



Research Article

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## Simulation in General Obstetrics and Gynecology

Oroma Nwanodi\*

### Abstract

Obstetrical simulation dates from the Paleolithic period. Gynecologic simulation has its origins in the 1920s Link box trainers. By improving maternal-fetal outcomes, obstetric simulation secures our existence. Improved maternal-fetal outcomes create a need for gynecologic surgery and simulation. Therefore, gynecologic simulation may be an afterthought that has yet to attain a validated place in medical education and professional practice. The objectives of this review article are to assess the scope of simulation in obstetrics and gynecology, identify simulation's strengths and weaknesses, review barriers to simulation growth in obstetrics and gynecology, and present a route forward.

Google scholar and Google Internet searches phrased "simulation obstetrics gynecology", performed on November 25, 2015 yielded 29 references from 2001 to 2015. PubMed search on December 19, 2015, terms "simulation obstetrics gynecology, found 12 relevant, non-redundant articles. Additional Google scholar hand search on December 20, 2015, and September 14, 2016 yielded 45 articles for timely topic completion.

Post-Halstedian apprenticeship based medical training guarantees an ever-increasing role of simulation in obstetrics and gynecology training. Patient safety, healthcare quality, and healthcare provider credentialing concerns assure the future of medical simulation. Given positive association with neonatal outcomes, medical student interest in obstetrics, and obstetrics team building, obstetrics simulation has proven itself. Gynecologic simulation needs to address fidelity, reliability, and validity concerns to secure an enduring position in gynecologic education and professional practice.

### Keywords

Cervical conization simulation; Laparoscopic box trainers; Medical student simulation; Obstetrics and gynecology simulation; Obstetric emergencies; Pelvic ultrasound simulation; Physician assistant simulation; Simulation; Virtual reality simulation

## Introduction

Globally, simulation is a part of health care workers' (HCWs) education, training, malpractice insurance provision, medical board certification, skill maintenance, performance assessment, clinical rehearsal, and human factors research [1-3]. Simulation may involve individual HCWs or groups thereof, challenging

\*Corresponding author: Oroma Nwanodi, MD, DHSc, Locum Tenens Obstetrician & Gynecologist, PO Box 59, Salinas, California 93902, USA, Tel: (314) 304-2946; E-mail: o.nwanodi@juno.com

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knowledge, associative technical and autonomous judgement decision-making skills, as well as attitudes and behaviors. Simulators may be high-fidelity virtual-reality software-based with computer screen displays and robotic mannequins (Figures 1 and 2) low-fidelity box trainers, or hybrids thereof [2-5]. A detailed history of modern simulation is provided in Table 1 [6].

Seventeenth century obstetric *phantom* simulators gave way to Madame du Coudray's, King Louis XV of Frances' midwife's instructional full-size bone, leather, and wicker mannequins, *the Machine* shown in Figure 3 [6]. Modern medical simulators evolved from Link trainer flight simulators, hand skill training tools, plastics, digital (instead of analog) computing, and the sequela of the Three Mile Island nuclear power plant accident in 1979 [2,5,7]. In the 1990's Eggert, Eggert, and Vallejo made Noelle, an electronic mannequin shown in Figure 1 [5]. Human cadaver imaging, completed in 1994 by the National Library of Medicine's

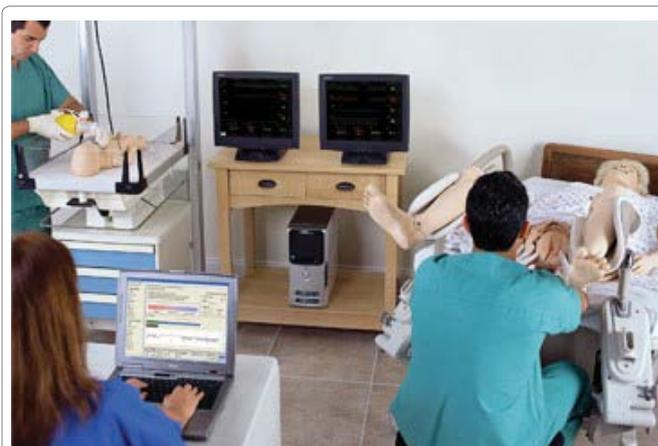


Figure 1: Noelle S575. Reproduced with permission from Gaumard Scientific.



Figure 2: LapSim virtual reality laparoscopic simulator. Haptic and non-haptic versions. Reproduced with permission from Surgical Science™.

**Table 1:** Simulator development timeline. Reproduced with the publishers' permission.

Date(s)	Event(s)	Reference(s) from Rosen, 2008
1928-1929	Edwin Link builds first blue box trainer in basement of father's Binghamton, NY, piano and organ factory.	[87]
1931	Link becomes full-time flight instructor. His school offers both trainer and actual flight time.	[87,88]
1934	United States (US) Army buys 6 Link trainers.	[87,88]
1938	US Military purchases 10000 Link trainers. First plastic skeleton made by founders of Medical Plastics Laboratory.	[87,88]
1941	Rocket flight simulator completed.	[89]
1957	First successful external defibrillation with Johns Hopkins' equipment. Bohumil Peleska (Prague) states that defibrillation is ineffective after 3 minutes. Combination of compression and electricity is optimal	[90-92]
1958	Laerdal begins research and development for mouth-to-mouth mannequin. United States (US) National Aeronautics and Space Administration (NASA) develops biotelemetry.	[90]
1960	Resusci Annie was born.	[93]
1960	William Kouwenhoven introduces closed-chest massage.	[94,95]
1961	First primitive use of computer-assisted learning in Medicine.	[96]
1963	Rescue vehicle equipped with coronary care equipment in Belfast, Ireland.	[94]
1963	Ivan Sutherland presents PhD thesis for manipulation of objects on a computer screen with a pointing device.	[97]
1964	GPE and NASA develop simulators for Gemini program. Howard Barrows introduces "Programmed Patient," providing first description of standardized patients (SPs) in medical education.	[97]
1965	California Governor Ronald Reagan authorizes paramedics to act as physician delegates. Direct current shock developed.	[90]
1967	First report of ventricular fibrillation resuscitation out of the hospital.	[98]
1968	AT&T designates 911 as national emergency telephone number.	[90]
1968	Cardiology Patient Simulator—Harvey—debuts from University of Miami.	[99]
1970's	Massachusetts General Hospital produces computerized clinical encounter simulations.	[96]
1972	National Library of Medicine provides sponsorship and free access to medical simulations from The Ohio State University, Massachusetts General Hospital, and University of Illinois.	[96]
1973	Cardiopulmonary resuscitation (CPR) introduced with instruction by the American Heart Association (AHA) and Red Cross. University of Wisconsin develops patient encounter simulation prototype as basis for future National Board of Medical Examiners (NBME) computerized examinations.	[95]
1974	First AHA guidelines published with support from Laerdal.	
1975	First description of Objective Structured Clinical Examination (OSCE).	[100]
1978	Singer-Link pioneers computer imaging with introduction of DIG digital image generator. N Ty Smith's group creates analog precursor to BodySim.	
1985	First Pediatric Advanced Life Support (PALS) course offered.	[98]
1985	University of Michigan publishes first catalog of patient simulations. Effectiveness of computer simulations in medical practice demonstrated.	[96]
1986	CASE developed as standard precursor of CAE-Link simulator. CD-ROM systems revolutionize medical information storage and retrieval.	[96]
1988	CAE purchases Link simulation divisions from Singer. CAE-Link patient simulator born in Palo Alto. Precursor to Medical Education Technologies, Inc. (METI) Human Patient Simulator (HPS) born in Gainesville, FL.	[88]
1990	Anesthesia Simulator Consultant program released (pre-Anesoft anesthesia simulator).	
1990-1991	Educational Commission for Foreign Medical Graduates (ECFMG) pilots SP examination.	
1992	Rhythm and Pulse released (pre-Anesoft Advanced Cardiac Life Support [ACLS] simulator).	
1993	First Medicine Meets Virtual Reality Conference. Rhythm and Pulse 2.0 update released. Medical Council of Canada uses SPs for assessments. Immersion Corporation patents TouchSense technology. Medical Council of Canada incorporates SP examination into licensure.	[100]
1994	Netscape appears.	
1994-1995	ECFMG formally adopts SP assessment. US NBME endorses SP examination to be implemented in 4 to 7 years.	
1995	First University of Rochester Human Patient Simulation Conference. Wright's Anesthesia and Critical Care Resources Internet launch.	[101]
1995	Anesoft Corporation founded and releases Anesthesia Simulator 2.0, ACLS Simulator 3.0, and Critical Care Simulator.	
1997	Sophus Medical develops acute care PC-based simulation. Minimally Invasive Surgical Trainer-Virtual Reality simulator introduced.	
1998	Anesoft Hemodynamic and Sedation Simulators introduced.	
1999	Link facility in Binghamton closed.	[102]
1999	PediaSim created by METI. UMedic 4-year multimedia computer instruction system for cardiology introduced. Denx simulator for dentistry introduced.	[100]
2000	First International Meeting on Medical Simulation. Laerdal SimMan begins beta testing.	
2001	METI releases Emergency Care Simulator. Sophus Medical partners with Laerdal.	
2002	Medical Simulation Corporation's SimSuite opens first 2 centers: Swedish Heart Institute (Seattle, WA) and Geisinger Health System (Danville, PA). Anesoft Bioterrorism Simulator introduced.	
2003	David Gaba receives the Society for Education in Anesthesia's Duke Prize for Excellence and Innovation in Anesthesia Education.	

Note: Adapted from Rosen KR (2008).



**Figure 3:** Madame du Coudray's *the Machine* obstetrical simulator. Reproduced with permission from the Musée Flaubert et d'histoire de la médecine, Rouen.

Visible Human Project, subsequently facilitated 3-dimensional virtual reality human anatomy manipulation [6]. Virtual reality simulation (VRS), initiated in Morton Heilig's Sensorama in 1956, evolved to the avatar using Second Life internet-based virtual world, which began hosting medical simulations in 2007 as Ann Myers Medical Center [6].

Simulator form may affect the cost, skill acquisition effectiveness, useful lifetime, and skill transferability to in vivo procedures [7]. Live animals, including pigs and goats have different gynecological structural relationships than humans; consequently, they do not serve as adequate simulators. Human cadavers lack perfusion, therefore are not appropriate simulators. Live animals, complete human cadaveric simulators, and e-Learning programs are not discussed below [3,8].

Residency work hour restrictions reducing residents' procedural volume, a shift away from Halstedian apprenticeship-based training to objectives-based competency assessment, evidence-based medicine recommendations favoring medical therapies, and interventional radiology options over surgical intervention, have paved the way for simulation [7,9]. Rare, critical adverse events and life threatening emergencies lend themselves to simulation-based HCWs' training [2,10]. In practice these situations are assigned to experts, leaving less experienced staff to watch or at most, assist, depriving less experienced staff of hands-on experience [10]. Less than 4% of obstetrics and gynecology (ObGyn) residents are confident in their ability to perform robotic surgery without further training. Only 28% of ObGyn residency program directors believe their robotic training is at least effective [11]. Therefore, reliability and validity are the goals of procedural simulation in obstetrics and gynecology.

**Current uses of simulation in obstetrics and gynecology**

Google scholar and Google Internet search phrased "simulation obstetrics gynecology", performed on November 25, 2015 yielding 29 references published from 2001 to 2015, for a coursework review paper. PubMed search on December 19, 2015, terms "simulation obstetrics gynecology", date limited to 2001 to 2015, restricted to free full text, English articles on female, human subjects found 61 articles of which 12 were relevant and non-redundant. Google scholar hand search on December 20, 2015

and September 14, 2016 yielded 45 articles to complete discussion areas as shown in literature flowchart Figure 4.

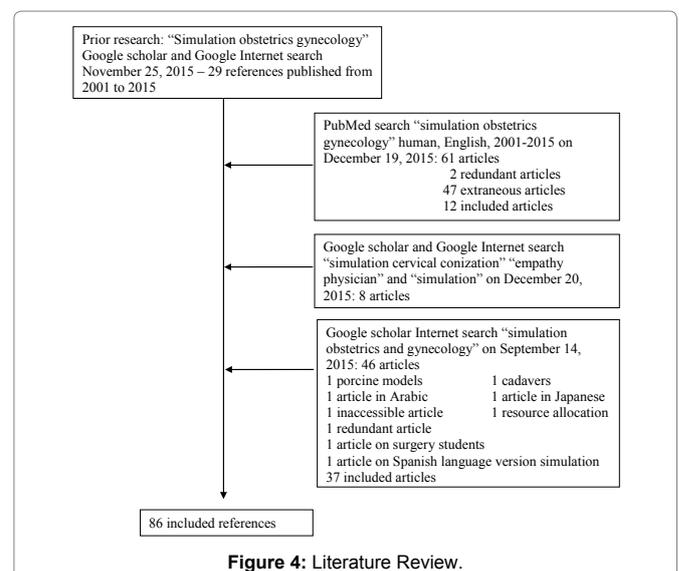
More medical schools use simulators than do teaching hospitals [12]. Both medical schools and teaching hospitals use simulation for obstetric delivery and episiotomy with and without force monitoring, pelvic transvaginal ultrasound, urethral catheterization, gynecologic examination with cervical cancer screening, hysteroscopy, and laparoscopy. Medical schools and teaching hospitals both use VRS for cystoscopy and laparoscopy [12].

Simulators are evaluated in terms of fidelity, reliability, or validity. Construct validity is the simulator's ability to differentiate operators' experience and skill level. Content validity or conceptual fidelity indicates how comprehensively simulation steps match the steps required to complete the in vivo procedure. Face validity or physical fidelity is the simulator's realistic representation of in vivo conditions, for which the As Reasonably Realistic as Objectively Needed (ARRON) rule may be a good measure [13]. Simulation reliability or predictive validity indicates durable translation to in vivo procedures and team work resulting in error reduction, quicker procedures, and improved patient outcomes.

**Gynecology breast and pelvic examination**

Simulators permit the learner to experience normal anatomy and a range of abnormal pathology without exposure to a large number of real and standardized patients [14]. Most silicone breast simulators have set masses. A few breast simulators have responsive, changeable masses, or computer linked feedback pressure sensors. Changeable masses and pressure feedback improve breast simulation training reliability. Overall, breast simulation training skill product outcome has a .69 standard mean difference (SMD) over no breast exam training, with N=538 pooled effect size [14].

Pelvic exam simulators may be part or whole mannequins, with or without computer linked feedback pressure sensors [14]. Again, pressure feedback improves pelvic simulation training reliability. Standardized patient pelvic exam training has greater reliability than mannequin training, which is better than training



**Figure 4:** Literature Review.

by a gynecologist without a mannequin. Overall, pelvic exam simulation training skill process outcome has a 1.18 SMD over no pelvic simulation training, with a N=402 pooled effect size [14]. A cluster randomized control trial (RCT) of 48 medical students after their 8-weeks obstetrics and gynecology rotation in North Bristol National Health Service Trust found that hybrid pelvic part trainer pelvic examination simulation did not increase confidence in future performance of pelvic examinations,  $p=0.1$  [15]. Nevertheless, the intervention group had higher technical scores (mean difference 6.3, 95% CI 3.0 to 9.6) and higher communication skills (mean difference 6.7, 95% CI 4.8 to 8.5) than the pelvic part trainer group [15]. When simulation is added to didactics for genital examination, Tanner staging, vaginal sampling and flushing, hymenectomy, vaginoscopy, laparoscopic adnexal detorsion, and pediatric and adolescent examination, mean objective structured clinical examination (OSCE) scores can increase 23.5 percentage-points,  $p < 0.001$  [16].

### Contraception: intrauterine device insertion

Simulation provides medical students opportunities to practice long-acting reversible contraceptive insertion. An American prospective cohort of 35 third year medical students was given a 45-minute didactic and a 30-minute simulation of levonorgestrel and Cu380A intrauterine contraceptive devices (IUDs) [17]. The simulation used real instruments and placebo devices in a pelvic part trainer [17]. Post simulation participants were more comfortable counseling patients about IUDs, and performing a supervised insertion in a patient,  $p < 0.01$  [17]. Data from an unexposed cohort is unavailable for comparison.

### Endoscopy

Endoscopy and minimally invasive surgery require ambidexterity, depth perception, fine motor skills, and hand-eye coordination. Loss of haptic sensation may be combined with a fulcrum effect whereby hands move opposite to the limited mobility surgical instruments [3,9]. Therefore, endoscopy lends itself to simulation training.

**Cystoscopy and hysteroscopy:** For hysteroscopy, VRS have construct validity based on the Objective Structured Assessment of Technical Skills (OSATS) as well as face validity [8]. However, hysteroscopic simulation validity assertions have been questioned [18]. Commercially available cystoscopy simulators do not yield better results than low-cost homemade \$15 simulators [19]. Simulation can provide the equivalent of 2 years of general residency surgical experience, elevating first and second year residents' (PGY-1 and PGY-2) skills to third and fourth year residents' (PGY-3 and PGY-4) skill level [20]. In a German prospective cohort study, used a pelvic simulator (EVA ETXY/Hystero; Prodelphus, Brazil) for initial hysteroscopy experience. All medical students' OSATS scores increased with repeated training, but male students' scores were consistently higher than female students' scores. Overall, performance time and self-assessment (SA) improved ( $p < 0.0001$ ). SA achieved construct validity [20].

Virtual reality resectoscope simulation can improve PGY-1 resident hysteroscopy knowledge and confidence with hysteroscopy,  $p < 0.01$  [21]. A German cohort of 42 novice hysteroscopists and 15 advanced hysteroscopists underwent HystSim training with an adapted 10-mm resectoscope and a virtual patient [22]. Cavity visualization, economical hysteroscopy usage, fluid handling, safety, and myoma resection were evaluated

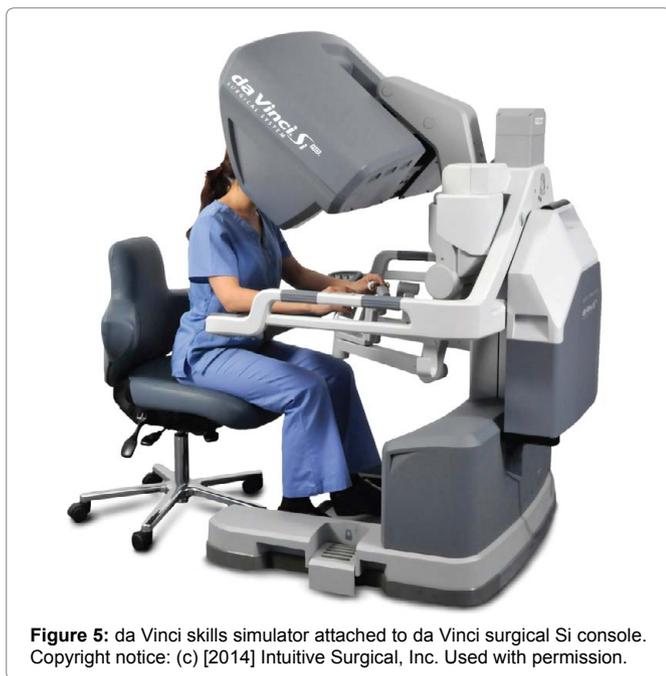
in a multimetric score system (MMSS). Significant pre- to posttest improvement was achieved by all participants,  $p < 0.002$  [22]. HystSim has known face and construct validity from MMSS [22]. The novice cohort benefited from the MMSS which showed clinical relevance, critical relevance (revealed worsening safety), and motivating balance (training session feedback reduces the learning curve and provides overall positive improvement).

**Laparoscopy and robotics:** Laparoscopy and robotics training involves psychomotor skill acquisition and visual perception [23]. Low-cost homemade box trainers costing less than USD150, were rated by ObGyn residents as having equivalent image quality to the USD 1,745 TRLCD03 3-D Med Standard Minimally Invasive Training System laparoscopic trainer [24]. Fundamentals of laparoscopic surgery (FLS) simulation training are associated with improved general surgery laparoscopic procedure performance [25].

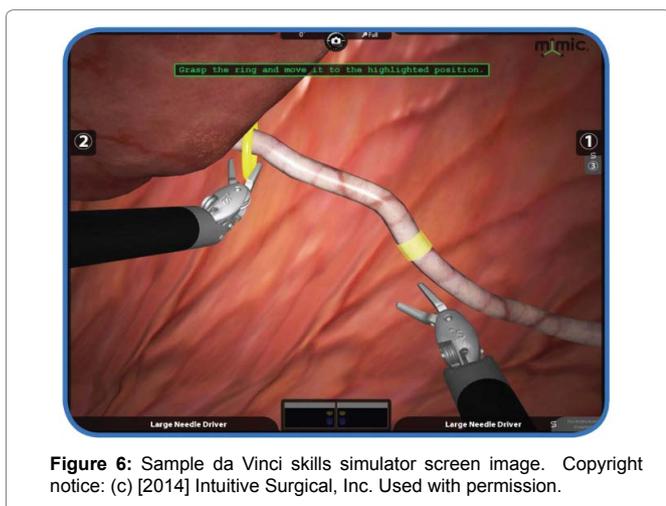
The Global Operative Assessment of Laparoscopic Skills (GOALS) and OSATS evaluate laparoscopic simulation [8]. VRS, which may cost USD 100,000 or more, is used for FLS with proven translational durability and construct validity for laparoscopic procedures [3,8]. This includes LapMentor, LapSimGyn<sup>®</sup> (Figure 2), the Minimally Invasive Surgical Trainer-Virtual Reality simulator (MIST-VR), and SurgicalSim™ [5,8,9,26,27]. LapSimGyn<sup>®</sup>, which simulates ectopic pregnancy, has construct and face validity: Bleeding organs change 3-dimensional conformation during procedures [5,27]. Following eight hours of intensive LapSim Gyn v 3.0.1 salpingectomy training Danish PGY-1 and PGY-2 ObGyn trainees demonstrated experience equivalent to 20-50 laparoscopic cases,  $p < 0.001$  in comparison to controls [23]. This is consistent with MIST-VR requiring 20-30 repetitions for skill plateauing [27]. The effect of instructor feedback on VRS training is under investigation in Denmark [28].

FLS and VRS laparoscopic tubal ligation simulation have been validated for salpingectomy [8,25]. Irrespective of years of training and total number of laparoscopic procedures, residents given unlimited access to a low-fidelity FLS laboratory achieved significant laparoscopic bilateral Pomeroy tubal ligation OSATS posttest performance improvement ( $p < 0.01$ ) in comparison to residents with operating room practice only [29]. Some robotic surgery VRS have predictive validity and haptic feedback [3]. Novice robotic surgeons comprising medical students, residents, and fellows, achieve skill performance plateau at 6.4 to 9.3 repetitions in a single training session with the da Vinci skills VRS (MdVT; Figures 5 and 6), which has construct, content, and face validity for urology [11]. Although medical students and ObGyn residents or fellows prefer the da Vinci skills VRS, for suturing task acquisition the da Vinci dry laboratory simulator is as effective as the da Vinci skills VRS [30]. This is consistent with the lack in statistically significant difference between training with box trainers or VRS [27]. In a study of 31 medical students the daVinci Skills Simulator<sup>®</sup> was most effective for those medical students with the lowest baseline skills. Low performers achieved the greatest reduction in total simulation time for camera targeting and match-board tasks,  $p=0.03$  [31].

The FLS box trainer has been adapted using a RUMI advanced uterine manipulation system, neoprene, and custom brackets to form a laparoscopic vaginal cuff closure simulation model for USD 180 in addition to the FLS box trainer cost [32]. The modified FLS box trainer was tested by an American cross-sectional convenience



**Figure 5:** da Vinci skills simulator attached to da Vinci surgical Si console. Copyright notice: (c) [2014] Intuitive Surgical, Inc. Used with permission.



**Figure 6:** Sample da Vinci skills simulator screen image. Copyright notice: (c) [2014] Intuitive Surgical, Inc. Used with permission.

sample of 13 PGY-3 and PGY-4 ObGyn residents and urogynecology fellows, and 20 practicing gynecologic laparoscopists as experts [32]. GOALS scale for depth perception, bimanual dexterity, efficiency, and tissue handling was used. Construct validity was achieved as experts were differentiated from trainees,  $p=0.001$  [32]. Face validity was achieved with 85% of participants finding the simulator realistic and useful for technique improvement [32].

Interestingly, teenaged video gamers are able to complete the Bean and Pom-Pom Drop and the Checkerboard Drill box trainer simulator procedures significantly quicker than PGY-1 ObGyn residents ( $p=0.05$ ,  $p=0.03$ ) [33]. Forty-two obstetrics and gynecology residents, faculty, and rotating medical students participated in a 30-minute video gaming RCT [34]. Nintendo Wii 3-dimensional movement with haptics improves bead transfer scores to 1.5 times that of PlayStation 2 joystick/push button controls, but neither video gaming system improves laparoscopic suturing [34].

**Morcellation:** Modified part trainers can be used to introduce contained tissue extraction to ObGyn residents [35]. Fourth year ObGyn residents may be unfamiliar with any abdominal manual morcellation techniques as well as manual contained vaginal morcellation. In a cohort of 6 PGY-4 ObGyn residents, low fidelity contained manual tissue extraction simulation increased mean procedural confidence level on a 5-point Likert scale from 1.83 to 4.17 (standard deviation 0.41,  $P=0.001$ ) [35].

### Laparotomy

Despite being the basis of surgical training, laparotomy may have the least simulation research [7]. The haptic, 3-dimensional Virtual Reality Educational Surgical Tools (VREST)-Virtual Lichtenstein Trainer for inguinal hernia repair may only be applicable to gynecologic-oncologists or other gynecologists performing ventral wall ovarian wall suspensions [7]. The Imperial College Surgical Assessment Device with motion analysis electromagnetic sensors can be validated for manual dexterity but not surgical quality [7].

### Vaginal hysterectomy

The modified Angoff method, the Global Rating Scale, and the Vaginal Surgical Skills Index have determined that 21 to 27 vaginal hysterectomies are required to attain competency cutoff scores [25]. Vaginal hysterectomy volume decreases as laparoscopic and robotic hysterectomies increase. A homemade hysterectomy simulator, necessary for procedure teaching achieved face validity for resident vaginal hysterectomy training [36].

### Cervical conization

Several low-cost, low-tech vagina and cervix simulators have been used to teach the loop electrosurgical excisional procedure (LEEP) [37-39]. An American \$10 low-tech LEEP simulator was used as part of a comprehensive 2.5 day colposcopy course, resulting in statistically significantly improved post-program LEEP OSATS performance,  $p<0.001$  [38].

### Obstetrics

Obstetric delivery efficacy and obstetric emergencies management affect the United Nations' Millennium Development Goals 4 and 5—reduction of maternal and infant, including neonatal, mortality [1]. Globally, postpartum hemorrhage (PPH) affects 21% of deliveries [40]. Umbilical cord prolapse causes 10% of fetal deaths, but has an incidence of <1% of deliveries [40]. Maternal cardiopulmonary arrest has an incidence of 1:30,000 pregnancies [40]. Unlike most medical situations, obstetricians have two, not one patient [1]. Therefore, simulation has an important role in obstetrics [41].

**Communication skills:** PGY-2 residents selected four difficult obstetric patient communication scenarios for seven PGY-1 residents to practice in a 2-hour simulation exercise: Peri-viable preterm rupture of membranes, placenta accreta, placenta previa sentinel bleed, trial of labor after cesarean section [42]. Following the simulated patient exercise, all PGY-1 participants believed that they would use the knowledge and skills learned in the future [42]. A 1:1 RCT of 35 ObGyn residents to faculty debriefing or didactic lecture following a “Breaking Bad News” (BBN) simulation showed improvement in self-evaluation ( $p=0.01$ ) and faculty ( $p <0.001$ ) post-intervention BBN simulation scores [43].

Six-months post intervention the groups were switched to receive the intervention that was not initially received, therefore extended follow-up data is unavailable [43].

A 16 weeks pregnant crack cocaine user is one of four empathy simulation cases fourth- and sixth-year Brazilian medical school students participate in weekly for four weeks [44]. Interestingly, sixth-year medical school students had consistently higher pre- and posttest scores than fourth-year medical school students [44]. This is consistent with an international systematic review of Jefferson Scale of Physician Empathy-Student version scores, which indicated that contrary to previous belief, medical students' empathy may not decline in the course of medical training [45].

At Erasmus University College Brussels, Belgium, 15 perinatal simulation sessions are used to ensure that student midwives obtain decision-making and inter-professional communication competencies [46]. Student midwives practice the Situation, background, Assessment, Recommendation, and Repeat (SBARR) and closed-loop communication techniques during the simulations [46]. Opportunity for post-debriefing simulation for learning goal fixation and implementation into practice was provided [46]. Extension of this program to Vrije Universiteit Brussel (VUB) medical students and practicing physicians is planned [46].

**Deliveries:** By 2005 pelvic simulators were used to teach best practice shoulder dystocia management based on measured applied force on the brachial plexus [5]. Pelvic simulator training improves performance of shoulder dystocia and vaginal breech delivery [20]. Shoulder dystocia simulation with force monitoring improved basic procedure performance ( $p=0.002$ ), successful deliveries ( $p<0.001$ ), and provider patient communication ( $p<0.001$ ). Practice with high-fidelity simulators reduced delivery time ( $p=0.004$ ), reduced applied force ( $p=0.006$ ), and further increased the successful delivery rate ( $p=0.002$ ). Reliability was ascertained as even initially unsuccessful participants were able to successfully complete the shoulder dystocia delivery 6 and 12 months post-simulation training [5]. Obstetric delivery simulation can reduce low 5-minute Apgar scores ( $p<0.001$ ) and hypoxic-ischemic encephalopathy ( $p=0.032$ ) [5].

High-fidelity simulation of operative vaginal deliveries can track forceps or vacuum cup placement, training participants to place instruments properly [4,47]. Inappropriate vacuum cup placement accounts for 40% of failed vacuum-assisted vaginal deliveries [48]. In Western Australia, junior and senior Obstetrics trainees and practicing Obstetricians participated in vacuum-assisted vaginal delivery simulations with the Lucy™ pelvic model and fetal head mannequin [48]. The simulations focused on vacuum cup placement at the flexion point. All measured skills improved from pre- to posttest,  $p<0.001$ , except for episiotomy timing,  $p=0.197$  [48]. Based on expert opinion, a 26-step Simpson forceps-assisted vaginal delivery (FAVD) simulation procedure using SimMom due to high fidelity maternal ischial spines and fetal cranial sutures examination, supported by didactic lecture and checklist has been developed [49]. From 4,279 subsequent FAVD deliveries, those performed by simulation trained ObGyn residents showed an adjusted 26% reduction in severe perineal lacerations (OR .74,  $p=0.002$ ) [49]. Adjustments were made for known risk factors for perineal laceration [49].

Third-year medical students who receive a 90-minute Noelle Simulator vaginal delivery training session (Figure 1) at the start of their ObGyn rotation rate their clinical preparedness as 4 out of 5 on a 5-point Likert scale [50,51]. Fourth-year medical students who did not participate in the vaginal delivery simulation training rated their clinical preparedness as 2.6 on the same 5-point Likert scale [51]. Medical students who had vaginal simulation training also participated in more deliveries than those who did not have vaginal simulation training [47,52]. A French, single-center, RCT of 55 medical students assigned to perform 10 or 30 part-trainer simulated vaginal examinations found 10 simulated vaginal examinations to be the skill acquisition threshold,  $p<0.001$  [53]. The two simulation groups also received a 30-minute didactic session. A control group of 11 medical students only received a 30-minute didactic session. Assessment of cervical dilation, consistency, length, and position was significantly more accurate in the 10 simulated vaginal delivery group than the control ( $p<0.001$ ,  $p=0.003$ ,  $p=0.008$ , and  $p<0.001$ , respectively) [53].

Midwives and emergency paramedical staff benefit from obstetric simulation, including emergencies involving home births [54]. From 2012 to 2014 a cohort of 42 home birth midwives and 7 paramedical staff participated in and completed pre- and posttests for a home-based Practical Obstetric Multi-Professional Training (PROMPT) workshop in a community home, in Melbourne, Australia [54]. Each scenario had two active midwives which is their normal practice, and an additional pair of midwives and paramedics who were recruited assistants. Scenarios began with a call that a woman was in labor, and most scenarios ended with the transfer of the mother and/or newborn to the hospital. A part trainer was used for pelvic examination, internal maneuvers, and delivery. SimBaby was used for newborn resuscitation [54]. Participants learnt to plan ahead, understand the role of other health care professionals, and improve communication amongst midwives, paramedical and hospital staff, and the patient's partner [55].

Obstetric simulation for medical students can take on a game-like atmosphere. "The Labor Games" in which 97 medical students rotated through amniotomy, blood loss estimation, cervical dilation measurement, fetal heart tracing, fetal weight estimating, knot tying, and suturing simulation stations increased the students sense of preparedness for ObGyn rotation,  $p<0.001$  [54]. Physician assistant (PA) students also benefit from obstetrics and neonatal simulation [56]. A prospective cohort of 75 PA students underwent SimBaby Apgar assessment, Noelle 565 normal vaginal delivery, and a softball and clay cervical dilation simulation [56]. The PA students reported significantly increased comfort level with each procedure [56]. A uterine contraction generator for normal labor, abruptio placentae, and uterine rupture, and an oxytocin augmented labor UC generator for hypotonic, adequate, and hypertonic contractility have both achieved face validity [57,58].

**Obstetric emergency teams:** In the United Kingdom, obstetric emergency team training halves poor perinatal outcome incidence [59]. Initially, time to magnesium sulfate administration as a surrogate end point for preeclampsia showed multidisciplinary team simulations were as effective as multidisciplinary team training on labor and delivery [40]. However, at four months follow-up, simulation training was deemed more effective than lecture-based training [40]. Consistent with team, team simulation

(preceded by online modules on the new system, team dynamics, and TeamSTEPPS derived communication protocols) can be used to introduce operational changes to multidisciplinary teams. For example, when a change to a cesarean delivery team emergency pager system was implemented at an American hospital, 12 team simulations over a 6-month period increased proper use of the new pager system from 7% to 61% [60]. Timely patient arrival in the operating room increased from 67% to 85% [60].

Filmed interdisciplinary Team Strategies and Tools to Enhance Performance and Patient Safety training and Situation, Background, Assessment, and Recommendation communication technique training may be combined with annual obstetric emergency simulation, achieving significant year-to-year improvements,  $p=0.004$  [61]. In Malawi, pairing hospital-based trained emergency obstetrics and neonatal care mentors with mentees, and providing access to pelvic and neonatal mannequins, led to sustained improvement in written and practical management of all tested skills 6 months after intervention,  $p<0.001$  [62].

Breech vaginal delivery and shoulder dystocia simulation revealed incomplete shoulder dystocia documentation, and failure to appropriately use episiotomy for vaginal breech delivery and shoulder dystocia resolution [10]. In a group of 32 ObGyn residents, high-fidelity shoulder dystocia simulation resulted in technical and non-technical skill improvement that was retained 8 weeks after intervention ( $p=0.008$  and  $p<0.001$ , respectively) [63]. Shoulder dystocia simulation has been shown to reduce neonatal birth injury from 9.3% to 2.3% [40]. However, these outcomes have not been consistently replicated. Following shoulder dystocia simulation implementation at a single institution in Minnesota, the reported incidence of shoulder dystocia increased from 1.8% to 3.7%, adjusted  $p=0.0002$  [64]. But, post simulation birth injury increased from 7.5% to 11.4% ( $p=0.59$ ), PPH increased from 10% to 12.9% ( $p=0.80$ ), third and fourth degree lacerations increased from 10.0% to 6.8% ( $p=0.51$ ), and episiotomies increased from 5.0% to 5.3% ( $p=1.00$ ) [64].

Eclampsia and postpartum hemorrhage (PPH) simulations revealed inadequate knowledge of prostaglandin reversal of uterine atony, blood loss underestimation delaying both moving PPH patients to the operating room, delaying blood product administration in disseminated intravascular coagulopathy, and deficient cardiopulmonary techniques [10]. Within the simulation process teams were able to rapidly improve using the PPH trial to better their eclampsia scenario performance and vice versa ( $p=0.03$ ) [10]. Repeat performance of the PPH and eclampsia scenarios 6 months later showed significant improvement,  $p=0.018$  and  $p=0.012$  respectively. This simulation series achieved context validity as midwives' performance could be differentiated from residents' performance [10].

While PPH simulation can significantly reduce mean delivery blood loss, the need for postpartum blood transfusion is unchanged [40]. A RCT of simulation- and didactic-based PPH training or didactic-based PPH training only with 21 ObGyn residents in India found the simulation group performed significantly better on multiple choice question posttest and direct observation of simulation skills (DOPS) posttest,  $p=0.0003$  [54]. A prospective cohort of 6 ObGyn residents who received PPH simulation drills at 3 month intervals for 1 year achieved increased pre-post

knowledge scores and performance tests,  $p<0.01$  [65]. Significant improvements were also seen in time to operating room and confidence in ability to manage PPH,  $p<0.01$  [65]. The "Helping Mothers Survive: Bleeding after Birth" simulation-based training program for PPH for the basis for a program in rural Rwanda [66]. Generalist physicians had unrestricted access to mannequins on training days. Posttests at 6 to 14 days and 2-years after initial training were completed by 8 of 11 initial participants, who had not received post-intervention PPH or other obstetric emergency training [66]. Initial post-intervention PPH communication and management scores were significantly improved from baseline ( $p=0.034$  and  $p=0.027$ ). This improvement was maintained at the 2-year posttest [66].

Maternal myocardial infarction simulation plays a role in TeamSTEPPS Crisis/Crew Resource Management (CRM) obstetric emergency team training [67]. Four pathways to maternal myocardial infarction are simulated with a modified NOELLE Maternal and Neonatal Birthing Simulator that has simulated subcutaneous fat, fascia, and muscle [67]. This intervention increased individual ObGyn residents' knowledge and self-reported confidence ( $p=0.016$  and  $p=0.007$ , respectively). Team airway management, resuscitation drug-shock cycles, left-uterine displacement, and etiologic identification of myocardial infarction all improved,  $p=0.008$  [67]. However, chest compressions, drug and dose selection, pre-intubation bag-mask ventilation, return of spontaneous circulation identification, therapeutic hypothermia consideration, and team leadership did not improve,  $p=0.074$  [67].

Low-cost, low-tech obstetric and neonatal team emergency training, PRONTO, uses a hybrid birth simulator PartoPants™, the NeoNatalie™ mannequin for neonatal resuscitation, and a cloth doll for the delivering fetus [68]. PRONTO is based on World Health Organization standards, and has been implemented in Guatemala, Kenya, and Mexico. PRONTO requires a 2-day initial training with six simulations for teamwork, uncomplicated deliveries, PPH, and neonatal resuscitation, followed 2 to 3 months later by a 1-day training session on pre-eclampsia/eclampsia, chorioamnionitis, and shoulder dystocia [68,69]. A paired cross-sectional study of 18 Guatemalan clinics found the PRONTO intervention led to better active third stage of labor management ( $p=0.015$ ), increased intervention to decrease neonatal mortality ( $p<0.001$ ), increased patient privacy ( $p=0.014$ ), more informed patients ( $p=0.001$ ), and increased skill-based tool use ( $p=0.012$ ) [69]. In Mexico, 450 physicians and nurses participating in PRONTO inter-professional teams gained increased knowledge and self-efficacy,  $p<0.001$ - $.009$ , with retention at 3-month follow-up [69].

The Managing Obstetrical Emergencies and Trauma simulation-based course has been used in Armenia and Bangladesh [10]. TeamGAINS structured team self-correction, advocacy-inquiry, and systemic-constructivist debriefing is assessed by the Objective Structured Assessment of Debriefing (OSAD) scale [25]. However, the OSAD has yet to be validated against other debriefing tools. The efficacy of resource intensive TeamGAINS is undetermined [25].

**Ultrasound:** Obstetric ultrasound for antepartum prenatal diagnosis is an instance of finding rare anomalies [70]. Minor fetal anomalies have a 5% incidence, major fetal anomalies

have a 2% incidence [70]. Pelvic ultrasound simulation used by residents, midwives, and physicians, while found to be beneficial ( $p < 0.05$ ) and complementary to didactic instruction ( $p = 0.001$ ), only achieved face validity for 63% of participants [71].

The Sonotrainer<sup>®</sup> VRS doubles expert ultrasonographers' nuchal translucency and crown-rump length measurement accuracy [70,72]. Five to six training sessions, an average of 219 minutes total, are necessary with the Scantrainer™ high-fidelity simulator for ultrasound novices to attain expert ultrasonographer level [73]. However, due to small study sizes, estimates of time to ultrasound competency are subject to personal learning curves [74]. Nevertheless, VRS Scantrainer™ simulator training may result in steeper early learning curves than mannequin based training, but the same endpoint is achieved [74]. Scantrainer™ demonstrated construct validity and reliability [73]. A 4-site, single-blind, RCT of 6 months of clinical ultrasound training with- or without 2-hour sessions VRS Scantrainer™ followed by unlimited BluePhantom mannequin transvaginal ultrasound simulation training enrolled 54 Danish ObGyn residents [75]. The Objective Structured Assessment of Ultrasound Skills (OSAUS) was used to determine ultrasound proficiency on the mannequin [75]. An average of 3 hours 22 minutes was needed for VRS Scantrainer™ mastery. Patients' ratings of the residents associated the ultrasound simulation trained residents with reduced discomfort ( $p < .001$ ), increased safety ( $p = 0.04$ ), confidence ( $p = 0.01$ ). Doubling the amount of clinical training leads a 23.5 percentage point greater reduction in double examination with clinical trained residents than simulation and clinic trained residents,  $p = 0.005$  [75].

A single-blind, prospective, RCT of second trimester fetal anatomy simulation-based versus patient-based ultrasound training with 18 trainees, found similar pretest to posttest improvement  $p < 0.04$  and  $p < 0.05$ , respectively [76]. Ultrasim<sup>®</sup> VRS obstetric ultrasound for fetal biometry (gestational age calculation) achieved construct validity ( $p < 0.001$  on initial scan)

and reliability for trainees who were able to achieve near-expert scanning efficiency after three performance simulations (Figure 7) [72]. The Vimedix obstetric ultrasound simulator has been validated using candidates for the Annual French National Examination of Ultrasound in Obstetrics and Gynecology [77]. While dexterity is similar in simulation ( $6.5 \pm 2.0$ ) and patient examination ( $5.9 \pm 2.3$ ),  $p = 0.31$ , overall biometric and morphological image scores with the different,  $p = 0.027$  [77]. Therefore, the pass/fail threshold must be higher for the Vimedix than for a patient examination [77]. A VR fetal brain ultrasound tutor for 20 and 26 weeks estimated gestational age is also available [78].

Ultrasound simulation training is also available for fetal head position determination in second stage labor [79]. A prospective study of 13 ObGyn residents provided two obstetric ultrasound simulation training sessions after 12 weeks of performing 83 transabdominal suprapubic ultrasounds. Following the training sessions 74 transabdominal suprapubic ultrasounds were performed. Consistency between pre-simulation training digital examination and transabdominal suprapubic ultrasound was 59%,  $\kappa = 0.52$  [79]. Consistent between post-simulation training digital examination and transabdominal suprapubic ultrasound increased to 70%,  $\kappa = 0.65$  [79].

### Strengths of simulation

Simulation allows HCWs to learn and develop appropriate skill sets in a safe environment, without harming patients [2,4,47]. HCWs may gain appropriate hard to achieve experience in rare, critical adverse events: Simulation uniformly increases the range of learning for all group members [2,4,47]. Simulation identifies knowledge, procedural, and collaborative skills requiring improvement [10]. Simulations run on-site instead of in a separate simulation suite may identify facility organizational or equipment issues requiring correction [80]. For instance, calcium gluconate for magnesium toxicity treatment had been removed from a labor and delivery unit's automated drug dispensing system. An eclampsia simulation uncovered this situation, which was then rectified [4].

An Adverse Outcome Index reduction of .009 has been achieved by combining obstetric emergency team training with electronic fetal monitoring interpretation training [40]. Simulation is also a means to introduce new techniques or procedures to skilled HCWs [4]. 97% to 100% of Obstetric team training participants believe that the simulation training is worth their time, and 99% believe the simulation will change their current practice [81]. Thus, obstetric team training achieves Miller's Pyramid of Learning level 4.

Simulation is an ecologically valid replication of operating rooms [2]. VRS removes observer bias via cost-saving automatic results recording for future evaluation (Figures 8 and 9), whereas box trainers or independent mannequins require an evaluator's real-time presence for evaluation [3,5,9]. Box trainers with recycled laparoscopic instruments are cost-effective and provide tactile feedback [33]. Hysteroscopy simulation can improve the skills of advanced hysteroscopists as significantly as novice hysteroscopists [22]. VRS ultrasound simulation combined with mannequin ultrasound simulation may reduce the amount of patient ultrasounds required to achieve proficiency, and reduce the time needed per ultrasound examination by 20% within 6 months [75]. VRS ultrasound simulation combined with

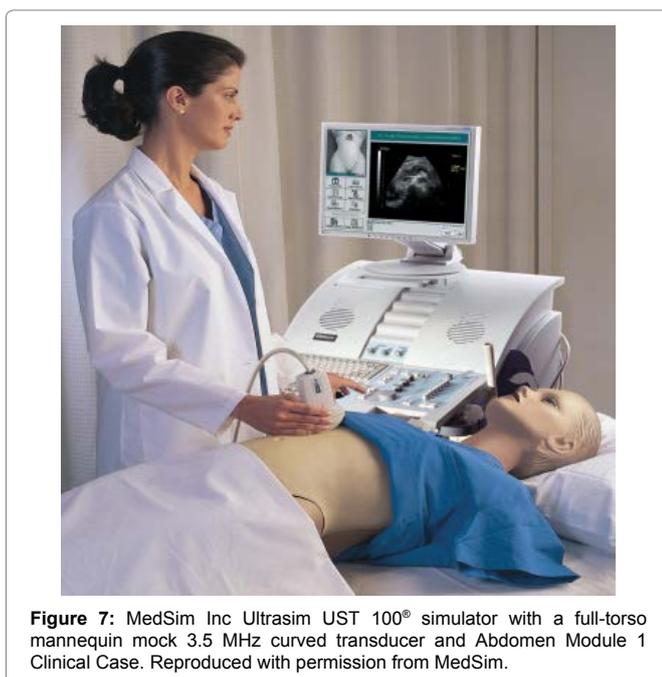
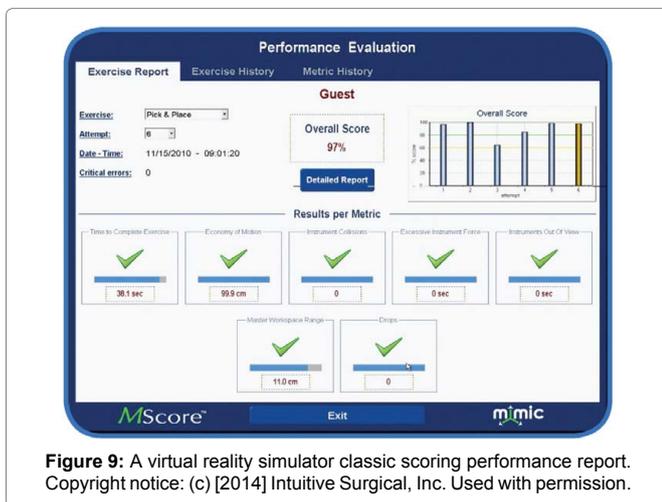
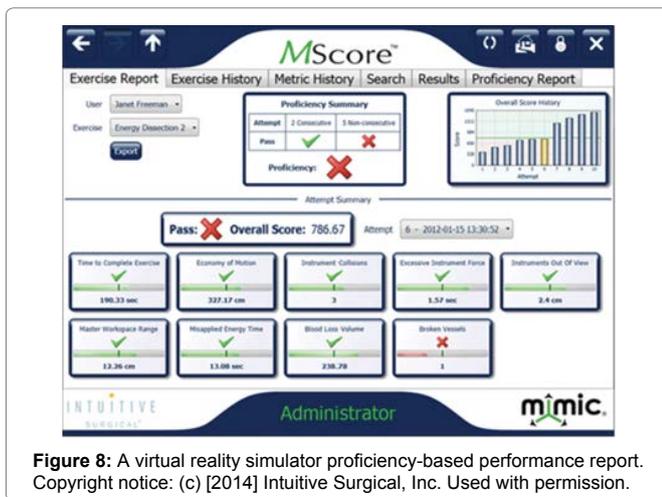


Figure 7: MedSim Inc Ultrasim UST 100<sup>®</sup> simulator with a full-torso mannequin mock 3.5 MHz curved transducer and Abdomen Module 1 Clinical Case. Reproduced with permission from MedSim.



mannequin ultrasound simulation increases quality of care [75].

**Weaknesses of simulation**

Fidelity to actual situations varies across devices [2]. Reliability for medical simulation may be as low as 25% [6]. VRS may lack other simulators’ haptic sensation and depth perception [3,9]. Therefore, novices find that box trainers have greater face validity than VRS [5]. Disparities also occur between novices’ and experts’ ratings of content and face validity [74]. Novices may rate virtual ultrasound simulation higher than experts [74]. Studies on hysteroscopy simulation tend to lack validity evidence [18].

Despite providing artificial tasks, skill retention from laparoscopic box trainers is longer than with laparoscopic VRS [33]. Many of the available studies use a single simulator precluding assessment of training efficacy differences across simulators [18]. When simulation is used for summative assessment or interim professional development plan in OSCE or Test of Integrated Professional Skills (TIPS) situations, unfamiliarity with the simulator can increase examinee anxiety [82,83]

Simulation-based learning is more expensive than classroom-based learning and may require additional physical space [2,5]. Simulation experiences must occur over long periods of time to achieve the most durable outcomes [7], but VRS should be limited

to 1-hour long sessions to reduce headache and eye and neck strain [11]. Some simulation experiences also need repetition by 6 months post-instruction [84]. A RCT of neonatal resuscitation simulation training versus didactic instruction with 33 ObGyn residents found significant performance difference in favor of simulation at 3 months post-intervention,  $p < 0.001$ , that was lost at 6 months post-intervention,  $p = 0.11$  [84].

Although simulation participants can verbally model interactions with patients during simulations, nevertheless, the interaction with the mannequin or other simulation device is not identical to an interaction with a living patient. Therefore, certain social interactions, “the bedside manner” cannot be evaluated with aforementioned simulations [77]. There are numerous studies with small number of participants that lack heterogenous population-wide external validity [18].

Similarly, predictive validity, skill transfer from the simulation laboratory to clinical practice is not assured. While simulation has demonstrated improved participant situational reaction, knowledge and skill learning, and durable behavior changes, demonstration that simulation improves perinatal morbidity and mortality is only evident for PPH, increase in 5-minute APGAR scores of seven or higher, and a reduction in newborns’ hypoxic ischemic encephalopathy [40]. Despite simulation significantly reducing time to initiation and performance of obstetric cardiopulmonary resuscitation- and peri-mortem cesarean section, maternal-fetal outcomes remain unchanged [40]. While simulation significantly reduces median time to delivery for umbilical cord prolapse from 25 to 14.5 minutes, neonatal outcome are unchanged [40]. Similarly, shoulder dystocia simulation can lead to increased recognition of incident shoulder dystocia without adverse outcome diminution [64].

**Barriers to simulation use in obstetrics and gynecology**

As of 2011, only 55% of U. S. surgery training programs had surgical skills laboratories [24]. Similarly, in Australia, the Netherlands, and New Zealand, surgical skills labs have variable availability across health care institutions [3,40]. While 92% of ObGyn trainees at tertiary hospitals in Australia and New Zealand have access to simulation, at other institutions only 76% of trainees have access to simulation [84].

A cost-based type specific simulator distribution is evident. In Australia and New Zealand, box trainers are the most common (56% to 70%) and VRS the least common (2% to 22%) [84]. Consistent with this, in the East Midlands Local Education Training Board in the United Kingdom only 50% of ObGyn trainees have access to ultrasound simulation [85]. In the United States only 39% of ObGyn trainees may have access to ultrasound simulation [85]. At facilities with 1,000 or fewer deliveries annually, on-site obstetric team emergency training is cost prohibitive [59]. Similarly, VRS, which is not as consistently reliable as box trainers, remains an expensive investment for many organizations.

Simulation access maintenance is crucial to skills retention. To retain competency, medical students need to return on the daVinci Skills Simulator’ at 5-week intervals [31]. Opening hours and travel time to surgical skills laboratories limit medical student and resident access [24]. There is a lack of dedicated simulation training time with teaching staff [84]. In Australia and

New Zealand only 6.1% of ObGyn trainees may have dedicated simulation time with teaching staff: An additional 12.1% have dedicated simulation time during which teaching staff may be unavailable [84]. Lack of access to box trainers, as opposed to box trainer use per se, may underlie the failure of gynecology residents to achieve performance standards on laparoscopic box trainers [27]. In addition to overcoming cost and time issues, simulation training has yet to achieve buy-in from all stakeholders. In the United Kingdom, 46% of ultrasound coordinators do not agree that simulation has a significant place in ultrasound training [85].

### The future of simulation in obstetrics and gynecology

Simulation feedback, debriefing, and training translation into improved patient outcomes should be the focus of future research [25,47]. While simulation skill transfer durability research has validated FLS for general surgery and produced a general surgery curriculum, this research and standardized curriculum development have yet to be done for general obstetrics and gynecology [25,47]. Validated VRS for hysteroscopy, laparotomy, and vaginal hysterectomy should become research foci with reliability/predictive validity ascertainment [7,8]. Gynecologists and urologists may collaborate to develop cystoscopy and hysteroscopy VRS [8]. Clinical knowledge transfer of hysteroscopy simulation skills needs to be assessed, and assessment tools for technical and theoretical hysteroscopy skills need to be developed [18]. Further evaluation of the da Vinci VRS is necessary to determine the most effective skills acquisition exercises, the optimal repetitions per session, session interval, and optimal number of sessions [11]. The da Vinci skills VRS should be evaluated for gynecologic construct, content, and face validity. VRS should be tested in real operating rooms to evaluate if the surroundings in which simulation occurs alters reliability or validity as environmental context affects older persons' recall [86].

Low-cost laparoscopic box trainers used in medical students' or residents' homes or other convenient locations may increase simulation training [24]. Obstetric simulation could delve into alternatives to cesarean section for umbilical cord prolapse: Bladder filling, manual elevation of the presenting part, maternal all fours or exaggerated Sim's positioning [40]. Timely peripartum sepsis recognition is another obstetrical scenario amenable to future simulation training [80].

### Conclusion

As obstetrics simulation training has been linked with some improved neonatal outcomes, medical student interest in obstetrics, and obstetrics team building, obstetrics simulation has secured its place in obstetrics training. Fidelity, reliability, and validity concerns may reduce the speed of gynecologic, more so than obstetric simulation growth [6]. However, given continued patient access reduction with resident work hour restrictions, increasing medical and interventional radiology patient management, and increasing medical board need to ascertain surgical skills first hand, short of assessment of recorded patient procedures, obstetric and gynecologic simulation can only grow.

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## Author Affiliations

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Locum Tenens Obstetrician & Gynecologist, PO Box 59, Salinas, California 93902, USA

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