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ORIGINAL ARTICLE

Percutaneous pelvic fixation model: an affordable and realistic simulator for pelvic trauma training

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Abstract

Purpose To describe the construction and use of a percutaneous pelvic fixation model, evaluate its translational validity among fellowship-trained orthopedic trauma surgeons, and investigate the importance of specific criteria for effective competency-based assessment of pelvic fixation techniques.

Methods Five orthopedic trauma surgeons were asked to place percutaneous wires on a pelvic fixation model, including anterior column (antegrade/retrograde), posterior column (antegrade/retrograde), supra-acetabular, transsacral, and iliosacral. Evaluation criteria included successful wire placement, redirections, cortical breaches, procedure duration, radiation exposure, and quality of fluoroscopic views. Following completion, participants were provided a survey to rate the model.

Results There were no differences between approaches on successful screw placement, wire redirections, or fluoroscopic quality. Antegrade approaches to the anterior and posterior columns took longer ($p = 0.008$) and used more radiation ($p = 0.02$). There was also a trend toward more cortical breaches with the antegrade anterior column approach ($p = 0.07$). Median ratings among surgeons were 4 out of 5 for their overall impression and its accuracy in tactile response, positioning constraints, and fluoroscopic projections. Learning parameters considered most important to the progression of trainees (most to least important) were successful screw placement, corridor breaches, wire redirections, quality of fluoroscopic views, radiation exposure, and procedure duration.

Conclusion In being affordable, accessible, and realistic, this percutaneous pelvic fixation model represents an opportunity to advance orthopedic surgery education globally. Future research is needed to validate the findings of this pilot study and to expand upon how trainees should be evaluated within simulations and the operating room to optimize skill progression.

Keywords Percutaneous pelvic fixation surgery training model · Percutaneous pelvic ring surgery training · Pelvic ring wire placement · Percutaneous approaches · Anterior column · Posterior column · Antegrade · Retrograde · Ramus screw · Supra-acetabular · Transiliac transsacral · Iliosacral · Surgical model · Affordable · Realistic · Surgical education · Surgical evaluation

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Introduction

Pelvic ring injuries have been increasing in incidence across the world over the last 20–30 years, accounting for 34.3 per 100,000 patients in the USA in 2007 [1–3]. With expanding human lifespans, these rates have risen particularly in more elderly populations[1–3]. Since the earliest studies and descriptions on percutaneous techniques, improvements in our understanding of these injuries and operative techniques over time have translated into improved outcomes and survival, with increasing rates of internal fixation being associated with improved odds of mortality from these injuries [1, 4, 5]. However, acquiring


(A)
(B)
(C)
(D)
(E)
(F)
(G)
(H)
(i)
OEC

◂**Fig. 1** Assembly of the percutaneous pelvic fixation model. **A** Main supplies utilized in model build. **B** A bisecting midpoint toward the caudal edge of the plywood sheet is marked and drilled. **C** A pilot hole is drilled into the midline of the posterior sacrum, and this is then fixated to the plywood by a simple wood screw. **D** Further fixation is applied through the plywood and into the bilateral posterior inferior iliac spines (PIIS) of the sawbones model with pre-drilling and screw placement. **E** The yoga mat is placed underneath the sawbones model/plywood construct, lining up the end of the mat with the edge of the cranial aspect of the plywood. **F** Staples and/or duct tape are used to apply the mat to the model. **G** The mat can be trimmed to allow some overlap and is then stapled or taped to the plywood through the other end of the yoga mat. **H** The lateral aspects of the yoga mat are pulled taut with tension, and the sides are tucked and stapled/taped, producing the final model. **I** The exercises are performed in an operating room with the model placed on a radiolucent table and with the use of a fluoroscopy machine

the skills and "surgical art" of pelvic and acetabular orthopedic surgery is a lifelong challenge. The surgeon must develop expertise in surgical approaches around critical anatomic structures, reduction of bony fragments using strategic clamp placement, and proper placement of internal fixation—all of which require knowledge of safe bony corridors, control of power instruments, ability to modify vectors of drills/wires, recognition of improper placement/impending breach, sensitivity to proprioceptive feedback, and an understanding of how to obtain and utilize specific fluoroscopic views in real time for each pelvic approach utilized in practice [6–9].

Increasingly, learners face a squeeze between the need for high-quality, specialized training and limitations to work-hours, operating room time, and resource management—all of which have been further heightened in the setting of a pandemic that saw significant interruptions to orthopedic training [10–12]. From an international perspective, these concerns are particularly compounded in resource-constrained regions where access to cadavers, expensive models, and specialized fellowship training can be especially difficult [13]. Pelvic and acetabular management is one difficult area of orthopedic training given its spatial complexity and relatively concentrated volumes at major trauma centers. With low cumulative volumes in training and practice, operative proficiency in the management of pelvic and acetabular injuries is challenging to develop and maintain.

The percutaneous pelvic fixation model described in this paper is a realistic, inexpensive, and novel modality that enables surgeons around the world to practice and progress their technical skills and knowledge of this complex anatomic area within a risk-free setting—enabling surgeons-in-training and early-career attendings to gain the repetitions and experience needed to combat the challenges of modern training. The purpose of this technique paper is to describe the construction and use of the percutaneous pelvic fixation model, evaluate its translational validity among a sample of fellowship-trained orthopedic trauma surgeons, and investigate the importance of specific objective criteria for effective competency-based assessment of pelvic fixation techniques.

Technique

The percutaneous pelvic fixation model is made with inexpensive materials universally available across the world, including the following (Fig. 1a):

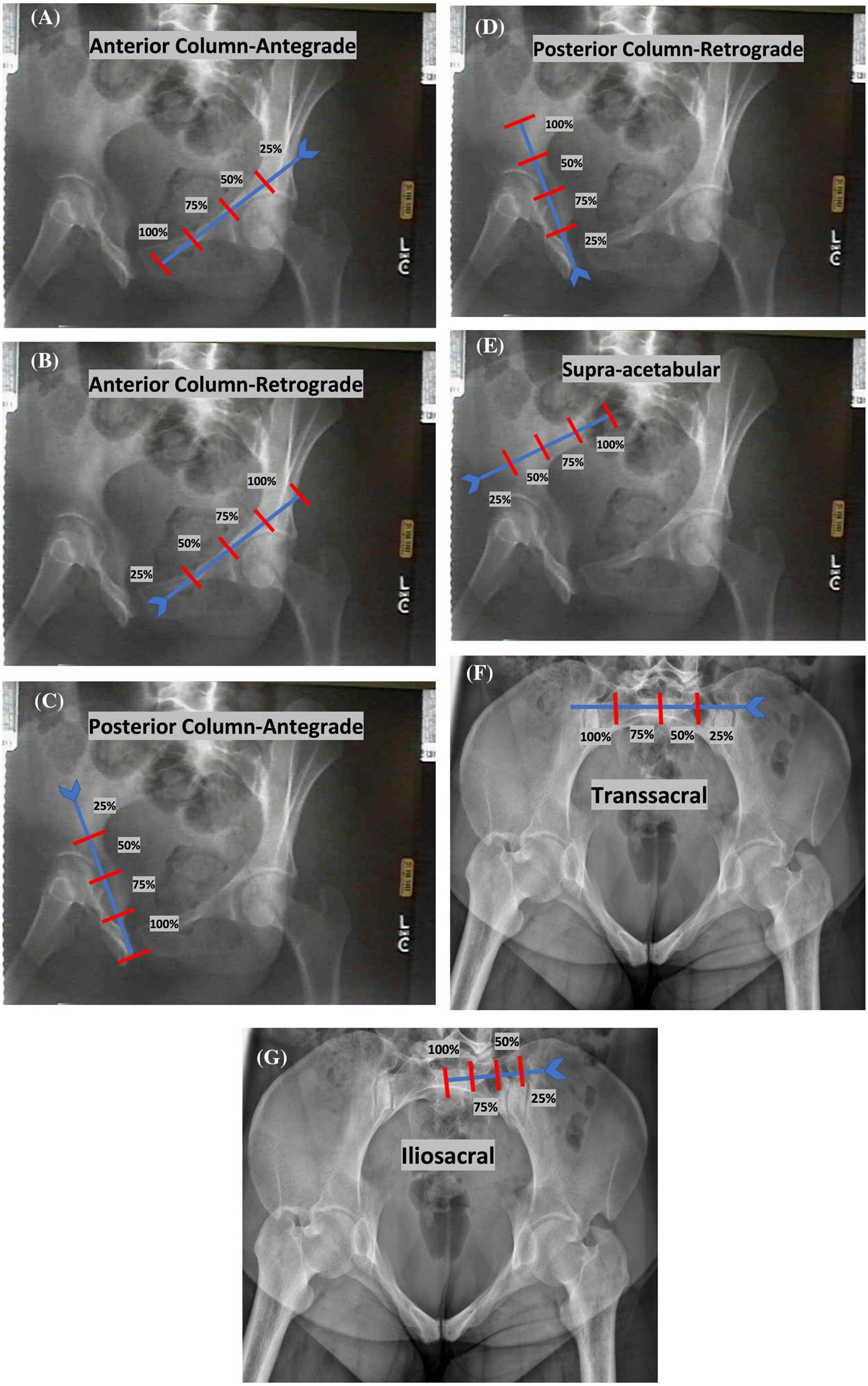
Supplies:

- Sawbones pelvis model (Vashon Island, WA)
- 1 cm thick yoga mat
- 35 × 26 × 1 cm plywood sheet
- Fixation materials (drill, wood screws (#10 × 3.2 cm), stapler/splint tape)

First, a bisecting midpoint toward the caudal edge of the plywood sheet is marked and drilled (Fig. 1b). This location is chosen to enable placement of all percutaneous wires, particularly the antegrade anterior column and retrograde posterior column wires, which are made difficult-to-impossible to place when the lateral and caudal borders of the plywood prevent the surgeon from dropping their hand sufficiently for proper placement inside the corresponding bony corridors. A pilot hole is drilled into the midline of the posterior sacrum, and this is then fixated to the plywood by a simple wood screw (Fig. 1c). To provide additional stabilization of the model, fixation is applied through the plywood and into the bilateral posterior inferior iliac spines (PIIS) of the sawbones model with pre-drilling and screw placement (Fig. 1d).

Next, the yoga mat is placed underneath the sawbones model/plywood construct, lining up the end of the mat with the edge of the cranial aspect of the plywood. Staples and/or duct tape are used to apply the mat to the model (Fig. 1e, f). After adequate fixation is obtained, the mat is wrapped around the model to completely encompass it. The mat can be trimmed to allow some overlap and is then stapled or taped to the plywood through the other end of the yoga mat (Fig. 1g). Finally, the lateral aspects of the yoga mat are pulled taut with tension, and the sides are tucked and stapled/taped (Fig. 1h). A 1 cm thick yoga mat was chosen because it was found to provide the most realistic soft-tissue tactile response. This entire build process is sequentially demonstrated in Video, Supplementary Digital Content 1.

In evaluating the model among fellowship-trained trauma faculty and a trauma fellow, each surgeon was asked to place various wires safely and accurately, including anterior column (antegrade and retrograde), posterior column (antegrade and retrograde), supra-acetabular, transsacral, and iliosacral wires. The wire used


(A)
Anterior Column-Antegrade
25%
50%
75%
100%
(D)
Posterior Column-Retrograde
100%
50%
75%
25%
(B)
Anterior Column-Retrograde
100%
75%
50%
25%
(E)
Supra-acetabular
100%
75%
50%
25%
(C)
Posterior Column-Antegrade
25%
50%
75%
100%
(F)
100%
75%
50%
25%
Transsacral
(G)
100%
50%
75%
25%
Iliosacral

◂**Fig. 2** Criteria for successful wire/screw placement for each percutaneous screw approach based on percent of passage (0–25-50–75-100%). **A** Anterior column, antegrade, **B** Anterior column, retrograde, **C** Posterior column, antegrade, **D** Posterior column, retrograde, **E** Supra-acetabular, **F** Transsacral, **G** Iliosacral

was a 2.8-mm drill tip guide wire. The exercises were performed in an operating room with the model placed on a radiolucent table and with the use of a fluoroscopy machine (Fig. 1i). An X-ray technologist well-versed with the views most frequently used in pelvic and acetabular fracture surgery maneuvered the image intensifier. Participating surgeons were briefed before the exercise on evaluation criteria including successful wire placement (0–25–50–75–100% of the total length of the bony corridor, Fig. 2), wire redirections (n = number of times that the wire had to be entirely withdrawn and repositioned), cortical breaches (n = number of times that the wire penetrated outside of the safe bony corridor), procedure duration (min), radiation exposure (mGy), and quality of fluoroscopic views (1: poor, 2: fair, 3: good, 4: excellent). Example videos utilizing the percutaneous pelvic fixation model with descriptions of the technique for each approach can be found in Video, Supplemental Digital Content 2–5.

Following completion of the exercise, participants were provided a survey to rate the model (1–5 scale, 1 being lowest accuracy and 5 being highest accuracy) on their overall impression, its tactile response, positioning constraints, and fluoroscopic projections. Finally, participants were asked to rank learning parameters in order of importance based on what they believed would be most valuable to assess the surgical progression of trainees. Criteria included all the parameters used for evaluation, including successful wire placement, wire redirections, corridor breaches, procedure duration, radiation exposure, and quality of fluoroscopic views.

Statistics were performed in a standardized manner [14]. The Shapiro–Wilk W test determined normality of continuous data. All nonparametric continuous data is presented with the median and interquartile range (IQR), comparisons between percutaneous approaches were made using the Kruskal–Wallis test, and post hoc Wilcoxon rank sum tests were performed for individual comparisons between groups with the Hodges-Lehmann estimator calculating the median difference, 95% confidence interval (CI), and p value. All parametric continuous data are presented with mean and CI, comparisons between approaches were made using one-way ANOVA (analysis of variance), and post hoc student's t tests were performed for comparisons between groups with reporting of mean difference, CI, and p value. P values less than 0.05 were considered significant. JMP Pro version 16 statistical software (SAS; Cary, NC) was used for all analyses.

Case series

Five fellowship-trained orthopedic trauma surgeons participated in the percutaneous pelvic fixation model exercise. Their results were separated by percutaneous approach and are presented in Table 1. Briefly, there were no differences between approaches on successful screw placement, wire redirections, or fluoroscopic quality. There were differences, however, in procedure duration and radiation exposure, with the antegrade approaches to the anterior and posterior column taking significantly longer ($p = 0.008$) and using more grays of radiation ($p = 0.02$). There was also a trend toward a higher number of cortical breaches with the antegrade anterior column approach ($p = 0.07$). Specific post hoc analyses for significant results are presented in the description of Table 1.

Following the exercise, the median ratings among all surgeons were 4 out of 5 for their overall impression (IQR: 4 to 5) and its accuracy in tactile response (IQR: 3.5–4), positioning constraints (IQR: 4–5), and fluoroscopic projections (IQR: 4–5) (Table 2). The learning parameters considered most important to the progression of trainees, from most to least important, were successful screw placement, corridor breaches, wire redirections, quality of fluoroscopic views, radiation exposure, and procedure duration.

Discussion

This percutaneous pelvic fixation model is a realistic, inexpensive, and novel modality that enables surgeons around the world to practice and progress their technical skills and knowledge of one of the most complex anatomic areas in orthopedics. Pilot testing among fellowship-trained trauma surgeons demonstrated high model accuracy and provides a framework by which trainees can be evaluated and have their progress measured in future. In this first cohort, the antegrade approaches to the anterior and posterior columns were found to more time-intensive and require more radiation from fluoroscopy, implicating a potentially increased difficulty for these particular approaches.

To our knowledge, Riehl and Widmaier [15] is the only study to date to describe a percutaneous pelvis model, focusing on the placement of iliosacral screws. To setup their model, they used vise grip pliers from a hardware store for model fixation/stabilization and a cardboard box lined with pink patient positioning pads to blind participants during wire placement. While possessing many parallels to the present model, this setup is arguably more difficult to construct and utilizes materials that may compromise realistic tactile feedback (such as a cardboard

Table 1 Performance results by percutaneous approach

	AC (antegrade)	AC (retrograde)	PC (antegrade)	PC (retrograde)	Supra-acetabular/LC2	TITS	IS	*p* Value
Successful screw placement (%)	100 (100 to 100)	100 (100 to 100)	100 (88 to 100)	100 (100 to 100)	100 (100 to 100)	100 (100 to 100)	100 (100 to 100)	0.42
Wire redirections (n)	1 (0 to 2)	0 (0 to 1.5)	0 (0 to 0.5)	0 (0 to 2)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0.5)	0.27
Cortical breaches (n)	1 (0 to 2)	0 (0 to 1)	0 (0 to 0)	0 (0 to 0.5)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0.07
Duration$^{\phi}$ (minutes)	6.1 (3.5 to 8.7)	3.9 (2.1 to 5.7)	5.5 (3.1 to 8.0)	3.4 (2.2 to 4.6)	2.7 (0.1 to 5.2)	3.4 (0.9 to 5.9)	2.0 (0.6 to 3.3)	**0.008***
Radiation exposure$^{\phi}$ (mGy)	0.28 (0.20 to 0.36)	0.16 (0.07 to 0.24)	0.26 (0.18 to 0.35)	0.18 (0.11 to 0.25)	0.16 (0.05 to 0.26)	0.21 (0.08 to 0.34)	0.14 (0.09 to 0.20)	**0.02****
Fluoroscopic quality (1–4)	4 (4 to 4)	4 (4 to 4)	4 (4 to 4)	4 (4 to 4)	4 (4 to 4)	4 (4 to 4)	4 (4 to 4)	1.00

AC anterior column, *CI* 95% confidence interval, *IS* iliosacral, *LC2* lateral compression type 2, *MD* mean difference, *PC* posterior column, *TITS* transiliac transsacral

Nonparametric data presented as median (IQR)

$^{\phi}$Parametric data presented as mean (95% confidence interval)

*Post hoc analysis revealed significant differences in minutes of duration between AC antegrade and IS (MD: 4.1, CI 1.9–6.4, $p=0.0007$), supra-acetabular/LC2 (MD: 3.5, CI 1.2–5.7, $p=0.004$), PC retrograde (MD: 2.7, CI 0.5–5.0, $p=0.02$), and TITS (MD: 2.7, CI 0.5–4.9, $p=0.02$); and PC antegrade and IS (MD: 3.6, CI 1.3–5.8, $p=0.003$), supra-acetabular/LC2 (MD: 2.9, CI 0.6–5.1, $p=0.01$)

**Post hoc analysis revealed significant differences in radiation exposure (mGy) between AC antegrade and IS (MD: 0.14, CI 0.05–0.23, $p=0.005$), AC regtrograde (MD: 0.13, CI 0.03–0.22, $p=0.01$), supra-acetabular/LC2 (MD: 0.13, CI 0.03–0.22, $p=0.01$), and PC retrograde (MD: 0.10, CI 0.01–0.20, $p=0.03$); and PC antegrade and IS (MD: 0.12, CI 0.03–0.21, $p=0.01$), AC retrograde (MD: 0.11, CI 0.01–0.20, $p=0.03$), supra-acetabular/LC2 (MD: 0.11, CI 0.01–0.20, $p=0.03$)

Table 2 Post-exercise survey results

	Median (IQR)
Overall impression	4 (4 to 5)
Tactile response	4 (3.5 to 4)
Positioning constraints	4 (4 to 5)
Fluoroscopic projections	4 (4 to 5)
Importance of learning parameters	
Successful screw placement	1 (1 to 1)
Corridor breaches	2 (2 to 3.5)
Wire redirections	3 (2.5 to 3)
Quality of fluoroscopic views	4 (4 to 5)
Radiation exposure	5 (5 to 5.5)
Procedure duration	6 (3.5 to 6)

IQR interquartile range

Ratings from 1 to 5 (1 representing lowest accuracy, 5 representing highest accuracy)

Importance ratings in order of perceived importance from 1 to 6 (1 representing most important, 6 representing least important)

box). The novel percutaneous pelvic fixation model described in this technique guide specifically focuses on situating a trainee in a scenario as close to reality as possible while being readily accessible regardless of resource constraints. These goals were achieved with attendings rating the overall model and its tactile feedback highly despite its affordable and accessible construction.

Surgical training has predominantly relied upon an apprenticeship model to teach trainees [10, 16, 17]. While this paradigm has successfully trained generations of surgeons to effectively care for patients, it has significant limitations in the present day with increasingly specialized practices and trainees running into barriers obtaining a large enough volume of cases to feel comfortable practicing independently in their chosen field [10–12, 18]. Fellowships are typically required to properly master skills of practice with more than 90% of orthopedic residents in the USA pursuing at least one year of additional training [19]. While unlikely to completely replace a training model that has stood the test of time and continues to produce excellent surgeons, simulators offer major benefits that confront these modern challenges by allowing trainees to develop their own volume with independent learning in a risk-free setting in a field where repetition matters [18].

Literature has overwhelmingly embraced the value of simulators across medicine, and orthopedics shares in this trend with over twenty new studies in the last 15 years alone investigating the utility and benefit of simulators in teaching specific procedural skills [10, 15–18, 20–31]. Unfortunately, the large amount of data generated is not standardized, and evaluation across studies varies dramatically [18, 23]. While most agree that training must shift to competency-based assessments that evaluate procedure-specific skills, the means by which this is to be achieved is unclear [16–18, 23, 28]. Some tools that have been studied to evaluate orthopedic surgical skills include the Global Index for Technical Skills (GRITS) tool and the Objective Structured Assessment of Technical Skill (OSATS) system. The GRITS tool is a validated general surgery evaluation tool that focuses on a 1–5 grading for various skills, including respect for tissue, time and motion, instrument handling/knowledge, flow of operation, knowledge of specific procedure, use of assistants, communication skills, depth perception, and bimanual dexterity [32]. Its study in orthopedics, however, remains limited [32]. The OSATS system was originally developed for obstetrics and gynecology training and is also graded on a 1–5 scale, including categories of flow of operation/forward planning, knowledge of specific procedure, time and motion, instrument handling, and knowledge of instruments [20, 29, 33]. While thought to be one of the more comprehensive measurement tools for trainee evaluation, its efficacy and clinical relevance have also had mixed reviews [20, 29, 33]. In moving forward, it is important that programs utilize a form of measurement that is objective, valid, reliable, feasible, cost-effective, and has significant educational impact [23]. Additionally, with the wide variety of procedures within the field, tools that are procedure-specific may have higher internal validity [28]. The grading system utilized in this study focused on objective criteria thought to be important in the passage of percutaneous pelvic wires, including percentage of successful placement, need for redirections, cortical breaches, duration of procedure, radiation exposure, and ability to obtain quality fluoroscopic images through communication with the radiographic technician. These were all discrete, measurable, and specific to the practice of pelvic wire placement. When tasked with rating the most important skills for trainees in development of this skill, our study sample placed greater weight on skills related to successful passage, minimization of complications, and ability to obtain quality fluoroscopic views. As with the GRITS and OSATS tools, however, the validity and applicability of these criteria in the development of safe pelvic surgery practices require further evaluation.

Simulators have taken on a new importance recently given the constraints brought out by the COVID-19 pandemic, which saw a reduction in case volumes and a mandatory transition to hybrid learning [21, 24–27, 34]. Asynchronous learning for surgical walkthroughs in this context was embraced by trainees with high satisfaction, with most orthopedic interns in a recent study by Bhashyam and Dyer finding a 'take-home' surgical simulator to have improved their orthopedic knowledge base, surgical skills, and overall preparation for the operating room [21]. While not a sole replacement, simulators and e-learning during the pandemic had their growth accelerated out of necessity and ultimately were found to enhance the trainee experience [24, 27].

Perhaps the most valuable aspect of the model is its simplicity and potential for international impact. Resource limitations throughout the world only compound the constraints of modern training discussed previously [13, 35, 36]. Authors across the world have written on the benefits of surgical simulators as a complementary modality to traditional global surgical education with potential for improving patient safety, reducing complications, and decreasing overall costs [35, 36]. Additionally, as in the USA, the pandemic likely made hybrid learning even more relevant throughout the world [34].

Nonetheless, there are challenges and limitations to simulators, which this model is undoubtedly susceptible to. First, the use of effective criteria to measure improvement varies widely across studies [17, 20, 21, 23, 26, 28, 29, 31–33]. Our study sought to determine what would be considered most meaningful to attending surgeons in terms of what trainees should focus on, however, this data is based on a small sample of surgeons at one institution. While the data collected did demonstrate significant trends in terms of varying difficulty with certain percutaneous approaches despite this sample size, the criteria chosen in this study requires validation in its ability to track the progress and point-in-time skills of trainees. Second, the ability for this model to translate into the clinical environment is unknown. While the surgeons sampled in this study found the model to be a realistic representation of the experience in the operating room, this aspect would also benefit from further study. Finally, the Sawbones model is limited by its inability to represent the wide variety of pelvis shapes and statures that the surgeon may encounter in practice.

In being affordable, accessible, and realistic, this percutaneous pelvic fixation model represents a significant opportunity to advance orthopedic surgery education globally. Future research is needed to validate the findings of this pilot study and to expand upon how trainees should be evaluated within simulations and the operating room to better optimize their skill progression and enable them to feel comfortable providing high-quality care despite the ever-increasing challenges of training.

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

Ethics approval Institutional Review Board approval was obtained prior to initiating this study.

Informed consent Informed consent was obtained from all participants.

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