nagamoto et al., 2023). We propose an innovative approach that utilizes the traditional method of hands-on surgical training, enabling learners to fully cultivate these skills with a liver-shaped simulator. In this manuscript, we describe the creation of a low-cost, easily made simulator to replicate traumatic liver injuries.

Objective

This project sought to create a cost-effective, alternative to animal products to train surgeons in repairing liver injuries with techniques such as primary suture repair, ligation and intrahepatic tamponade. As an AP alternative, we aimed to create a model reusable across multiple simulation sessions. A key goal of this project is to highlight the importance of simulation training for liver injury management, given the high number of traumatic liver injury cases in both the United States and globally (Chien et al., 2013; Taghavi & Askari, 2023).

Model Design Methods

The cost and materials to create the simulated liver model are presented below (Table 1). Full instructions for this model can be found in Appendix A. Upholstery foam was cut into cubes, and red food coloring was mixed with warm water. These products provided the liver model with structural integrity and the color of living tissue, respectively. The fundus tissue (*Replaceable Fundus Tissue 10-Pack*, 2024) was chosen as the model's foundation due to its likeness in shape to the liver. The esophageal attachment of the fundus tissue was repurposed to simulate the falciform ligament by attaching it with twine to divide the model into the right and left lobes. Other required instruments included trauma shears, a needle holder, and sutures.

(continued on next page)

Table 1

Total Cost of Materials

Model Components	Cost per unit (In USD)
SimuLab Replaceable Fundus Tissue	$70.50 / Count
Goto Foam Upholstery Cushion	$8.99
Natural Twisted Jute Twine	$4.67
Trauma Shears	$2.50
6 Inch Needle Holder	$15.99
Chefmaster Super Red Liqua-Gel Food Coloring	$6.26
ETHICON 0 Perma Hand Silk Suture	$7.20 / Count
Total Cost of Design	**$116.11**

Note. Items are typically bought in bulk, and individual units are used to create the model. The brands listed are not required but represent those used in our simulator. Prices are reflective of USD as of January 2025 and may be subject to change.

After the foam cubes and red solution were prepared, we began the model making process. The esophageal attachment of the fundus was removed using trauma shears, and foam cubes were inserted into the fundus tissue (Figure 1A). As cubes were inserted, the tissue adopted the shape of a liver, with the area distal to the opening appearing smaller than the more proximal region. This allowed a clear distinction between the right and left lobes to place the twine and the esophageal attachment, as they both differ in size anatomically. A realistically size falciform ligament was simulated by utilizing twine to bind the esophageal attachment. After filling, the opening was sutured shut using a needle holder and 0 Perma-Hand® silk suture (*PERMA-HAND™ Silk Suture*, 2022) (Figure 1B). Once closed, twine was tied on one end of the model creating the border to separate the right and left lobes of the liver made by the uneven distribution of foam for durability. The liver was then left to soak in the red solution for 10-15 minutes to give the appearance of living tissue. Finally, the esophageal attachment was bound tightly above the twine to simulate the falciform. This step is performed after soaking, as the falciform ligament is a different color biologically compared to the remainder of the liver. This completed construction and overall construction for this liver model should take approximately 30 minutes, including the time for soaking (Figure 2). The liver model was then simulated to have a grade II laceration for repair simulation (Figure 3).

(continued on next page)

Figure 1

A *Component Materials* **B** *Closing the Liver Model*

Note. Panel A: Component materials used by STRATUS staff to create the liver model. Esophageal portion of fundus tissue was cut prior to photo. Panel B: Needle holder and 0 Perma-Hand® silk suture was used to close the incision site. If suturing is not feasible, standard stapling can be used.

Figure 2

Completed Liver Model

Note. Liver was soaked in red liquid solution for 10-15 minutes prior to tying the esophageal attachment onto the model.

Figure 3

Simulated Liver Model with Grade II Laceration

Note. Simulated laceration was made into the model before the falciform ligament was added. Grade II liver lacerations are 1-3 centimeters deep and ≤10 centimeters in length (*Injury Scoring Scale*, 2009). Simulated bowel (*Sim Bowel Segment*, 2024) and tissue suture pads (*Tissue Suture Pad*, 2024) were added into a plastic container for an abdominal surgery simulation requiring an exploratory laparotomy.

Results

We created a sustainable and reusable liver model for surgical skill training using materials easily obtained in our simulation lab. The cost to make one liver model is $116.11 USD. The model allows for the learner to practice technical skills during surgery simulation that include, but are not limited to, laceration repair and perihepatic packing with. For the initial liver model, we created a grade II laceration for suture repair using an #11 blade scalpel. However, there is potential for customization, with future iterations including mechanisms of injury such as impalement or gunshot with retained bullet. For high fidelity surgery simulations, this liver can be placed inside of a full-body mannequin and paired with other simulated organs to create a more immersive surgical experience for learners.

Discussion

The net cost for the construction of one liver model was $116.11 USD, with the most expensive component being the fundus tissue. For this reason, the fundus tissue may not be readily accessible, and cheaper alternatives can be made using silicone as the mold of a human liver. Foam can also be used to fill the interior of the silicone model, although some silicone may become trapped between the foam layers in this design. If necessary, for repair, additional silicone may be applied to the open lesions for model closure.

With this simulator, surgical practitioners can practice the fine motor skills essential for open surgery injury repair, like suturing. Severity of the injury grade can be manipulated accordingly (*Injury Scoring Scale*, 2009). Additional customization of this model can include the addition of liver tumors by adding small Styrofoam spheres to simulate semicircular liver projections and a silicone skin layer. For this model, Styrofoam is preferred as it can maintain its shape after infiltration by a biopsy needle or ablation antenna. With these additions, learners can practice minimally invasive surgical procedures such as tissue biopsy, hepatectomy, and microwave tumor ablation. The liver's major blood vessels, the hepatic portal vein and hepatic artery, can be simulated with rubber tubing spanning from the superior to the inferior aspects of the model. With the addition of these structures, learners can practice more advanced surgical procedures like portal vein and hepatic artery ligations.

This liver model can be integrated into a container with simulated abdominal organs for use with the Fundamentals of Laparoscopic Surgery (FLS) trainer for a minimally invasive approach to surgical repair. Given that laparoscopic surgery is a commonly required skill in addition to traditional open surgery techniques (Carr et al., 2018; Patil et al., 2024), combining this model with the FLS trainer enables the learner to practice core techniques associated with laparoscopic surgical repair. As this is an alternative to AP, there is a decreased risk of disease transmission and environmental hazards when pairing this model with a multi-purpose FLS trainer. This model shows great promise for high-acuity surgical simulations. By adding a red fluid mixture inside the simulated liver, it can be lacerated to create a team-based scenario focused on managing actively hemorrhaging liver injuries.

Limitations of Simulator

There are some limitations with this simulator to consider. First, it does not fully replicate the complexity of responding to a trauma with patients who have sustained high-grade liver injuries requiring emergent operative intervention. In a case-based scenario, a simulation lab can potentially work with a script, actors, and mock clinical and operating rooms, but the true pressure of a real trauma situation cannot be fully replicated with our model.

Second, this initial liver model is designed to simulate a grade II laceration in an otherwise healthy liver and does not replicate other liver conditions which might result in a more complicated repair, such as cirrhosis, hepatic steatosis, hepatitis, or carcinomas. Additionally, the size of this simulated liver does not accurately replicate the liver of a larger adult, child, or infant, limiting the simulator's use for trauma surgeons in training. This limitation could, however, be addressed by adjusting the size of the fundus tissue and foam padding. For pediatric livers, models could utilize a smaller tissue sample and less foam padding. For larger adult livers, multiple layers of fundus tissue and foam padding may be needed to expand the surface area of the existing model, though this could increase the cost of model construction.

The lack of an active circulatory system with pulsatile arterial spray and venous obstacles limits realism. In a trauma situation, the operator would need to take careful steps around these vital structures to avoid introducing more damage. This is particularly relevant vascular injuries due to a grade III-IV injury (*Injury Scoring Scale*, 2009). In these situations, the surgeon must manage both parenchymal tears and vascular injuries, which can complicate repair due to blood loss.

Similarly, our model is limited by the lack of simulated bile ducts. Significant structures like the common hepatic and bile duct are commonly used landmarks for gallstone removal. Without the addition of rubber tubing to simulate these structures, the ability to practice these skills on the simulated liver model is significantly limited. Lastly, this model does not include the gallbladder, which is attached inferiorly to the liver. We solely focused our efforts into constructing the liver. To address this, a gallbladder and associated ducts can be simulated with a balloon and tubing on the inferior aspect of the liver.

Finally, this model has not been evaluated by subject matter experts. The feedback from subject matter experts is vital to improve the model's utility and efficacy in surgical laceration repair training. At the time of this writing, we have not obtained expert feedback due to logistical challenges. Future simulation studies and training sessions utilizing this model should seek to gather expert feedback on this model's resemblance to a real liver and comparison to APs as an educational tool.

Conclusion

In summary, a simulated liver was created using materials available in our medical simulation center. The model is a viable and reusable alternative to animal liver, addressing ethical and practical considerations associated with the use of these items. The customizability of the model allows for the practice of managing different mechanisms of liver injury.

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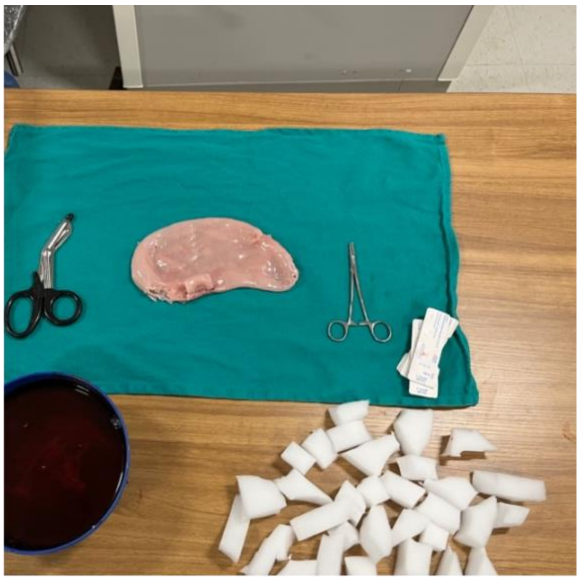
Appendix A

Model Making Instructions

1. Obtain and cut upholstery foam into cubes utilizing trauma shears (Figure A1).

Figure A1



2. Add red food coloring to warm water and place foam cubes in to create structural integrity and realistic color for the liver model.

3. Once obtained take artificial fundus material and remove esophageal attachment utilizing trauma shears this will be used later for mimicking falciform ligament (Simulab Corporation, Seattle, Washington, United States of America).

4. Shape fundus tissue into liver-like structure.

5. Insert foam cubes from step 2 into the esophageal opening of the newly formed liver like structure you will notice as the shaped fundus fills it will adopt a more realistic three-dimensional liver like structure.

6. Once fundus is filled and approximates a liver like structure, use suture and needle driver to close the esophageal opening (Figure A2) (Ethicon Inc., Raritan, New Jersey, United States of America).

Figure A2

7. Take twine and cut to length to be able to tie it at a point roughly central on the liver model to simulate left and right lobes.

8. Soak liver model in solution of warm water to help dye it into a more realistic color, allow it to soak for 15 minutes minimum. Do not soak previously removed esophageal attachment.

9. After the model has been soaked, remove and allow to dry.

10. Place previously removed esophageal attachment atop twine utilized for separating left and right lobes. This will mimic the falciform ligament which is a different color in real human liver tissue (Figure A3).

Figure A3

Note. Considering the materials used in the construction of this liver model, this trainer may not be suitable for electrocautery use or training.