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# Surgical Abdominal Wall (SAW): A Novel Simulator for Training in Ventral Hernia Repair

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**Abstract**

Laparoscopic ventral hernia repair (LVHR) is a relatively common procedure that requires advanced minimally invasive surgical skills to perform. The role for simulation is increasingly supported as an effective way to teach surgical skills and accelerate the learning curve. This article describes The University of Maryland's Surgical Abdominal Wall, an inexpensive procedure-specific physical simulator for LVHR, and summarizes the authors' early experiences using this model in a curriculum for surgery residents.

**Keywords**

incisional, ventral, hernia, laparoscopy, simulation, surgical, education, curriculum, model, mesh, skills

## Introduction

Ventral hernia is a common complication of abdominal surgery. One study reported recurrent hernias in 34% of patients requiring laparoscopic ventral hernia repair (LVHR).[1] Following LVHR, the hernia recurrence rate—equated with obesity, sizable defects, perioperative complications, and prior open repair—then reported in that same study was a mere 4.7%. Continued reports of low rates of recurrence[2] as well as improved rates of complications[3] have contributed to increased reliance on LVHR as the standard surgical approach, with the caution that adequate experience and training accompany its performance.[4] Not surprisingly then, this procedure has been designated as 1 of the 15 procedural skills by the American College of Surgeons and the Association of Program Directors in Surgery Surgical Skills Curriculum Task Force included in phase II. The goal of phase II is to train residents on all relevant steps of a given procedure or operation in a nonthreatening simulated environment.[5]

This article describes an inexpensive abdominal wall physical simulator that can be effectively configured for procedure-specific LVHR training and summarizes early experiences using this model in curricula for surgery residents and fellows. This Surgical Abdominal Wall (SAW) model (patent pending) invented by Park and colleagues is in continuing development and research phases at the University of Maryland (UM) Medical Center.

## Model Description

The primary configuration for which this simulator has been developed is the training of surgical residents, fellows, and practicing surgeons to perform LVHR in total or in part. Its use allows learners to comprehend normal anatomic relationships, recognize the sequence of LVHR procedural steps, and practice mesh sizing and fixation techniques. The model is made from low-cost, readily available materials and is easy to assemble, and many of the consumable materials may be used repeatedly before replacement.

### *Components*

The simulator consists of 5 primary components.

*Box*. There are variants of the SAW model that can be fitted to a variety of trainer boxes (Figure 1). In our pilot

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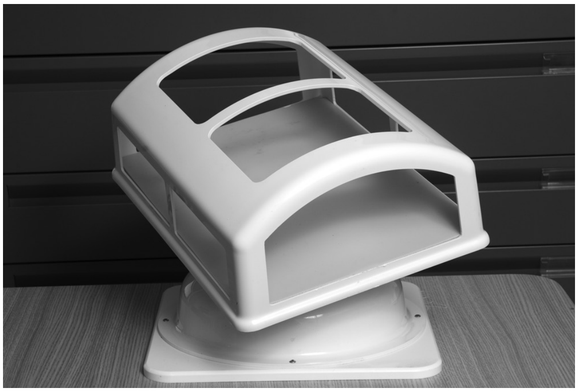

**Figure 1.** The trainer box from Stryker Endoscopy can be tilted in different axes; it possesses 2 working spaces, each measuring 18 × 20 cm$^2$

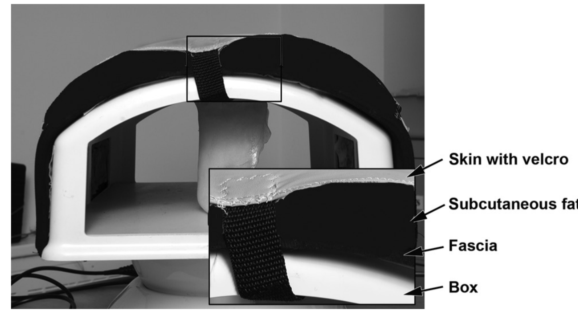


**Figure 2.** The surgical abdominal wall (SAW) model covers 3 sides of the box (left, top, and right); note that the SAW model is affixed to the box with a series of Velcro straps

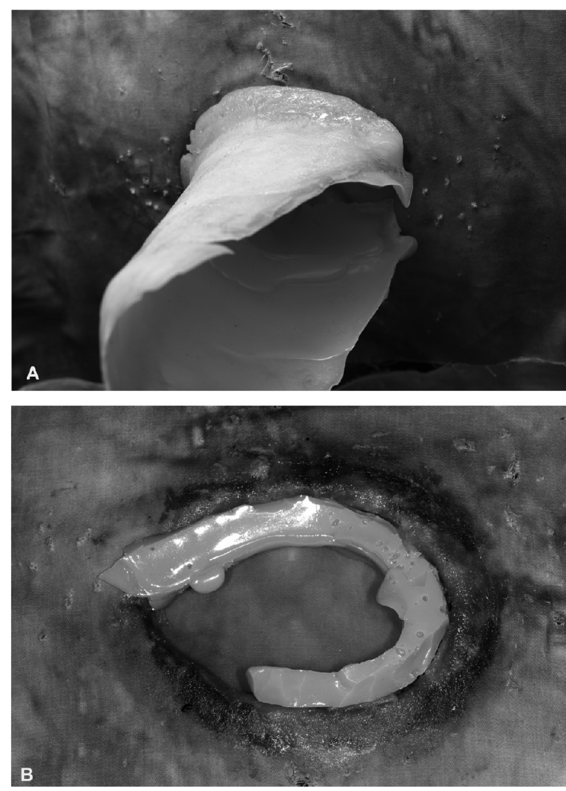


**Figure 3.** Inside the laparoscopic ventral hernia repair simulator: A. an adhesion can be seen attached to the hernia defect; B. a closer view of the hernia defect after adhesiolysis

uses, we fitted the SAW to a Stryker Endoscopy Park Trainer Box (San Jose, CA). The Stryker trainer box was chosen because of a number of characteristics, which include but are not limited to its relative approximation to the human abdominal shape and volume, its capacity to be rotated and tilted, its ability to allow rapid setup and deconstruction of the simulation materials, and to a lesser extent, its inherent capability to mimic a slight degree of insufflation. Another notable feature, largely otherwise unavailable, is that the equivalent of cephalad or caudad openings allow both learner and instructor to directly visualize the abdomen, acquiring an internal view beyond that available through the laparoscope.

*Skin and simulated abdominal layers*. The top of the box is opaque and is covered by layers of reusable materials (Figure 2). Key layers simulated from superficial to deep include skin, fatty tissue, and musculature and fascia. There is also a dual-sided imaging layer to simulate views of the peritoneum. The simulated skin is affixed to the trainer box with Velcro straps. The simulated fatty layer's coverage is limited to the anterior aspect and is modeled as a reproduction of subcutaneous fat. The thickness of this layer can be changed to simulate obesity and to allow variable difficulty in delineating the hernia defects for measurement. Musculature and fascia have been simulated by a black-colored layer, strategically placed over the top and lateral sides of the trainer box. To most closely approximate what is done in a live procedure, our model allows trocars to be placed contralateral to the simulated defect through the lateral sides of the trainer box. The SAW model embodies in its deepest layer a peritoneal surface that is photorealistic on both its superficial and deep sides.

*Defects*. In the case of our pilot research, 2 hernia defects (Figure 3) have been configured. Each was formed by holes in both the fascia and the subcutaneous fat layers. Each defect was modeled to approximately 5 cm in diameter to allow mesh to be placed with overlap of up to 3 cm. The shape of each defect was asymmetrical, requiring the learner to measure it intracorporeally in 2 axes and challenging the learner to orient the mesh appropriately. Each assembly of the simulation allowed 2 repairs to be performed. The reinforcing plastic bar across the middle of the lateral and anterior surfaces (Figure 1) of the trainer

**Table 1.** List of Materials and Instruments for LVHR Simulation

| Item | Quantity |
|---|---|
| Hemostat | 4 |
| Monofilament suture (2-0) | 6 |
| Suture passer | 1 |
| Suture scissors | 1 |
| Curved 5-mm laparoscopic dissector | 2 |
| Curved 5-mm laparoscopic scissors | 1 |
| Trocar (5 mm) | 2 |
| Trocar (12 mm) | 1 |
| Blade # 11 | 1 |
| Mesh | 1 |
| Tacker (minimum 4 tacks for each procedure) | 1 |
| Adhesion | 1 |
| Skin | 1 |
| Transparent adhesive drape (optional) | 1 |
| Erasable marker | 1 |
| Ruler | 1 |
| Umbilical tape | 1 |
| Spinal needle (optional) | 1 |

Abbreviation: LVHR, laparoscopic ventral hernia repair.

box allowed for 2 distinct working areas of $18 \times 20$ cm$^2$, each configured with a defect. This particular trainer stand feature—in conjunction with the SAW model in which each distinct working area contained a defect—facilitated the performance of 2 separate simulated herniorrhaphies.

*Adhesions*. These have been constructed of a tissue-like plastic that fits onto the edge of the hernia defect via a notched groove in the adhesion (Figure 3). The adhesion is a replicable component of the model. Such simulation is useful for teaching the concept of adhesiolysis and for encouraging division of the adhesion as close to the hernia as possible. Adhesions currently in development include blood vessels and bowel.

*Mesh*. Actual or simulated mesh may be used. A version of a double-layer mesh that simulates both smooth and adhesiogenic surfaces can be made inexpensively of polyester and crinoline net fabric attached together with a fabric adhesive sheet. Commercial mesh products vary considerably in texture and handling, and no single mesh serves all purposes.

## Instruments and Equipment Required

Instruments and supplies necessary for the LVHR simulation discussed herein are listed in Table 1. The required optical system uses a laparoscope (30° or 45° scope is preferable), light source, and cable, with a camera box and monitor.

## Simulation Capabilities

The UM SAW model was envisioned to be configured to meet the needs of various abdominal wall procedures. Those procedures could include open herniorrhaphy, adhesiolysis, and scope navigation training. Our pilot studies focused on LVHR and the steps described below, in particular, each of which comprises a skill within itself.

*Trocar placement*. The simulated abdominal space allows the placement of trocars in a variety of positions relative to the patient and relative to the hernia defect. Allowing the learner to choose placement provides training in decision making and highlights the effects of proper trocar location for good visualization of the defect and access to the relevant anatomy. This simulation emphasizes the proper location of the trocars more than it emphasizes the manual-technical aspects of trocar insertion because the configuration of the SAW model and training box typically promotes placement of trocars in the single-layer lateral sides.

*Adhesiolysis*. The simulated adhesions have been produced with realism that provides learners with the opportunities to perform deliberate adhesiolysis at the lip of the hernia defect.

*Defect assessment*. The appearance and assessment of defect characteristics as they might present in actual surgical cases are possible with this model. Instrument shaft size demarcations, physical rulers, and transabdominal placement of "sounding" needles can all be deployed for defect assessment in this LVHR simulation in the same manner as in a human or animal model. This model provides realistic feel in relation to defect palpation while allowing laparoscopic inspection of the abdominal wall. Defects can be discerned through transillumination, a feature that enhances the model's realism. Assessment of the defect and the hernia sac may be undertaken independently. The lip of the simulated defect and the hernia sac can be misaligned as sometimes occurs in actual patients. Also, the hernia sac between the fascia and skin can be set up to have varying degrees of overlap with the fascial defect.

*Mesh insertion, orientation, and fixation*. By allowing the use of actual trocars and instrumentation, this simulation model provides realistic and relevant practice in the introduction of mesh into the abdomen as well as subsequent orientation of the mesh for efficient and appropriate fixation. Mesh fixation is accomplished with any of the currently available tacking and suturing techniques.

## Simulation Curriculum

The following components of training were part of our LVHR simulation development phase and pilot research. Potential methods and goals for each step are also described as means by which to achieve educational objectives.

*Orientation*. Prior to performing simulator exercises, trainees were provided with an overview of the procedure and other pertinent content, which included a brief orientation to the simulator, the surgical instruments, and the

**Table 2.** Steps of the Simulated LVHR

| | |
|---|---|
| 1. | Placement of trocars |
| 2. | Survey of simulated abdomen |
| 3. | Deliberate adhesiolysis |
| 4. | Measuring defect size |
| 5. | Mesh sizing and preparation for repair |
| 6. | Mesh insertion, orientation, and fixation |

Abbreviation: LVHR, laparoscopic ventral hernia repair.

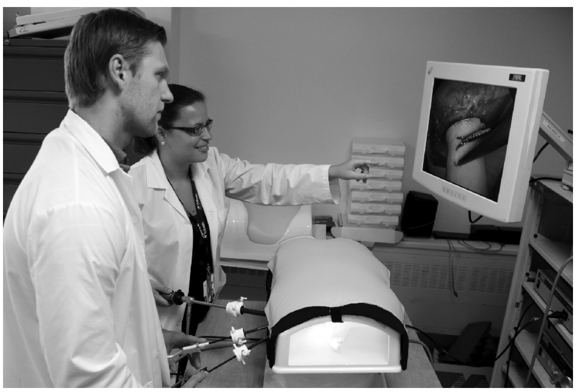

**Figure 4.** Note the 3 trocars in the lateral wall of the "abdomen" of the model; as in an actual procedure, the trocars have been placed contralateral to the defects, and the monitor is on the opposite side of the patient from the surgeons

materials. On occasion, presentation of this material was supplemented by a short video emphasizing the critical steps of an LVHR. The steps of the simulated operation are listed in Table 2.

*Placement of the trocars*. As detailed earlier, students can use either side of the box to insert the trocars (Figure 4). This capability is useful for demonstration and practice of correct trocar placement, achieved by proper distance from the defect, and for facilitation of optimized instrument/scope triangulation. After a trainee has placed at least 2 trocars into the lateral wall, he or she can then place into the simulator a 30° angled scope with or without an optical trocar.

*Adhesiolysis*. For this task, learners are asked to deliberately and sharply dissect the adhesions as closely as possible to the abdominal wall with curved laparoscopic scissors. Electrocautery is not required for this task.

*Measuring defect size*. As the layer representing the subcutaneous fat was approximately 2.5 cm in thickness, accurate measurement of the hernia defect was difficult by simple palpation. Learners could practice correct hernia defect sizing through the use of a long needle (such as a spinal needle) to delineate the margins of the defect and an umbilical tape or ruler for intracorporeal measurements.

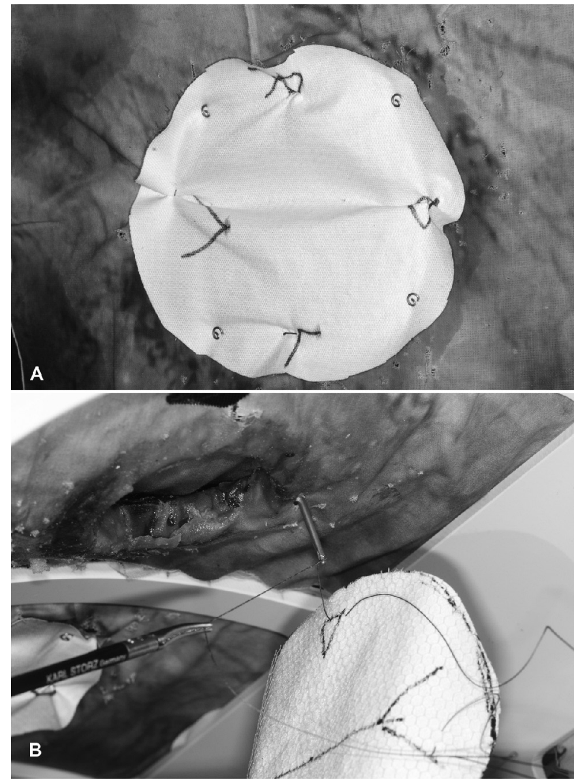


**Figure 5.** The hernia repair: A. view of the repair inside the simulator; B. fixation of the mesh with the sutures and suture passer

*Mesh sizing and preparation for repair*. Once the defect was marked, the learner was required to cut the mesh to an appropriate size for it to overlap the defect on all sides. Learners were instructed that the current clinical practice standard is a minimum 5-cm overlap. However, as this simulator was configured, only a 3-cm overlap could be achieved. The learner was instructed to then lay the mesh on the box in the position that corresponded to the desired fixation points. The placement of the transfixion stitches was to be marked appropriately on the skin and labeled on the mesh. A 2-0 monofilament suture was placed in each quadrant of the mesh, and appropriate length was left at both ends of each suture. Learners then oriented the appropriate side up (toward the abdominal wall), rolled it, and introduced it into the simulator through a 10-mm trocar.

*Fixation of the mesh*. After the mesh was introduced into the simulator, it was unrolled and appropriately oriented with previously placed corner sutures that faced the peritoneal surface of the model (Figure 5). A suture passer was inserted to grasp one tail of an anchoring suture and pull it out through the abdominal wall, and it was then

**Table 3.** Reported Confidence Before and After Simulator Use, on a Scale of 1 (*Not Comfortable*) to 5 (*Very Comfortable*) for 8 Components

| | Presimulation | Postsimulation | Improvement | Significance |
|---|---|---|---|---|
| Adhesiolysis | 4.18 | 4.31 | 0.13 | NS |
| Measurement of defect | 3.69 | 4.34 | 0.65 | $P < .001$ |
| Sizing of mesh | 3.64 | 4.34 | 0.70 | $P < .001$ |
| Fixation | 3.94 | 4.41 | 0.47 | $P < .001$ |
| Using transfascial sutures | 3.96 | 4.43 | 0.47 | $P < .001$ |
| Using suture passer | 3.95 | 4.46 | 0.51 | $P < .001$ |
| Using spinal needle | 2.49 | 3.6 | 1.11 | $P < .001$ |
| Using tacker | 4.07 | 4.43 | 0.36 | $P < .005$ |

reintroduced through the incision at a slightly different angle to pull out the second tail. (Suture passing could also be done using a spinal-needle technique.) Suture passing was completed for each of the 4 anchoring sutures. The corner sutures were held untied, with hemostats, until satisfactory positioning was confirmed. The sutures were then tied, anchoring the mesh to the simulated abdominal wall. One or more tacks were placed between each suture. Trainees were instructed to use a 2-handed technique, with one hand applying external counterpressure to the abdominal wall perpendicularly to the axis of the tacker. A suture passer was used to occasionally place additional transfascial sutures through the mesh.

## *Deployment and Acceptance*

Various features of this model make it applicable to a wide variety of learners. It has been deployed in pilot research at 3 national training meetings comprising approximately 240 advanced [minimally invasive surgery (MIS)] fellows, used over a 2-year period to train 120 residents in LVHR at UM, and used to train nonclinical industry representatives in the basic techniques of hernia repair.

A driving force informing the development of SAW was the limited options available for LVHR training: traditionally either porcine or human models are used. At UM, the SAW model allows residents to refine their techniques in a low-stakes environment. The expense differential is noteworthy. Excluding fixed costs such as durable, expendable goods, hardware, and one-time costs and resources common to both methods, the following typify approximate costs as incurred at UM for a 1-day, 8-hour training session: $3700 for 7 porcine models (requiring 48 hours prior housing) compared with $360 for 7 UM LVHR simulators. Estimated costs for such a course sponsored by industry can exceed $30 000.

Surveys of MIS fellows learning advanced hernia repair during a national conference in 2008 (n = 76) and in 2009 (n = 82) provide initial utility of the model in addition to other data. Asked to identify the means (mechanical, virtual reality [VR], animal, human) by which they had acquired the majority of their experience with 1 (*none*), 2 (*1 to 5*), 3 (*6 to 10*), and 4 (>*10*), fellows in both years indicated that the human model had been their primary source (3.65 in 2009, 1.84 in 2008). The respondents for the year 2009 indicated that VR was used the least to gain such experience (1.20), whereas those in 2008 used animal models least (0.95). When asked, however, to identify the means which they would prefer to train, the fellows from the year 2009 favored VR and mechanical models (3.46, 3.16) to animal or human models (1.99, 1.76), choices that mirrored those identified in 2008 (3.46 VR, 3.16 mechanical, 2.2 animal, 2.0 human). Subjective indications of comfort with the procedure before and after simulation training provided validation of the model's acceptance as an effective training modality. In the 2009 pretraining and posttraining survey, participants reported their comfort level on a Likert scale of 1 (*not comfortable*) to 5 (*very comfortable*) for 8 component steps involved in the hernia repair procedure (Table 3). The same respondents also reported their overall impression of the SAW simulator on a scale of 1 (*this simulation much worse than other training*) to 5 (*this simulation much better than other training*). All 8 of the steps in the LVHR training showed increases in confidence following simulated practice, with 7 of the 8 showing statistically significant increase (Table 3). All ratings noted after training averaged between *comfortable* and *very comfortable*. The exception was the technique of using a spinal needle as a suture passer, which resulted in the highest gains in confidence (1.11 points increase). The adhesiolysis skill, which did not show significant improvement, had shown the highest presimulation confidence ratings (4.18 rating pretraining). The average subjective rating of the relative merit of the SAW model by the fellows was 4.23. Of the participants from the 2009 survey, only 2 fellows felt that using the model was not equal to or better than other training modalities.

## Discussion

The UM SAW is an inexpensive model that replicates the entire LVHR procedure. The physical standardization assured by this simulator is not easily replicable with either porcine or human models. We have demonstrated initial utility and validation of the model's acceptance by advanced trainees (MIS fellows) through subjective ratings of the model. The model showed high levels of acceptance, and its use increased the learners' confidence in their abilities to perform the procedure independently. Validation for objective measures of performance is under way, and this current research undertakes to couple our simulation model with a modified version of the validated Global Operative Assessment of Laparoscopic Skills (GOALS) rating instrument.[6] Assessment metrics that are currently being validated are another of this simulator's features, one that allows it to meet the standards for level III verification of learning (verification of knowledge and skills) as put forth by the American College of Surgeons Division of Education.[7]

What we have constructed meets several desired simulation model attributes. SAW is inexpensive, readily available, and portable. The procedural steps are reproduced with high fidelity, and during initial trials, the simulator engaged the interest of surgical residents, fellows, and expert surgeons. With the development of reliable and valid metrics, it may be possible to establish levels for proficiency-based training.

Ventral hernia repair is a common abdominal surgical procedure, and use of the laparoscopic approach is evolving as the standard of care. Valid concerns about the learning curve and advanced skills needed for this procedure have led to a steady but slow procedure adoption rate.[8,9] Surgical experience in ventral hernia procedures is considered to be of great importance[10] in achieving good outcomes, and the recurrence rate is predictably affected by experience as well.[11]

Currently available VR simulators have gained in popularity.[12] One, the LAP Mentor (Simbionix USA Corp, Cleveland, OH), has a number of procedure-specific modules, including one for ventral hernia repair, but typically, VR simulators do not replicate all the procedural maneuvers required for LVHR, such as sizing and mesh insertion as well as the indispensable step of suture fixation. They similarly do not always provide training in essential skills. A case in point is the inability of this Simbionix simulator to simulate the bimanual requirements of counterpressure necessary when tacking mesh in place. Additionally, validation data for the Simbionix ventral hernia simulation has yet to be published.

Many high-fidelity simulators and sophisticated VR simulators are available to teach surgical skills and various procedures. Live animal and fresh human cadaver models, considered to be "high fidelity," are resources limited by availability, cost, potential for transmission of infectious disease, and ethical concerns.[13]

We have described here a valuable educational simulation packaged as the SAW model and using a mechanical trainer box configured for LVHR. Adding procedure-specific simulation onto a foundation of fundamental technical skills appears to result in an effective model for teaching surgical operations. Future addition of reliable and valid metrics applied to assessment of the simulator and then correlated to evaluation of performance in the operating room will considerably further surgical educators' investigations into the efficiency of this training approach and its transfer.

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