Simulation in Obstetrics and Gynecology

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The days of learning “by trial and error” or “see one, do one, teach one” are passing as the leading approaches to the acquisition of health care–related knowledge, skills, and abilities and to the provision of clinical care to the surgical or obstetric patient. Simulation is a practical and safe approach to the acquisition and maintenance of task-oriented and behavioral skills across the spectrum of medical specialties, including obstetrics and gynecology. The idea of practicing on inanimate objects before human beings dates back to antiquity. However, the idea of systematically embedding simulation within the fabric of a graduate or postgraduate medical curriculum or of using this technique as an integral part of professional certification or credentialing programs is relatively new. Since the 1990s, the profession of obstetrics and gynecology has developed a greater appreciation of the value of simulation and major steps are being taken toward incorporating this technique into specialty-specific training, evaluation, and credentialing programs. This article provides an overview of simulators and simulation in health care and describes the scope of their current use and anticipated applications within the specialty of obstetrics and gynecology.

Overview of simulators and simulation in health care

A “simulator” is a generic term referring to a physical object, device, situation, or environment where a task or a series of tasks can be realistically...
and dynamically represented [1,2]. Simulation typically involves the use of one or more simulators for educating, training, or evaluating learners from across the spectrum of experience from novice to veteran [3]. Depending on the educational goals and objectives of the curriculum, some or all portions of a routine or critical event can be reenacted using a combination of verbal role playing, standardized characters or actors, devices, mannequins, or environments. Full immersion medical simulation is when a complex set of tasks takes place in a re-created, realistic health care setting in which clinicians interact with each other and care for standardized or mannequin patients.

**Simulator taxonomy**

Simulators in health care range from simple objects or training devices to technologically advanced mechanical or haptic systems representing a patient or clinical work environment. Simulators are sometimes distinguished from training devices. For example, Good and Gravenstein [1] reserved the term “anesthesia simulator” for systems that mimic patients and realistically portray the anesthesia environment. Regardless of their level of sophistication or fidelity, training devices or “part-task trainers” are important for introducing learners to key components of a clinical procedure and for refining or assessing procedural technique. Part-task trainers replicate a body part or internal organ and are used to practice a clinical task, technique, or procedure. A model-driven simulator is typically a full-size mannequin that resembles and responds physiologically like a human being to medical interventions. Virtual reality (VR) simulators are computer based, having software designed to re-create a real-world, three-dimensional environment that may be confined to a computer screen display. VR simulators may be augmented by tools, known as haptics, that facilitate various sensory and tactile aspects of the real-world experience. Simulators, including part-task trainers, have been classified by such categories as capability, fidelity, user feedback, and cost (Table 1) [4]. Cost ranges from less than $100 for part-task trainers to well over $100,000 for VR or haptic simulators. Recognizing

<table>
<thead>
<tr>
<th>Simulator capability</th>
<th>Part-task trainer</th>
<th>Instructor-driven simulator</th>
<th>Model-driven simulator</th>
<th>Computer screen–based simulator</th>
<th>Virtual reality/haptic simulator</th>
</tr>
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<tbody>
<tr>
<td><strong>Fidelity</strong></td>
<td>Low</td>
<td>Intermediate</td>
<td>High</td>
<td>Low to high</td>
<td>Intermediate to high</td>
</tr>
<tr>
<td><strong>User feedback</strong></td>
<td>Nil</td>
<td>Nil to some</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Low to moderate</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate to high</td>
<td>Very high</td>
</tr>
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</table>
the lack of a standardized taxonomy, Cumin and Merry [5] recently proposed a schema for classifying anesthesia simulators by their attributes, including those related to (1) use for teaching (knowledge, cognitive skills, psychomotor skills), (2) user interaction (hardware-based, computer-based, VR-based), and (3) simulated physiology (none, script-controlled, model-controlled). It is not yet known if their schema will be widely adopted by anesthesiology in particular and health care in general. However, as Gaba [6] noted in 1997, no single classification system will be devoid of overlap and shades of gray.

**Human patient simulation**

The first reported computer-controlled patient simulator, SimOne, was created by Denson and Abrahamson [7] in the late 1960s. SimOne, modeled after a 6-ft tall male weighing 195 lb, was designed to be interactive and geared toward training anesthesiologists. Denson and Abrahamson [7] designed a system for students to learn necessary manual and decision-making skills before anesthetizing real patients. Their simulator, clearly ahead of its time, did not attain widespread use and was largely forgotten. Human patient simulators resurfaced when Gaba and DeAnda [8] created an interactive, comprehensive mannequin-based anesthesia simulation in the late 1980s. The Comprehensive Anesthesia Simulation Environment (CASE) was designed to facilitate assessment of anesthesiologists’ technical and behavioral skills. Gaba, Schwid, Howard and colleagues [8–10] appreciated the role of simulation-based training in non–health care industries and likened human patient simulation to cockpit simulation, an experiential learning environment used in aviation for professional education and training. Medical simulation was seen as a means to augment didactic instruction, providing an out-of-the-chair and hands-on experience in a safe environment without harming real patients. The practice of anesthesia-related procedural and behavioral skills for better managing routine and critical clinical events could safely take place in such an environment. The aviation and nuclear industries were among the first to confront the problem of human errors as contributing factors in accidents and to address the need for various skilled professionals to learn to work together better and communicate more effectively [11]. Crew resource management (CRM) embodied the aviation industry’s approach to optimizing teamwork behaviors, solving problems, and improving situation awareness for better error recognition, management, and recovery [12]. Gaba and associates [13] adapted aviation CRM to anesthesia in 1989, calling it anesthesia crisis resource management (ACRM). The hands-on simulation experience with CASE was followed by reflective debriefing, guided discussions about what went well, what did not go well, and how principles of ACRM could assist in better managing future simulated or real clinical events. The original CASE system has since been replaced by more technologically advanced mannequins, firmly grounding human patient simulation within the field of anesthesia.
for training, evaluation, and research. Human patient simulation has spread from anesthesiology into a number of health care specialties and domains, such as emergency medicine [14,15], critical care medicine [16,17], neonatology [18], obstetrics [19,20], invasive cardiology [21], nursing [22,23], and graduate and postgraduate medical education [24,25].

**Fidelity and realism**

Some degree of simulator and simulation fidelity is required to engage participants in a learning or evaluation activity. Physical fidelity, the degree to which a simulator looks and feels like the real thing; conceptual fidelity, the degree to which a simulation behaves appropriately; and emotional fidelity, the degree to which a simulation draws the participant into the situation, are all required in some measure to achieve engagement [26]. Attaining a high degree of realism is but one route to this end. For example, practicing an injection with a syringe, needle, and an orange does not have much realism, but has sufficient physical, conceptual, and emotional fidelity to engage the novice. Depending on the purpose of the simulation, be it task training or teamwork practice, the precise recipe for physical, conceptual, and emotional fidelity differs and is a matter of debate [27]. Moreover, fidelity is not a quality possessed exclusively by the simulator and simulation. Trainees involved in simulation have a vital role in the perception of fidelity and realism. They must recognize that simulators are proxies for the real item and that simulated scenarios take the place of or represent what has happened or could happen in the real world. Simulation participants do not “suspend their disbelief” so much as they agree to believe and behave as if the situation were real [28,29]. This agreement is facilitated by the design of the curriculum, the expertise of the instructors and trainees, the fidelity of the simulator, and the realism of the environment or system. Dieckmann and colleagues [29] regard the “as-if” concept as the cornerstone of effective simulation. The choice of simulator and how much realism is necessary to engage the participant for purposes of education, evaluation, or research depends on the goals and objectives of the task and the curriculum and the expertise of the instructors and participants [27,30]. Successful engagement of the participant does not hinge entirely upon the precision with which a simulator or simulation replicates reality. The educator’s knowledge of the subject matter, the simulators, and their attributes facilitates the process by which a simulation can best achieve the goals and objectives of the curriculum. Application of simulators in health care simulations may take place in centers designated for such purpose—so-called centers for medical simulation—or within contextually relevant health care settings—so-called “in situ” simulation.

**Medical simulation centers**

Centers dedicated for the purpose of medical simulation initially focused on the specialty of anesthesia and were established during the early 1990s in
North America and Europe. Among the first in North America were the Center for Medical Simulation of Harvard Medical School in Boston, Massachusetts [31]; the Peter M. Winter Institute for Simulation Education and Research of the University of Pittsburgh Medical Center in Pittsburgh, Pennsylvania [32]; the University of Rochester in Rochester, New York [33]; the Veterans Affairs, Palo Alto Simulation Center of Stanford University School of Medicine in Palo Alto, California [34]; and the Canadian Simulation Center for Human Performance and Crisis Management Training of Sunnybrook Health Science Center, Toronto, Ontario, Canada [35]. Among the first medical simulation centers established in Europe were the Swiss Center for Medical Simulation of the University Hospital in Basel, Switzerland [36]; the Danish Institute for Medical Simulation, Herlev University Hospital, in Copenhagen, Denmark [37]; and the Belgium Anesthesia Simulation Centre in Brussels, Belgium [38]. Since then, hundreds more have been established worldwide at various universities, hospitals, nursing schools, small colleges, technical colleges, and community colleges. Expanding beyond the domain of anesthesia, simulation programs are now used for procedural and behavioral skills training, performance evaluation, and competency assessment across the spectrum of specialties and disciplines. Simulation programs are also employed in technology research, development, and device testing. Simulation-based training programs in obstetrics and gynecology are among those offered in medical simulation centers worldwide.

Simulation in obstetrics

Obstetrical simulation is the reenactment of routine or critical clinical events involving a woman who is pregnant or recently delivered and her fetus or newborn for procedural or behavioral skills training, practice, evaluation, or research. The overall goal of obstetric simulation is to improve the quality and safety of care for women and newborns [4].

History of obstetric simulators

The use of small wax or wooden figures to illustrate reproductive processes of childbirth dates back to the ninth century [39]. Buck [40] reviewed the development of simulators in medical education and reported that obstetric mannequin torsos were among the earliest examples of simulators used in the history of medicine. Known then as “phantoms,” such obstetric simulators were developed in the 1600s as a way to teach midwives how to better manage difficulties of childbirth. Father and son surgeon-accouchers, Gregoire the elder and the younger of Paris, developed an obstetric simulator made of wicker and used this and a dead child for simulating normal and abnormal processes of childbirth to teach midwives during the 1700s. Sir William Smellie, the father of British midwifery, refined the Gregoire approach by using a pelvis fashioned from human bones covered by leather,
a mannequin fetus made of wood and rubber and complete with articulating limbs, and a placenta made of leather [41]. Around the same time, Sir Richard Manningham, another strong proponent of practicing obstetric maneuvers with phantoms, fabricated a glass machine for simulating childbirth and showing midwives in London the maneuvers of the fetus as it passed through the birth canal [39]. Madame du Coudray, midwife in the court of King Louis XV, continued the use of childbirth simulators for training midwives of France [42]. She was known in the 1700s for creating “the Machine,” an anatomically correct, life-size mannequin birthing pelvis, made of wicker, flesh-colored fabric, and leather and padded with sponges, and mannequin babies, made of cloth (Fig. 1). Her mannequins were highly regarded for their lifelike appearance and she traveled with them throughout the French countryside, teaching village midwives how to deliver babies and perform maneuvers for managing childbirth-related complications. The phantoms or “machines” of the 1600s and 1700s are best classified as part-task trainers.

The use of obstetric phantoms for teaching obstetrics continued through the 1800s and 1900s. Professor B.S. Schulze, Director of the University Women’s Clinic in Jena, Germany, during the 1890s, modified obstetric phantoms by creating interchangeable pelvic floors and sacral promontories to better simulate pelvic anatomy for teaching clinical pelvimetry (Fig. 2) [43]. Dougal [44] of Manchester, England, was a strong proponent in the early 1900s of using lectures in combination with practical hands-on experience with mannequins for teaching obstetrics. Concerned by the high cost of obstetric phantoms, he commissioned the creation of simple, inexpensive glazed earthenware obstetric “basins” to simulate a female pelvis. He used these in combination with stillborn fetuses and their placetas to teach

Fig. 1. “The Machine” obstetrical simulator of Madame du Coudray. (Courtesy of the Musée de Flaubert, Rouen, France; with permission.)
Obstetric maneuvers. Transparent models resurfaced through the work of Wakerlin and Whitacre [45] were inspired by the University of Illinois’ “greater than life-size transparent model of a pregnant woman” at term. They were avid proponents of transparent mannequins for teaching normal labor and operative delivery and collaborated to create a transparent, plastic female abdominal-pelvic torso modeled on the anatomy of a typical European female. In 1947, Eloesser [46], a thoracic surgeon of San Francisco, California, described how he modified this simulator by outfitting the transparent plastic pelvic canal and abdominal cavity with a rubberized abdominal wall and external genitals. His goal was to create a phantom that was lightweight, inexpensive, and easy for a midwife-instructor to transport in medically remote or underserved areas around the world.

A range of obstetric part-task trainers has since been created for training in such procedures as determining cervical dilation, repairing episiotomies, and applying forceps. The transition from the use of obstetric birthing pelvises to the use of realistic, full-size interactive birthing simulators took place during the 1970s. During this time, Knapp and Eades developed a mechanical female birthing system outfitted with an electro-pneumatic device capable of generating sufficient fluid pressure to push out a mannequin baby and simulate vaginal birth [47]. This device did not gain traction in the obstetric arena and, like SimOne, was not commercially produced. Eggert, Eggert, and Vallejo took a different approach in the 1990s by installing a motorized mechanism that pushes a life-size mannequin baby out of the pelvis for simulating vaginal delivery [48]. They outfitted their life-size female birthing mannequin with a self-contained, indwelling, audible, fetal heart tone simulator. Now known as Noelle, this high-fidelity, human patient mannequin was patented as a “computerized education system for teaching patient care” (Fig. 3).
Current obstetric simulators

Currently available obstetric simulators range from part-task trainers to high-fidelity life-size female mannequins, situations, and environments for realistically representing obstetric events. Table 2 displays select features of commercially available obstetric simulators. High-fidelity birthing simulators currently available are equipped with motor-driven mechanics that move the mannequin fetus out of the birth canal. The most technologically advanced models are outfitted with wireless computer-based software that allow for remote control. Low- and high-fidelity simulators are useful for teaching and practice, depending on the goals and objectives of the curriculum. A low-fidelity birthing pelvis can be paired with a high-fidelity adult-size mannequin to enhance the capability or achieve the desired effect needed for an obstetric scenario. A birthing pelvis can also be held by a live person close to her own body so that the human and mannequin seem as one. The pairing of simulators with other simulators or with humans creates so-called “hybrid simulators,” useful for more realistically simulating a patient or a clinical environment (Fig. 4). Hybrid simulation techniques can augment realism at little to no extra cost. Such techniques are especially useful where resources or storage capabilities are limited or where portability is essential.

Current use of obstetric simulation

Much has been written about the use of obstetric simulators since their introduction during the 1600s. Since Eloesser’s [46] article on the transparent phantom in 1947, most of the published literature involving obstetric simulation has focused on acquisition and training of procedural skills. For example, Burd, Motew, and Bieniarz [49] in 1972 described a simulator they created for teaching how to perform fetal scalp sampling. Many articles have since been written describing the creation or use of a variety of obstetric simulators for teaching such skills as assessing cervical dilation [50]; performing ultrasound-guided amniocentesis [51,52]; using forceps [53,54]; determining fetal
<table>
<thead>
<tr>
<th>Simulator capability</th>
<th>Company</th>
<th>Cost</th>
</tr>
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<tbody>
<tr>
<td>Postpartum suturing trainer</td>
<td>Part-task trainer</td>
<td>Gaumard</td>
</tr>
<tr>
<td>Episiotomy or anal sphincter trainers</td>
<td>Part-task trainer</td>
<td>Limbs and Things</td>
</tr>
<tr>
<td>Breast milk hand expression trainer</td>
<td>Part-task trainer</td>
<td>Limbs and Things</td>
</tr>
<tr>
<td>Birthing pelvis</td>
<td>Part-task trainer</td>
<td>Gaumard</td>
</tr>
<tr>
<td>Obstetrical mannequin or birthing pelvis</td>
<td>Part-task trainer</td>
<td>Simulaids</td>
</tr>
<tr>
<td>Forceps, vacuum delivery obstetric mannequin</td>
<td>Part-task trainer</td>
<td>Simulaids</td>
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<tr>
<td>The Obstetric Phantom</td>
<td>Part-task trainer</td>
<td>Schultes Medacta</td>
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<tr>
<td>Maternity Model Type 1 (with fetal heartbeat)</td>
<td>Part-task trainer</td>
<td>Koken</td>
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<td>Midwifery practice model</td>
<td>Part-task trainer</td>
<td>Koken</td>
</tr>
<tr>
<td>Full-body pregnancy simulator</td>
<td>Part-task trainer</td>
<td>Koken</td>
</tr>
<tr>
<td>Practical Obstetric Multi-Professional Training birthing simulator</td>
<td>Part-task trainer</td>
<td>Laerdal; Limbs and Things</td>
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<tr>
<td>FetalSim</td>
<td>Instructor-driven simulator</td>
<td>Advanced Medical Systems</td>
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<tr>
<td>UltraSim</td>
<td>Instructor-driven simulator with force monitor</td>
<td>MedSim Advanced Medical Systems</td>
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<tr>
<td>Newborn Pedi Simulator or Nita Newborn</td>
<td>Instructor-driven simulator</td>
<td>Gaumard</td>
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<tr>
<td>Noelle Birthing Torso</td>
<td>Instructor-driven simulator with automated capability</td>
<td>Gaumard</td>
</tr>
<tr>
<td>Noelle Maternal, Neonatal Birthing Simulator</td>
<td>Instructor-driven simulator with automated capability</td>
<td>Gaumard</td>
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<tr>
<td>Noelle Interactive Maternal, Neonatal Birthing Simulator</td>
<td>Model-driven simulator</td>
<td>Gaumard</td>
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<td>Newborn Hal</td>
<td>Model-driven simulator</td>
<td>Gaumard</td>
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<tr>
<td>BabySim</td>
<td>Model-driven simulator</td>
<td>Medical Education Technologies</td>
</tr>
<tr>
<td>SimBaby</td>
<td>Model-driven simulator</td>
<td>Laerdal</td>
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</tbody>
</table>
station [55]; conducting breech birth [56]; managing shoulder dystocia [57–59]; managing obstetric emergencies and trauma [60–63]; managing the obstetric airway [64,65]; performing intubations [64,65]; and inserting epidural catheters [66]. Since 2004, obstetric simulation–based research has been increasingly used to address issues related to teamwork [61–63], team performance [67–69], the identification of clinical errors [70–73], the reduction of clinical risks [74,75], and the improvement of clinical outcomes [76–78].

Shoulder dystocia

A number of articles have been published in the obstetric literature involving simulation related to research about, training for, and management of shoulder dystocia. The earliest research in this area was led by Gonik, Allen and colleagues, [79–81] in the late 1980s and early 1990s. To study the applied pressure or force on the brachial plexus, Gonik and colleagues [82] in 2003 used a “computer software crash dummy” modified with a female pelvis and a mannequin fetus and outfitted with a spring device to represent the brachial plexus. They discerned that stretch on the brachial plexus varied with the degree of force applied, the position of the pelvis, and the position of the fetal head within the pelvis. They also found that the McRobert’s maneuver reduced stretch of the brachial plexus. Deering and colleagues [58] in 2004 reported on the positive impact of using simulation for teaching residents the maneuvers for managing shoulder dystocia and for promoting best practice
for residents in medical record documentation of such clinical events [83]. Kim and colleagues [84] and Gurewitsch and associates [85], with Allen and colleagues, created a biofidelic maternal birthing simulator they have since used in research involving various aspects of shoulder dystocia. In 2005, they compared the force applied on the brachial plexus during McRobert’s maneuver with that of the Rubin’s maneuver and found less force was generated with Rubin’s maneuver [85]. In 2007, Allen and colleagues [86] discerned greater stretch on the posterior brachial plexus was generated during second stage of a simulated routine vaginal delivery compared with one complicated by shoulder dystocia, but before the application of clinician-applied traction. They concluded that even though the fetal posterior brachial plexus may stretch as it traverses the pelvis during the second stage of labor, clinicians should aim to minimize applied traction, especially lateral traction, in all deliveries to reduce the risk of brachial plexus injury. Crofts and colleagues [87] in 2005 discussed the use of a new birthing simulator they helped develop for training in shoulder dystocia. After the training program, none of the trainees applied greater than 100 N of traction, a degree of force beyond which is associated with fetal injury. In 2006, they presented results of a randomized controlled trial of simulation-based training in Bristol, United Kingdom, involving shoulder dystocia scenarios with the Practical Obstetric Multi-Professional Training (PROMPT) birthing simulator (Fig. 5) [57]. They compared training with a high-fidelity mannequin with force monitoring to training with a low-fidelity mannequin and found that all training improved performance of basic maneuvers ($P = .002$), the achievement of

![Fig. 5. The PROMPT birthing simulator. (Courtesy of Limbs and Things, Bristol, United Kingdom; with permission.)](image_url)
successful deliveries ($P < .001$), and communications with the patient ($P < .001$). High-fidelity simulation with force monitoring led to more successful deliveries ($P = .002$), lower applied force ($P = .006$), and shorter head-to-body delivery ($P = .004$). This study underscores the importance of training for managing shoulder dystocia and demonstrates how force monitoring in simulated vaginal births heightens clinician awareness of what they can potentially generate in the process of managing birth complicated by shoulder dystocia. In 2007, Crofts and colleagues [88] described the use of PROMPT in a standardized shoulder dystocia scenario to assess the force applied by obstetricians and midwives to the fetal neck. They found a wide range of variation in the pattern and degree of applied force, ranging from 6 N to more than 250 N, and over two thirds of study participants exceeded 100 N, an amount of force considered excessive. While the force applied during simulated shoulder dystocia may not exactly represent what occurs in real cases, this study reiterates the value of educating clinicians about the degree of force they are capable of generating, and reinforcing the importance of accurately using maneuvers to successfully achieve a safe delivery. In a separate study using the PROMPT mannequin, Crofts and colleagues [89] assessed retention of skills at 6 and 12 months after obstetric providers attended a structured training program on shoulder dystocia. They found a high percentage (>80%) of participants, including those who had failed to successfully deliver the mannequin baby before training, were able to successfully deliver the mannequin baby at 6 months and 12 months after training. This study suggests that annual training is likely appropriate for those who demonstrated proficiency before training. For others, more frequent training sessions may be warranted to reinforce such skills.

**Fetal station and the use of forceps**

In 2005, Dupuis and colleagues [55] conducted a prospective, randomized trial for assessing reliability in determining fetal station. They constructed a laboratory birthing simulator consisting of a female pelvis and a mannequin fetus with an anatomically correct fetal skull. They then compared the assessment of fetal station, ranging from $-5$ to $+5$, and engagement conducted by residents and attending physicians. They found that 88% of residents and 67% of attendings misdiagnosed “high” fetal station, and about 12% of both groups incorrectly classified engagement of the fetal head. In view of these findings, Dupuis and colleagues advocated simulator-based training as a way to improve skills for determining fetal station and engagement. In 2006, Dupuis and colleagues [53] combined computer screen–based or virtual capabilities with a birthing pelvis and equipped forceps with spatial location sensors to teach and assess forceps application. These sensors made it possible to monitor forceps blade trajectory in a simulated operative vaginal delivery, and to compare forceps application by attendings and residents. Forceps blade trajectory was excellent, very good, or good in 92% of cases involving
senior obstetricians and in 38% of cases involving junior obstetricians ($P < .001$). Dupuis and colleagues concluded that simulation provides a safe way to acquire and practice skills in forceps application before trying it on real patients, and can be used to certify skills in the use of forceps. Moreau and colleagues [90], including Dupuis, are now using forceps trajectory patterns created by experienced obstetricians as templates for training residents.

*Virtual reality and haptic simulation*

Applications of VR and haptic simulation to the field of obstetrics are few but have increased over the past decade. Three articles published in the 1990s and three since 2002 focused on VR simulation in obstetrics [91–96]. In 2002, Letterie [94] assessed the use of VR in a variety of non–health care and health care industries, exploring potential applications in obstetrics and gynecology. He concluded that VR environments could assist residents and medical students in surgical skills training and in developing better conversing skills with patients. In 2004, Obst and colleagues [95] created a virtual obstetric environment with feedback mechanisms embedded in the simulator to assist learners in acquiring skills for managing normal and complicated deliveries. In 2005, Lapeer [96] of the United Kingdom assessed the feasibility of using VR technology to create a mechanical model augmented by haptic feedback for simulating forceps delivery. He demonstrated that such a device could facilitate skill acquisition and performance of forceps application. His findings align well with those of Dupuis’ forceps-related research in France.

*Structured simulation-based training programs*

Several multidisciplinary obstetric skills training programs have been established in the United Kingdom, the United States, and Canada. These programs include Managing Obstetric Emergencies and Trauma [62] and Multidisciplinary Obstetric Simulated Emergency Scenarios (MOSES) [68] of the United Kingdom; the Advanced Life Support in Obstetrics [97–99] of the American Academy of Family Physicians in the United States; and Advances in Labor and Risk Management [100] and Managing Obstetrical Risk Efficiently [101] of the Society of Obstetricians and Gynecologists of Canada. These procedural skills and team training courses have been offered in some cases for over a decade and have generally been well received by clinicians in their respective areas.

Leaders in obstetrics and gynecology and simulation researchers within the military medical corps have long been proponents of simulation-based training in obstetrics and gynecology. Macedonia and colleagues [20] described the integral role that medical simulation has in the training and practice of obstetrics and gynecology, highlighting aspects of their obstetric skills simulation curriculum at the National Capital Area Medical Simulation Center of the Uniformed Services University of the Health Sciences in Bethesda, Maryland. More recently, members of the Madigan Army
Medical Center announced the development of a mobile obstetrics simulator, Simulator for High Acuity Deliveries, to facilitate training for managing obstetric emergencies [102]. Plans are in place to deploy these units to military treatment facilities to help obstetric clinicians maintain and update clinical skills for managing high-acuity, low-frequency perinatal events.

Reducing risk

Several articles published since 2005 target the use of obstetric simulation for identifying clinical error, reducing clinical risk, and improving clinical outcomes. Cioffi and colleagues [77] conducted a pilot study using simulated scenarios for teaching clinical decision-making to midwives. The study showed a positive effect of this approach on clinical decision making in simulated clinical settings. The investigators noted that translating this effect into the real world setting was inconclusive. Draycott and colleagues [78] assembled a retrospective cohort of births between 1998 and 2003, and investigated whether simulation-based training in Bristol, United Kingdom, made a difference in perinatal outcomes after clinicians attended a day-long simulation-based training session for managing obstetric emergencies. They compared pretraining (1998–1999) to posttraining (2001–2003) outcomes for singleton, cephalic term births at tertiary care and teaching hospitals. They found that 5-minute Apgar scores of less than six decreased from 86.6 to 44.6 per 10,000 births ($P < .001$) and hypoxic-ischemic encephalopathy decreased from a rate of 27.3 to 13.6 per 10,000 births ($P = .032$). Theirs is the first study whereby an obstetric simulation-based educational program has been associated with improved perinatal outcomes.

Error identification and management

Simulation can assist in identifying recurrent pitfalls in managing obstetric emergencies. Maslovitz and colleagues [72] in 2007 described using simulation to identify mistakes in obstetric management. They observed team performance of residents and midwives during simulated obstetric emergencies, such as eclampsia, hemorrhage, shoulder dystocia, and breech birth. The most common errors involved delay in transport to the operating room (82%), lack of familiarity with medications for treating obstetric hemorrhage (82%), poor techniques in using cardiopulmonary resuscitation (80%), and inadequate documentation of shoulder dystocia (80%). They acknowledged that although simulation is useful for training, the transfer of skills acquired in simulated emergencies to managing real clinical events is uncertain and remains an important area of research.

Teamwork, team performance

Simulation facilitates multidisciplinary team training and improves team performance in obstetric emergencies and trauma as demonstrated by Freeth
and colleagues [68] in 2006. MOSES, launched in the United Kingdom as a day-long program, aimed at improving multidisciplinary team performance via lectures, workshops, and skills training sessions, concluding with a post-course evaluation. While not yet proven, this program is expected to reduce by 25% the occurrence of harmful adverse events in obstetrics and gynecology that result in litigation.

Tools for evaluating team performance in simulated obstetric events are the subjects of much research. Scavone and colleagues [103] in 2006 developed and piloted a scoring system for assessing the performance of anesthesia residents during emergency cesarean delivery. They found the scoring instrument useful and the simulator contextually valid and reliable. Morgan and colleagues [70] in 2007 investigated tools for evaluating performance of multidisciplinary obstetric teams during simulated obstetric emergencies. They concluded that obstetric-domain–specific behavioral markers and assessment tools should be developed instead of using or modifying existing tools, such as the Human Factors Rating Scale and the Global Rating Scale.

Several investigators have recently explored the question of whether simulation offers advantages over a traditional didactic approach. Jude and colleagues [69] in 2006 compared third-year medical students who received simulator-based training in vaginal delivery to those who received traditional instruction. They found that students with simulated experiences expressed greater confidence in their own abilities to assist or attempt vaginal delivery in real clinical settings. Ohlinger and colleagues [104] reported that video simulation was a useful methodology for teaching effective communication and improving teamwork among perinatal care providers during deliveries. Birch and colleagues [71] in 2007 compared lecture-based methodology with a simulation-based approach and with a combined lecture- and simulation-based approach for teaching teams to manage postpartum hemorrhage. Six multidisciplinary teams, randomized to one of these three methods, all demonstrated improved fund of knowledge and skill performance. However, teams trained with simulation demonstrated sustained improvement in clinical management, interdisciplinary communication, and self-confidence when tested 3 months later. Teams taught by simulation also improved their interdisciplinary communication skills compared with those taught exclusively by lecture. Although not powered for statistical significance, this study indicates that simulation-based training offers advantages over traditional lecture-only methodology. It remains to be seen if such improvements are long-lasting and how frequently simulation-based team-training coursework should be repeated to maintain clinical proficiency.

**Simulation in gynecology**

Simulation in gynecology involves the reenactment of routine or critical gynecologic events involving women across the lifespan for procedural or behavioral skills training, practice, evaluation, or research. As such, the full
spectrum of verbal role playing, standardized characters or actors, devices, mannequins, and environments can be used alone or in combination to achieve the desired educational goals and objectives of a curriculum. The focus here will be confined to simulation involving surgery and hospital-based care of women with reproductive or post-reproductive age-related gynecologic conditions. However, much of what will be addressed can be modified or adapted to reflect routine and critical events and simulation environments typical of the primary care or outpatient settings. Simulation targeting the female newborn and pediatric age groups will not be addressed, nor will simulation involving use of animals or cadavers.

Gynecological simulators

The history of gynecology simulators dovetails with that of obstetrics as small wax or wooden figures have been used since antiquity for illustrating reproductive processes, contraceptive techniques, and other gynecologic conditions that women experience [39]. A number of objects or more elaborate part-task trainers have been developed for training in and practicing procedures and surgical techniques or for examining the female breast and pelvis. These objects and trainers include suture trainers; training devices for proper placement and positioning of barrier, subcutaneous, and intrauterine contraceptives; and devices for practicing placement of periurethral slings. Pelvic ExamSim (Medical Education Technologies, Sarasota, Florida) is an example of an elaborate part-task trainer equipped with sensors and computer-based software that feeds back information to the learner about his or her performance [105,106]. High-fidelity, physiologically interactive, life-size human female mannequins are available and can be used for simulating gynecologic surgery scenarios in a simulated or real operating room environment. However, mannequin technology currently available is inadequate for realistically simulating open laparotomy involving major abdominal and pelvic organs, such as a benign or radical hysterectomy, an oophorectomy, or major vaginal surgery, such as hysterectomy, fistula repair, or vaginal vault suspensions. Gynecology-related video simulation or VR, computer screen–based or haptic systems currently offer greater opportunities for such purposes [107]. Few gynecology-oriented, total immersion VR-haptic environments exist and are primarily used in research. Hysteroscopic and laparoscopic simulators are best classified as part-task trainers ranging in fidelity from simple box trainers, or “physical simulators,” to hybrid mechanical-virtual or haptic systems.

History of minimally invasive surgery simulators

The acceptance and integration of laparoscopy as a credible technique for abdominal and pelvic surgery triggered growth in the number and variety of minimally invasive gynecologic simulators. The first endoscopy may have occurred in Greece during the time of Hippocrates. However, not until
1806 was an instrument created instrument that could be inserted into the body for visualizing internal organs. This was the invention of Phillip Bozzini of Germany. His idea, although never tested on humans, was ultimately reintroduced and accepted by physician-surgeons in the late 1800s [108]. Visualization of the stomach and urethra was first accomplished. Then visualization of the organs of the abdomen and thorax was made possible when Kelling of Germany created the technique of pneumoperitoneum in the early 1900s [109]. The technique was adapted for use in gynecology in the late 1930s by Telinde and in the early 1940s by Palmer shortly after introduction of the Veress needle for creating a pneumoperitoneum. Semm [110], a gynecologist in Germany, invented an automatic insufflator in the 1960s, a device that the American medical community embraced for its simplicity and safety features. Semm used the term pelviscopy to describe his surgical procedure. The American Association of Gynecological Laparoscopists was founded in 1971, but it was not until 1981 that the American Board of Obstetrics and Gynecology mandated that laparoscopy training be included in residency training programs. Semm [111] created the first laparoscopy training device in 1985 for colleagues to practice their surgical techniques. His “pelvi-trainer” had a clear cover that permitted novices to directly view their techniques. An opaque cover could be used in place of the clear cover. A video screen was later added to the system for more realistic simulation of the laparoscopic procedure. Application of VR technology was initially proposed by Satava [112] in 1993, but was slow to be adopted and integrated into surgical training programs. VR technology is now commercially available and is an integral component of advanced minimally invasive surgical simulators. Gallagher and colleagues [113] defined VR as a “computer-generated representation of an environment allowing sensory interaction,” giving an impression of realism. They noted in 2005 that the two most likely reasons for delayed adoption of VR technology in surgical simulation included the lack of solid scientific proof supporting its use for skills training and the lack of knowledge of how best to incorporate simulation within a surgical training program.

Current use of gynecologic simulators

Minimally invasive gynecologic surgery simulators should be able to differentiate between the experienced clinician and the novice and to discern improvement with successive use [114,115]. Ideally, such a simulator should be affordable and user-friendly as with a simple box trainer or physical simulator. Physical simulators are mannequin torsos or similar objects that can be placed on a table or platform and that can accommodate the insertion of laparoscopic instruments and the operation of such instruments to grasp or manipulate small objects within the simulator resembling or representing internal organs. Physical simulators permit the use of the same or similar instruments and camera equipment employed in real operating rooms and
give learners the opportunity to perform surgical gestures similar to those used in real cases, providing realistic depth perception and tactile feedback to the student. The original VR simulators were expensive and not equipped to provide the depth perception and tactile feedback typical of real cases. Such limitations have been addressed with newer models that benefit from advances in computer technology and increasing demand for safer and more practical ways for clinicians to acquire and practice their skills without harming patients. However, VR simulators continue to be more costly than physical trainers. Examples of VR laparoscopic simulators include the Minimally Invasive Surgical Trainer–Virtual Reality (MIST-VR) simulator (Mentice, Gothenburg, Sweden); the LapSim virtual reality laparoscopic simulator (Surgical Science, Gothenburg, Sweden) (Fig. 6); the Xitact instrument haptic port simulator (Gothenburg, Sweden) (Fig. 7); the Lap Mentor simulator (Simbionix USA, Cleveland, Ohio); and the Computer Enhanced Laparoscopic Training System (Center for Integration in Medicine and Innovative Technology, Boston, Massachusetts).

Skills acquisition and training

Much has been written about the use of minimally invasive surgery simulators for skill acquisition and practice. These reports have investigated whether or not such simulators facilitate training and their ability to detect change in performance. The following selection of recently published articles in the gynecology and surgery literature illustrates the utility of laparoscopic

Fig. 6. LapSim-VR. (*Courtesy of Surgical Science, Gothenburg, Sweden; with permission.*)
simulators for skill acquisition and training. Fichera and colleagues [115] in 2002 to 2003 investigated the use of physical trainers for skills acquisition, clinical training, and differentiation of novice from veteran gynecologic and surgical laparoscopists. Using the LTS 2000, Fichera and colleagues showed that this device reliably detected laparoscopy expertise and change in performance over time with improved suturing and coordination scores ($P<.05$). Scott and colleagues [116] in 2000 compared surgical skills of residents using physical trainers to the skills of residents who did not use the trainer. They found higher global assessment scores during real-time laparoscopic cholecystectomy for the simulator-enhanced training group compared with those without such training. The improved global scores were accompanied by improved respect for tissue, skills in handling instruments, use of surgical assistants, and overall performance. These findings demonstrated that physical trainers are a viable alternative to VR simulators.

VR simulators have been scrutinized in a similar fashion and their use has also been shown to reliably detect laparoscopy expertise and change in performance over time.

Seymour and colleagues [117] in 2002 used a randomized, double-blind controlled trial methodology to evaluate VR simulator–based training. They found that such training improved performance in the operating room. Additional studies have used the MIST-VR system, a skills-oriented trainer without haptic feedback that requires the student to perform six tasks: (1) acquire and grasp, (2) transfer and place, (3) traverse a segment, (4) withdraw and insert, (5) perform a diathermy, and (6) perform
a diathermy and manipulate. Gallagher and colleagues [118] and Grantcharov and colleagues [119] found that prior laparoscopic experience was highly correlated with technical skills using the MIST-VR system. Munz and colleagues [120] in 2004 investigated whether laparoscopic VR trainers were superior to box trainers and found no significant differences in laparoscopic skills acquired between groups of novices who trained with either of these simulators. Grantcharov and colleagues [121] also investigated whether or not skills acquired in the laparoscopic simulator would transfer to the real surgical arena. They randomized surgical residents to usual training or usual training enhanced by MIST-VR training. Evaluated with global rating forms, surgical residents who trained with the simulator demonstrated shorter operating times and more efficient surgical gestures during real laparoscopic cholecystectomy compared with those who had not.

Hart and Karthigasu [122] in 2007 reviewed the use of VR simulators for laparoscopic surgery and noted that the MIST-VR is the most widely used, studied, and validated simulator system for general surgery training in the United States. The MIST-VR is also the simulator most demonstrated to be of value for the education and training of gynecologists. However, LapSim remains a useful system because it provides more realistic simulations. For example, it can simulate bleeding organs that deform and change as the procedure evolves. Aggarwal and colleagues [123] reported in 2006 on the use of the LapSim for training technical skills in managing ectopic pregnancy. Using LapSim in successive sessions, they compared experienced and novice gynecologists in their performance of tasks involved in such surgery. They found that novices demonstrated significant improvement in their surgical gestures, whereas experienced gynecologists demonstrated little change over time. LapSim appears to be useful for facilitating skill acquisition for novice surgeons who plan to perform laparoscopic surgery for ectopic pregnancy. Hamilton and colleagues [124] found that surgical trainees considered the box trainer more realistic because it provided better tactile feedback and depth perception compared with other simulators. Similar findings were noted more recently by Madan and colleagues [125] in 2005. Laparoscopic simulators, either box trainers or VR trainers, facilitate skill acquisition and training, especially for the novice, and such training is translatable to the operating room.

Assessment

Assessment of skill performance and competence is possible with the box trainer and the VR laparoscopic system, each having its own advantages and limitations. Chou and Handa [126] appreciate a more promising role for VR systems. Objective data can be recorded by the software and later analyzed for such factors as accuracy of task performance and completion times, efficiency of surgical gestures, and handling of thermal-generating devices. Feedback is provided in an unbiased manner and reports can be
generated showing change over time. Gor and colleagues [127] evaluated the use of a VR system (MIST-2) and found it useful as an objective measure of laparoscopic skills demonstrated by gynecologic surgeons. By comparison, box trainers require the presence of an instructor to observe performance and provide feedback, which can be biased and unreliable. Structured assessment programs have been developed to standardize the process and minimize observer bias. One such program is the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills (MISTELS) [128]. MISTELS requires users to perform a series of five tasks. These tasks are scored using an objective system that has met reliability criteria for high-stakes testing. However, the box simulator and the VR systems can be used to objectively assess competency and proficiency in task performance, making it possible to discern skills of novices from those of veterans and to identify improvement in skill acquisition over time. These simulators may assist trainees in making career choices, especially those trainees unable to demonstrate proficiency in basic surgical skills [118], and in practicing new skills or new procedures before trying them for the first time on live patients [122].

**Credentialing**

Simulation is being used in various accreditation programs around the world. The Israel Center for Medical Simulation is at the cutting edge in the use of simulation for summative evaluation and accreditation programs, including the medical school selection process, national board examination in anesthesiology, and national accreditation for paramedics [129]. Ziv and colleagues describe how prospective candidates for medical school must complete various questionnaires and behavioral assessments, and participate in observed structured clinical examination–like (OSCE-like) stations that include simulation of patient encounters with role-playing and standardized patients. The experience with these endeavors thus far has been positive. However, validity of this approach will be assessed and monitored as medical students selected progress through their training. The Israeli board examination in anesthesiology lacked a performance evaluation component until about 4 years ago. Capitalizing on the experience of the Fellow Royal College of Anesthesiology in the United Kingdom, the board examination committee joined with a panel of experts in testing and evaluating to create a series of simulation-based OSCE-like stations representing core problems that anesthesiologists encounter in the course of clinical practice. Subjective feedback with the process and satisfaction with the realism of the scenarios thus far has been favorable. The mean interrater correlations of examiners were high (0.89 to 0.76), the rate of incongruence was low (<15%), and the correlations for intercase reliability were significant ($P < .01$).

The Accreditation Council for Graduate Medical Education supports rigorous competency assessment of residents in a number of areas, including
those related to interpersonal and communication skills, professionalism, and systems-based practice [130,131]. With this in mind, Julian and Rogers [132] recommend changes in the way gynecologic surgeons are trained. They propose a model guided by evidence-based educational studies and evidence-based clinical reports. They further propose standardizing the measurement of surgical teaching outcomes and surgical education curricula. They argue that students should practice basic surgical skills before assisting in surgery on live patients. They thereby support the use of simulation. They state that “the acquisition of core surgical knowledge, judgment, leadership qualities, and skills before the resident participates in live surgeries is the keystone in fulfilling the mandate to improve the ethics and effectiveness of training gynecologic surgeons.”

The future of simulation in obstetrics and gynecology

The specialty of obstetrics and gynecology is taking measured steps toward seamlessly integrating simulation within the fabric of education, training, and assessment of obstetrician-gynecologists. The experience chronicled above illustrates the great progress made thus far in appreciating the value of simulation in such endeavors. Driving these efforts are multiple factors both within and outside of the profession. These factors include restrictions on work hours of residents [133]; reductions in the medical work force coupled with increasing demand among health care workers to balance work with lifestyle preferences and family obligations [134–136]; rising malpractice premiums, threats of litigation, and payouts by juries ruling against defendants [137,138]; and diminished clinical opportunities for trainees when patients refuse to permit their involvement [139–141]. Specialty and subspecialty examining boards are establishing mechanisms for assessing task-oriented and behavior-based competencies for professional certification, validation, and re-entry. Professional organizations are considering or requiring simulation-based experiences for credentialing and recredentialing [130,142–145]. The need for competency assessment has triggered development and validation of task-oriented and behavior-based tools that discern proficiency in clinical endeavors [70,103,104], and these efforts will intensify. In some cases, professional certification and hospital credentialing programs now require core competency assessment of procedural and behavioral skills, including skills that demonstrate teamwork and professionalism [130,144,145]. Since the Institute of Medicine’s report on human error in 2000 [146], pressure has been growing to reduce adverse events and improve the safety and quality of patient care. Steps being taken toward this end include the implementation of requirements or strong recommendations to conduct obstetric emergency drills and skills training [60,147–150]. There are sporadic reports of medical professional liability insurers who now offer insurance premium discounts for participation in obstetric simulation-based and didactic team training programs [151–153]. It is unclear if this “carrot” approach toward facilitating
patient safety and mitigating medical error in the obstetric arena will be implemented by other medical professional liability insurers. Similar efforts have been made in providing an insurance premium incentive to clinicians who successfully complete training programs in fundamentals of laparoscopic surgery [154]. There are also reports of using simulation for remediation. For example, the New York State Department of Health’s Office of Professional Medical Conduct recently used simulation as a key component in their efforts to remediate anesthesiologists [155]. If deemed successful, this approach may be more widely adopted across the medical specialties, including obstetrics and gynecology.

Challenges to seamless integration of simulation into professional training of obstetrician-gynecologists include such factors as the high costs and limited quality of currently available simulators, limits on time and space available for such purposes, and lack of sufficient personnel skilled in their use. Trainees grapple with the caliber of fidelity and realism of current mannequin technology. Mannequins that look and feel more humanlike, equipped with realistic organs and tissue layers that bleed, would enhance the immersive quality of simulated scenarios. Research is needed to determine suitable environments that best meet the educational needs of trainees, identifying essential characteristics of simulators that facilitate acquisition, training and competency assessment of procedural and behavioral skills. As simulation technology and its use evolves, there will soon be a day when (1) the methods and techniques necessary to facilitate learning are well understood, (2) all members of the team will be trained in the safest way possible to manage all manner of obstetric and gynecologic events, and (3) all trainees will demonstrate procedural and behavioral proficiency in a simulator before being permitted to treat human beings, regardless of specialty or level of experience. The day is coming when simulation-based activities will be required for practice, and no longer will a novice try a procedure for the first time on a real patient without having performed it in simulation.

Summary

The technique of simulation for education and training in obstetrics and gynecology is not new. A brief review of the history confirms that this technique has solid roots deeply planted within the field of obstetrics and gynecology. However, until recently, technological limitations and other factors inhibited the use of simulation. Now, an appreciation for the potential value of simulation in health care education, training, and research is emerging and more applications are appearing. The days of relying on the apprenticeship style of learning in obstetrics and gynecology have passed. Simulation offers clinicians a safe, practical, and credible means to acquire skills and learn how to optimally manage clinical scenarios from the routine to the most uncommon or unusual events in contextually relevant settings. The effectiveness of simulation in reducing adverse outcomes is a matter of
debate and the focus of much research within the simulation community. Dutta and colleagues [156] assert that despite the lack of incontrovertible proof that simulation directly reduces adverse outcomes, “...we must recognize that no hazardous industry has anything remotely approaching level 1A ‘evidence’ to support their practices ...” Securing such proof may be as elusive in health care as it has been in aviation. The medical simulation community should instead focus on defining the key attributes of simulation environments across the spectrum of health care specialties that will best serve the needs for education and training [3]. The published literature in obstetrics and gynecology thus far supports simulation for practicing routine and uncommon but critical procedures and events, for improving technical proficiency, and for building self-confidence and teamwork among clinicians. As the science of simulation evolves in obstetrics and gynecology, adherence to sound educational objectives will best guide its development and inform the extent to which realism and fidelity of a specific simulated clinical experience is necessary. VR environments in obstetrics and gynecology are ripe for research and development [53,54,84,112,114], offering the greatest opportunity for training in the most realistic settings possible without harming real patients. Most VR simulators currently focus on surgical specialty skills and procedures. However, Chou and Handa [126] admonish that gynecologic surgery is not simply general surgery of the pelvis. VR product design must be mindful of the unique tasks specific to gynecology, and so too with obstetrics. Whether virtual or not, simulated obstetric and gynecologic environments should be designed to address the unique tasks specific to care of women across the lifespan so that, in the words of Sir Richard Manningham, “…where every Case that can happen may be represented and repeated as often as we deem necessary, you will have the greatest opportunity of forming your Hands for Practice” [39]. Effectively forming one’s knowledge, skills, and abilities for the practice of obstetrics and gynecology is a matter of safety and quality; indeed it is our ethical imperative.

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