Early Use of Simulation in Medical Education

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An oft-cited belief that, until recently, simulators used in education of health care professionals were simple models is wrong. Hundreds of years ago and, in one instance, thousands of years ago, intricate models were used to help teach anatomy and physiology and in training in obstetrics and many surgical disciplines. Simulators were used to learn skills before performing them on patients and in high-stakes assessment.

The newest technologies were often used in simulators to improve fidelity. In the 18th century, obstetric simulators could leak amniotic fluid, and blood were used to train midwives and obstetricians to recognize and manage complications of childbirth. Italy was the major source of simulators early in the 18th century, but in the 19th century, dominance in clinical simulation moved to France, Britain, and then Germany. In comparison, much of the 20th century was a ''dark age'' for simulation.
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The simulators used in health care education and training in the past are mostly thought to have been simple models. For example, Meller[1] wrote that ''From antiquity … clay and stone models of humans were used to demonstrate clinical features of disease states.'' He also noted that such models had been found from many cultures and continents but did not provide any references on this. Bradley[2] wrote, ''Clinical simulation does, in fact, span the centuries; for example, models have long been used to help students learn about anatomical structures,'' but this was also unreferenced. Most recently, Khan et al[3] suggested the use of simulation in medical education dates back centuries, but his source, like that of the Wikipedia page on simulation,[4] was the article of Meller.[1]

The aim of this article was to outline the historical use of simulators in medical education and training up to the early years of the 20th century. Some early simulators were simple, but many were very detailed or provided feedback, and others accurately represented human functions. The simulators themselves are just representations and need to be used appropriately to promote learning,[5] so where possible, how a particular simulator was used is described along with who used it. Centuries and even millennia ago, pioneers of simulation understood how to use simulation to develop competence and confidence in students and trainee health professionals.

THE FIRST CARVED FIGURES

The developments of carving and sculpture were necessary prerequisites to creating the first simulators. One of the first stone carvings of the human form is the ''Venus of Willendorf,'' from between 24,000 and 22,000 years BC.[6] The ''Venus'' has exaggerated breasts and hips, but interpretation of the meaning of ancient artifacts is unreliable. The features may represent morbid pathology, but similar figurines have been found throughout Eurasia, so it could be artistic convention.[7] The ancient Egyptians knew much anatomy from the process of creating mummies and carved some of the first anatomic figures, but they were for private display rather than education.[8]

One of the earliest surviving clay models to show anatomy is an Early Classic Maya (AD 300–600) head (Fig. 1). Half of this fired clay sculpture shows the head in life, and the other half reveals the skull[9] and is very like some *memento mori* that were popular in 18th- and 19th-century Europe.[10,11] A *memento mori* is a small and macabre carving, often a skeletal or dissected figure, meant to inspire the viewer by reminding them that life is short and death is inevitable. The Mayan head might have had a similar function.

BASIC PATIENT SIMULATORS

In China during the Song Dynasty, the imperial physician Wang Wei-Yi (987–1067) was responsible for standardizing teaching of acupuncture.[15] In 1027, he had 2 life-size bronze statues made for teaching surface anatomy and location of acupuncture points.[15,16] These simulators contained organs and had 354 open holes on the body where acupuncture needles should be inserted. It is thought that these models were covered in wax and filled with a liquid so that a drip when the acupuncture needle was removed would indicate that a trainee had located the point correctly.[15,17]

A few more large simulators were cast over the next 500 years,[15] but smaller models showing energy meridians

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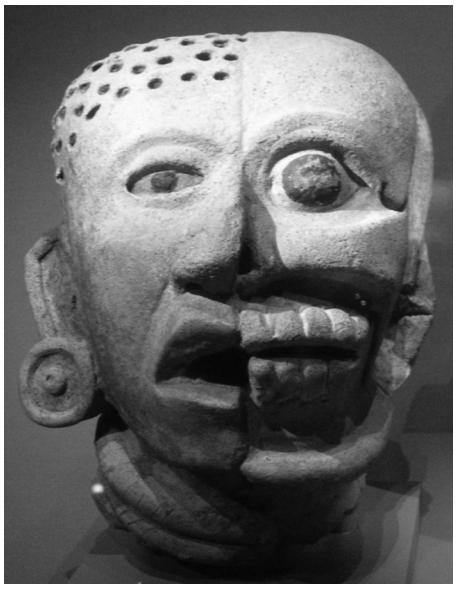

FIGURE 1. Pre-Columbian Mayan clay sculpture showing features of life and death at the National Gallery of Victoria (Adapted from Sailko. Available at: http://commons.wikimedia.org/wiki/File:Ngv,_veracruz,_testa_con_vita_e_morte,_300-600_dc.jpg).

and acupuncture points facilitated teaching outside the major cities. Thompson[18] described a small bronze model in the Wellcome Collection from the 14th or 15th century that had 90 acupuncture points marked by holes. The Science Museum in London has a 17th-century example carved from wood showing acupuncture points and meridians.[19]

Many miniatures of recumbent nude females were carved from ivory or horn in China between the 17th and early 20th centuries. The morality code of the Ch'ing Dynasty (1644–1912) meant that a female patient could not mention parts of her body to a male physician and, except for the pulse, a male physician could not directly examine a woman.[12,13] All physicians at this time were male, so to assist diagnosis, female patients would point out the site of the symptoms on a carved figurine. Alternatively, the patient could stay at home, and a relative or servant could just take the physician's lady or a diagnostic doll, as they are now known, to the consultation.[13,14]

ANATOMIC SIMULATORS

The desired effects of traditional Chinese or Japanese Medicine on body organs are more conceptual than anatomic or physiologic. In the Science Museum is a wooden carving from the 19th century of a human form that is cut away to show highly stylized anatomic structures.[20] The Wellcome Collection has another that has flower-shaped internal structures.[18]

In Europe, the publication *De humani corporis fabrica libri septum* by Andrea Vesalio in 1543 created interest in studying anatomy.[13,21] Dissected material was hard to preserve, and at various times and places, it was either difficult to acquire or illegal, so anatomic models were created from more durable materials. Wax body parts had been used as votive offerings in Catholic churches in Florence from the 13th century, and Ludovico Cardi (also known as Cigoli) used this technology to produce the first wax anatomic model in 1598.[22] The *Anatomia del Cigoli* ("Cigoli's Anatomy") or *lo scorticato* (the skinned man) is well preserved and displayed with a bronze copy in the Museo Nazionale del Bargello in Florence.[23] In 17th- and 18th-century Europe, écorché (flayed man) figures became widely used to instruct medical students.[13,24] The name described the model's appearance as if the skin had been cut away to reveal the muscles and blood vessels of someone often still standing, usually in an artistic pose.[25] Sometimes, sets of figures were created with successive layers of muscles peeled away to ultimately reveal the skeleton.[26] Full-size écorché figures were frequently copied in miniature for distribution, and miniatures were sometimes cast in bronze.[13]

Small carved human figures with representations of internal anatomy, and often presented as male and female pairs, were common in Europe in the 17th and 18th centuries.[18] Some had removable organs, and typically, the woman was pregnant with the fetus attached to the mother by a red silk umbilical cord.[27] In many of these models, the anatomy was quite crude, so it was thought that they would have been used by midwives to educate young couples about pregnancy and childbirth.[27] However, a note written by Joseph Fuardi de Fossau, professor at Verceil (Vercelli, Italy), that was found in the box of one anatomic model reveals that at least some were used to teach students. The professor had written that he made the anatomic model during the vacations of 1786 because he was ashamed that his surgical students knew so little anatomy.[18]

REALISTIC LIFE-SIZE PATIENT SIMULATORS

Cigoli had made his écorché out of red wax, and nearly a hundred years later, Gaetano Giulio Zumbo (or Zummo) used the latest technology, polychromatic wax, to make human figures.[21] His first models showed the stages of decay of a corpse and were so realistic that they were said to "…evoke a sense of overwhelming stench."[21] His first educational anatomic model was of a partially dissected head.[22] Zumbo was most productive during his time in Genova where he produced waxes of dissections by the French surgeon Guillaume Desnoues.[6] In the 1730s in Bologna, Ercole Lelli was commissioned by the pope to start making anatomic simulators specifically for medical education.[6,27] He was helped and succeeded by the husband-and-wife team Giovanni Manzolini and Anna Morandi. Anna became famous for her modeling especially of obstetric anatomy, and after John Morgan (founder of the University of Pennsylvania Medical School) visited her in 1764, he noted in his diary,[28] "…many anatomical preparations for teaching women the art of midwifery.…"

In 1771, Felice Fontana started a wax anatomic workshop in Florence to make educational models.[6,20] La Specola (the popular name for the workshop) specialized in female anatomy and made the subjects look more sensual than cadaveric.[29,30] The "Medical Venerina (Venus)," for example, is a young and beautiful reclining nude woman with real hair and a pearl necklace lying on a comfortable mattress, but her body is sliced open, and she has removable organs.

"The Florentine waxes are, moreover, irrespective of the subject, remarkably attractive; bodies seemed to be alive, pulsating; statues had a gentle look, a languid gaze; the 'Venuses' had long hair left loose or gathered into seductive plaits and were often adorned by pearl necklaces…"

and

'animated' eyes: coloured irises and candid whites give the impression of the eyes of a living person, or at the least those belonging to a still warm body.[20]

In the 19th century, anatomy exhibitions for entertainment began to appear in Europe and in the United States.[31] Popular exhibits included male and female anatomy, "the dreadful result of tight-lacing" corsets on the female body,[32] and demonstrations of the effects of syphilis.[33] These exhibitions had separate viewings for female visitors that had female guides and attendants, and some had special exhibits that could only be seen on payment of an additional fee. In the second half of the 19th century, attitudes to these exhibitions changed, and they were closed down, first in Europe (eg, Bates[34]) and then in the United States.[31] Anatomy displays in medical schools and professional colleges were exempted from obscenity laws because

Professionals such as doctors … were considered able, by virtue of their training and middle-class origins, to appreciate material that would corrupt weaker minds.[31]

MEDICAL MOULAGE

La Specola was open to the public from its inception, and this is partly why the Florentine anatomic simulators were imbued with sense of beauty.[20] Fontana was an artist who wanted the female models to appear perfect with all defects removed. In contrast, his male anatomic models were grotesque or in varying states of putrefaction. The wax models that Joseph Towne made for Guy's Hospital in London were for a medical audience and were exact copies of dissections and pathology, warts, and all.[20,35] Towne made more than 1000 models over 50 years, and the dermatologic models that he made are a unique record of conditions at an advanced stage that is rarely seen now.[35] Wax models of body parts showing manifestations of disease were known as medical moulages.[36–38] Medical moulages are expensive, but in the 19th century, wealthy medical schools developed extensive collections.[36] One of the reasons that some looked so realistic is that they were cast directly from patients.[37]

Limited access to dissections or wax models for learning anatomy in Paris led Auzoux, a French medical student, to experiment with less expensive media such as papier-maché.[8] Shortly after he graduated in 1822, he unveiled his first full-size model, and within a few years, he had a commercially successful company making detailed and accurate anatomic models.[39] An extensive collection of papier-maché anatomic models is held by the Smithsonian Museum of American History.[40]

In the 19th century, Germany developed a reputation as a leader of medical science. Most anatomists there agreed that models could be used for general education but that dissection was essential for medical education.[41] In the middle of the 19th century, after falling out with the medical establishment, the artist and modeler Paul Zeiller created a private collection of anatomy models. In 1864, Zeiller argued that there was not enough time in the medical curriculum for dissection and students would learn more if they visited the museum first.[42] Another role for models is to represent specimens too rare, small, transient, or difficult to preserve or preparations too laborious to make.[41] Adolf Ziegler, a contemporary of Zeiller's, specialized in embryology models. In the 1880s, Ziegler developed the ancestor of 3-dimensional printing by stacking up waxes of serial sections of embryos.[41] The large-scale models of small but rapidly changing structures were very successful in helping students learn how the fetus develops.

In the second half of the 19th century, Steger in Germany began making anatomic simulators from plaster that were less expensive than wax or papier-maché models from the established model makers.[43] They were also reputed to be more accurate because they were based on casts of frozen specimens.[43]

Phrenology briefly came to prominence in the 19th century, and porcelain was used for some phrenologic head simulators. Phrenologists believed that the shape and size of various areas of the brain (and therefore the overlying skull) determined character and personality. Porcelain heads marked off into phrenologic sections were produced for teaching,[44] and casts of heads of famous people and executed criminals were made for research and teaching.[45] Phrenology became very popular in the 1800s but was then proven to be worthless.

MUSCULOSKELETAL SIMULATORS

The earliest mention of an articulated model skeleton is in *The Satyricon*, the earliest surviving novel, probably written by Petronius around AD 61. The book is a satire on life in Rome under Nero.[46] In chapter 34, The Dinner of Trimalcho, at the end of the meal, a slave brings "…a silver skeleton, so contrived that the joints and movable vertebra could be turned in any direction."[47] Its purpose was that of a memento mori.

An iron model of the major joints of the skeleton thought to have been used to teach about limb articulation and limb dislocation, injuries to limb joints, and their subsequent treatment was made in Italy somewhere between 1570 and 1700.[48] It is very similar to the illustration in Fabricius's *Opera Chirurgica*, his "Surgical Works," first published in 1582. Fabricius himself made the first working eye simulator in 1609.[49] It had strips of leather for the ocular muscles and could be taken apart to demonstrate anatomy and physiology.

Fontana worked in wood and wax at La Specola and began developing a collection of jointed wooden statues hoping,

…it will be of infinite use in providing a perfect knowledge of all organs of the human body.[22]

One of the few surviving models is a standing figure made of 3000 intricately detailed wooden pieces that could each be moved, and the figure could be made into a male or

female.[8] It took Fontana 10 years to make this model, and in 1796, Napoleon Bonaparte ordered a copy but reputedly changed his mind after finding out how much the model would cost.[6] Good simulators have always been expensive.

AN EARLY TRAUMA SIMULATION

An early application of simulation to trauma care took place in 1559. During a tournament, a lance had pierced the helmet of Henry II, king of France.[50] The Royal surgeon Ambroise Paré attended the king but did not think that he would survive the infection developing in his right orbit from splinters of wood. The anatomist Vesalius was consulted, and then in an attempt to determine the exact injury and possibly find a cure, Queen Catherine "…had four criminals beheaded and broken truncheons thrust into the eyes of the corpses at the appropriate angle of penetration."[50] The experiment did not help, and as predicted, the king died soon afterward.

OBSTETRIC SIMULATORS

The models described previously are clearly more than simple carvings, but although highly detailed simulators and valuable for instruction, demonstration, and assessment, they were not designed for inclusion in simulation. The models described in the next section were designed for interaction.

In the middle of the 18th century, Giovanni Antonio Galli, a surgeon in Bologna, noticed that surgeons had theoretical knowledge but the midwives who assisted women in childbirth were often poorly educated and had only their limited personal experience.[6] Galli designed a birthing simulator, a glass uterus in a pelvis and a flexible fetus, to train midwives and surgeons in childbirth. Students were tested by having to deliver the fetus blindfolded.[6] This is possibly the first example of a learning need giving rise to simulation training and assessment. The actual simulator is on display at the Musei di Palazzo Poggi in Bologna (Fig. 2).[6,51] Also on display are a number of obstetric teaching models made from wax that were commissioned by Galli.

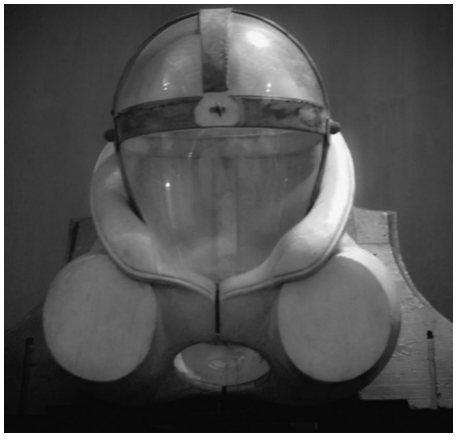

FIGURE 2. Birthing simulator made around 250 years by Dr Giovanni Galli in Bologna. The simulator is part of a display of anatomic models and obstetric teaching aids at the Museo di Palazzo Poggi, Università di Bologna, Italy (Dr Morgan Edwards).

In 1739, the first maternity hospital in Britain was founded by Sir Richard Manningham in London. From the beginning, Manningham used an obstetric simulator, also with a glass uterus, for students to practice management of complicated deliveries without risk to patients.[52]

> *Lectures will be read and young physicians, surgeons, and women, perfectly taught the art and practice of midwifery, and the performance of deliveries of all kinds even the most difficult with the utmost decency and dexterity by means of a contrivance made on the bones or skeleton of a woman with an artificial matrix (of glass), whereby all the inconveniences which might otherwise happen to women from pupils practising too early on real objects will be entirely prevented: for by this method and contrivance each pupil will become in a great measure proficient in his business before he attempts a real delivery.*

Marie-Catherine Biheron was a French anatomist well known for making lifelike "dissectable" wax models. In 1770 and again in 1771, she demonstrated a new model of a pregnant woman to the Académie Royal de Sciences in Paris.

> *The model reproduced exactly all the stages and mechanisms of birthing, complete with a moveable coccyx and a cervix that dilated or closed on demand and removable infants. The device was particularly useful for demonstrating to students how to cope with dangerous deliveries without doing harm to a living subject.*[53]

A reported decline in population in rural France worried Louis XV, and in 1759, he commissioned Angélique Marguerite Le Boursier du Coudray to teach midwifery skills throughout France to save babies for the state.[54(p3)] Madame du Coudray modernized obstetric pedagogy and promoted a consistent approach for managing childbirth and its complications through a course of 40 sessions over 2 months. She wrote a manual to accompany the course, *Abrege de l'art des accouchements* that went through 6 editions between 1759 and 1785. Unusual for the time, the book was lavishly illustrated with colored plates, but this was because most of her students, peasant girls in rural France, were unable to read. Another innovation was to color-code some illustrations to assist learning.[55]

For practical skills training, du Coudray made an obstetric "machine," a life-size mannequin covered in pink material representing the lower part of a female torso, genitalia, and upper thighs.[54(pp16,17)] The removable uterus was made with a nulliparous and multiparous os, and a silk ribbon drawstring was used to simulate cervical dilatation.[56] The basic set included a life-size newborn, a 7-month-old fetus, and even twins. Sponges to release clear and red liquids (simulating amniotic fluid and blood) at appropriate times were accessories for later models.[54(p62)]

In a letter dated August 1, 1760, she explained advantages of her simulator-based training program[54(p241)]:

> *A surgeon or woman who takes the sort of course available until now will learn only theory [and will expect] the situations to be uniform, or at least not very varied.*

But when difficulties arise, they are absolutely unskilled…

and

We have the advantage of students practising on the machine and performing all the deliveries imaginable. Therein lies the principal merit of the machine.

Madame du Coudray recognized the importance of repeat practice and arranged for simulators to be left at a number of places that she visited. She told the La Rochelle regional supervisor that

The machines I leave with surgeons must be used each year to renew the lessons for the country women.[54(p241)]

In turn, recommending du Coudray's program to surgeons in his region, the supervisor wrote about her teaching situational awareness to the midwives:

…her greatest lesson is to recommend prudence to them, to instruct them … to call capable surgeons early to help them out, to save the subject and turn her over in good shape to the surgeon without waiting.[54(p241)]

A restored du Coudray obstetric simulator from 1778 is on display at the Musée Flaubert et d'histoire de la Médecine in Rouen, France.[56,57] When it was being restored, it was found to contain the pelvic bones of a young woman. A late 18th-century copy of *la machine* (Fig. 3) is on display at the Dittrick Medical History Center and Museum at Case Western Reserve University, Cleveland, Ohio.[58]

Madame du Coudray had detractors, for example, the Parisian surgeon Jean la Bas, who in 1776 wrote publicly of the mannequin,

…as no more than a fable, a phantom, a simulacrum, a shadow of reality, capable of giving false ideas to beginners who, once their heads are thus filled, will not be able to avoid practicing bad work on live subjects.…[54(pp233,234)]

Apparently, his views were not universally accepted because, 8 years later, Madame Coutanceau, du Coudray's niece and now a midwife herself, was able to write,

FIGURE 3. An 18th-century "du Coudray" obstetric simulator with fetus (Dittrick Medical History Centre, Case Western Reserve University, Cleveland, OH).

…that du Coudray's machines, or 'phantoms,' are still in use throughout the kingdom, especially in Picardy, Dauphiné, Touraine, Anjou, Champagne, Flanders, Normandy, Brittany, and Lorraine.[54(p247)]

The revolt of Paris in 1789 led to the dramatic collapse of the royal administration, and the new Republic canceled funding for the rural obstetrics teaching program, and du Coudray, who had received payments from the now beheaded king, was hounded to death.[54(p274)]

Also in the 18th century in France, the Gregoire father and son surgeon accoucheurs (as obstetricians were once known) in Paris made obstetric "phantoms" for teaching and used dead babies.[59] They used a human pelvis and a dead baby. The Scot William Smellie attended courses by Gregoire Jr in Paris[60] in 1739 and learned to use a pelvis to demonstrate different delivery positions.[61(p133)] When Smellie returned to the United Kingdom, he constructed an improved phantom of human bones covered in leather and a fetus made of wood and rubber with articulating limbs and a placenta.[62] In 1742, he advertised that he would

…begin a course of lectures on the theory and practice of midwifery, wherein all the branches of that art would be fully explained, and the whole illustrated with proper machines so contrived as to represent real women and children.

Some midwives and surgeons ridiculed Smellie for using fetal simulators and not cadavers for training. A London midwife, Elizabeth Nihell wrote,

Instead of a child you make use of little stuffed Babies, which have rather amused than instructed your pupils.[63]

Others, such as Thomas Young who was a professor of midwifery at Edinburgh recognized the value of simulators and scorned courses that did not include them saying,

…it is impossible to make one understand the practical part without showing it upon the machines.[64]

There were many obstetric simulators made in the 18th and 19th centuries, but the maternal machines and mechanical fetuses constructed by Smellie were probably the most intricate. In "A Short Comparative View of the Practice of Surgery in the French Hospitals," John Harrison described Smellie's simulators,

…as composed of real human bones, arm'd with fine smooth leather, and stuff'd with an agreeable soft substance. All the parts seem very natural both to look and touch; the contents of the abdomen are beautifully contriv'd, the intestines look very natural, as likewise the kidneys, and large vessels. The uterus externum and internum are made to contract and dilate according to the difficulty intended for the delivery. The children for these machines are likewise excellently contriv'd, they having all the motions of the joints. Their craniums are so formed as to give way to any force exerted.[64]

The simulators were inherited by Dr John Harvie, one of his pupils who had married Smellie's niece.[61(p133)] In 1770, he sold 4 maternal simulators and 8 fetal simulators at auction. The surgeon William Hunter bought one and

subsequently sold it to Edward Foster, another student of Smellie, who was recorded as using it for teaching at the Rotunda Hospital in Dublin.[61(p134)] Sadly, none of the simulators have survived. Lieske[65] commented that there was strong evidence of who used obstetric machines in 18th-century Britain, but little else so they

> *…fall into a hazy void where their role in midwifery training is acknowledged, but details on what machines might have looked like and how they were used is hidden.*

The Dutch surgeon Roselt is recorded using a phantom for teaching midwives in the middle of the 18th century.[66] In Germany in 1794, the University of Göttingen purchased an obstetric phantom made from a female pelvis covered in leather for Friedrich Osiander to use in practical obstetric teaching at the university's maternity hospital.[67] Simulator-based teaching of determining fetal position and dealing with difficult births was first scheduled by Osiander for Wednesdays and Saturdays every week, but this soon had been increased. He had a maximum group size of 4, and when he was unavailable to teach, he had a more experienced student to supervise the others.[67] Osiander tried to make the teaching on the simulator as authentic as possible and preferred to use dead babies preserved in alcohol instead of dolls. Four years later, Osiander bought a second simulator that he paid for himself to give students more opportunities to practice.[67]

In 1831, Dr Ozenne[68] presented an improved mannequin that had been working on for 6 years to the French Royal Academy of Medicine. It was a very sophisticated whole-body patient simulator that was designed to be very realistic. The uterus was made of longitudinal and radial fibers that could be made to contract, and the strength, rate, and rhythm of contractions could be controlled. There was an amniotic sac, and the artificial fetus had a head with fontanelles and a moveable lower jaw and a rump. Ozenne[68] described how novices could use the model to learn to recognize the various presentations of the fetus and practice uncomplicated deliveries, including protecting the perineum against tearing. More complicated scenarios could then be presented such as tumultuous contractions, transverse lie, and those needing application of forceps. According to Ozenne,[68] using the simulator would allow students to participate in many more births than would be possible in clinical attachments. Ozenne[68] noted that the simulator could be used to recreate particular births and study possible interventions.[68] Commissioners of the academy proposed that it was a significant advance and would be useful for "schools of childbirth." A brief summary of the report appeared in the New-York Medico-Chirurgical Bulletin later that year.[69]

Most women in the 19th century chose to give birth at home to reduce the risk of puerperal fever. In his history of the University of Michigan Medical School, Davenport[70] noted that, in the late 19th century, there were very few obstetric cases for teaching and that

> *…what practical training students had was with a mannequin.*

Davenport[70] did not record anything about the simulator. It could have been an American simulator because, in 1858, Henry Habermehl of Philadelphia, a maker of cases in wood and leather for surgical and obstetric instruments, announced that he also made teaching aids including "mannequins for obstetric instruction."[71] It is, however, more likely to have been a European import (see next paragraphs).

Japan also had pregnancy and childbirth simulators in the 19th century. Although very detailed and once thought to have been used for teaching midwives, it is more likely that they were created for *misemono*, sideshows with "…educational and entertaining attractions designed to evoke a sense of wonder and satisfy a deep curiosity for the mysteries of life."[72] A report[72] from 1864 described a popular show in Tokyo's Asakusa entertainment district that

> *…featured a pregnant doll whose abdomen could be opened to reveal fetal models depicting the various stages of prenatal development.…*

Bodies have been used as simulators for medical education. Elek[73] described how the patients who died were prepared for teaching at the University of Vienna medical school in the 19th century:

> *The subjects for operation were the bodies of women who had died in the hospital, most likely in the lying-in division, because recent parturition would improve them as 'material'. The abdomen was opened and the pelvic viscera removed by way of preparation, so as to make room for the foetus. After the foetal corpse had been placed into position, it was held by the teacher, and the pupil proceeded to perform the operations of version, decapitation, etc. as required.*

Professor Johann Klein introduced teaching through postmortem, whereas his predecessor Lucas Boer had learnt obstetrics in London and used a mannequin to teach students.[74] Under Boer, the maternal mortality rate was around 1.25%, but after Klein replaced simulation with postmortem, it increased 10-fold. Semmelweis[74] was appointed assistant to Klein in 1884 and saw 406 women die of puerperal fever in his first year of work, so there was no shortage of this teaching material.

Klein was not impressed by the theory of Semmelweis[74] that poor hand hygiene was the cause of puerperal fever and denied him tenure. Semmelweis[74] petitioned the university for the post of docent, a private lecturer, but when this was eventually given in 1849, it was on condition that he only taught using a manikin. The low status implied by teaching using only simulators was humiliating for Semmelweis,[74] and he quickly left Vienna and returned to Pest. The status of teaching using simulators has improved, but more than 150 years later, poor hand hygiene is still a cause of adverse outcome in health care, and simulation is now being used to reduce the rate of hospital-acquired infections.[75]

In mid–19th-century Spain, a revolution led to widespread educational reform, and many new schools and universities were established. A school for midwives was founded in Madrid around 1868, and Francisca Iracheta, a midwife, was employed to provide theoretical and practical training.[76,77] In 1870, Iracheta published a basic manual for midwives that included explanations on how to pronounce technical terms

so that they could communicate better with obstetricians.[77] The book also included a pattern to make an artificial pelvis to use as an obstetric simulator if a *maniquini* ("manikin") was not readily available.[76,77]

Professor B. S. Schultze at the University Women's Hospital in Jena, Germany, designed gynecologic phantoms made of leather on a metal stand. Diagrams of these simulators and instructions on how to prepare tissues for attachment of the simulator were published in *Archiv fuer Gynaekologie* in 1834.[78] Schultes Medacta took over manufacture of the model in 1890,[79] and they still make obstetric simulators. Stedman's Medical Dictionary (2006) includes *Schultze phantom* as a generic term for a model of a female pelvis used in demonstrating the mechanism of childbirth and the application of forceps.[80]

In his textbook on obstetrics, Winkel[81] compared using cadavers and manikins for practice and described his improvement of Schultze phantom.

> *One can practice these operations on the cadaver as also on the manikin. Since the former is only possible in large maternity hospitals where there are many deaths among the recently confined, one is compelled to content himself with the manikin, which was devised, most probably, at the close of the seventeenth century by Guillemeau, Sen. This has been so much improved that it does almost as well as a cadaver. Practicing the operations on the pelvis of a woman who has recently died, still covered with the soft parts, has no advantage over practicing on good manikins, which contain both normal and contracted pelves, and in which the preserved body of a newborn child is used. Of late these manikins, which were formerly made separate for the back and the side positions, have been so perfected by B. Schultze, of Jena, that they serve alike for both. I have introduced into this an elastic uterus with cervix and vagina, and have thus produced a manikin which answers every purpose.*

At the January 1889 meeting of the Obstetrical Society of Philadelphia,[82] Dr Theophilus Parvin presented a Winkel obstetric simulator he had obtained in Munich,

> *…for the purpose of teaching students practically many of the operations upon such organs by the method proposed and pursued by Prof. Winkel—that is, the organ being properly fastened within and upon Schultze's obstetric phantom, many of the more common operations can be made by the student as upon the living subject.*

Parvin also presented an obstetric simulator made to his own design:

> *The joints are sufficiently mobile so that the model can be placed on the side or on the back, the limbs put in any position desired. The pelvis is of iron covered with leather and has a movable coccyx, while the external parts are made of rubber, which will dilate so as to admit the passage of a foetus. The abdominal cavity is ample for the introduction of two foetuses. One or both may be included in the rubber uterus designed by Prof. Winkel and thus placed in that cavity.*

A drawing of Parvin's simulator was included in an article published by Edgar[83] in 1890, where he described several and commented "…on the necessity for studying models before actually attending parturient women."

At the University of Pennsylvania, Penrose taught obstetrics using a manikin and staged all the emergencies of childbirth.[84] The simulator was known as Mr O'Flaherty and was said to have "lived on" for some years after Penrose died.[85]

In the article Williams[86] presented to the 1898 Association of American Medical Colleges annual meeting, he said that training on a simulator was integral to teaching obstetrics. He also reported that the teaching staff at Johns Hopkins University considered

> *…it advisable that the students be taught the rudiments of palpation, touch, and pelvimetry upon the manikin, so that they will know exactly what they are to do when they examine the patients in the wards, whereby clinical material is economized, and the patients saved considerable annoyance. For this purpose, the Budin-Pinard manikin is to be recommended.*

Busey[87] described his medical training in Washington, District of Columbia, in his *Personal Reminiscences and Recollections* published in 1895,

> *Every student was required to perform on the manakin, with the assistance of his nurse, in the presence of the whole class of men and women, every manipulation and operation necessary from the beginning of labor to its termination.…*
>
> *These manipulations had to be repeated as often as necessary to satisfy the Principal of the Institute of the student's competency to attend a case of labor.*

Writing on the history and development of the Department of Obstetrics and Gynecology at the Long Island College Hospital, Polak[88] observed that

> *It was [Charles] Jewett who popularized manikin instruction, teaching his students diagnosis by sight, touch and hearing, making them familiar with the manual operative procedures and drilling them on the manikin in the use of forceps; so that notwithstanding the paucity of clinical material, when a Long Island man was confronted by an obstetric proposition, he was qualified to deal with it.*

Around this time, several US medical schools (eg, Rush Medical College in Chicago,[89] Medical College of Indiana,[90] Meharry Medical College in Nashville,[91] and Medical College of Virginia[92]) specifically mentioned that simulators were used in their obstetric courses in promotional literature. However, Flexner,[93(p117)] in his damming report *Medical Education in the United States and Canada*, reported generally poor facilities for teaching clinical obstetrics with 2 medical schools having manikins (Flexner[93] used the term manikin) in poor repair (Table 1), and in others, there were "…recitations in obstetrics without a manikin in sight, often without one in the building."[93(p124)] Flexner[93(p97)] specifically recommended that obstetric training should commence with simulation.

> *After preliminary drill with the manikin, the student first assists, then has charge under an instructor, of the cases in question.*

TABLE 1. Facilities for Teaching Obstetrics in US Hospitals in 1909

Georgia College of Eclectic Medicine and Surgery, Georgia: ''…limited to a tattered manikin.''
Southwestern University Medical College, Texas: ''…in a corner of one [lecture theatre] is an abused manikin.''

Adapted from Flexner.[93] Available at: www.archive.org/stream/medicaleducation00flexiala/medicaleducation00flexiala_djvu.txt.

The report of Flexner[93] led to reform of medical education generally, but there was a mixed response to recommendations on using simulation in obstetrics. This was evident from the results of a questionnaire survey of 12 leading representative US medical schools' undergraduate obstetric teaching published by Mendenhall[94] in 1922.

> *The next four questions were submitted with the idea of ascertaining the relative importance given to didactic, clinical, and manikin courses, and the average length of time devoted to each of these divisions. The replies showed that 86 hours were given to didactic obstetrics, 81 hours to clinical obstetrics and 31 hours to manikin practice. There were no wide variations in these answers except that one school has as many as 90 hours of manikin practice, and another as few as 8 hours. It is doubtful whether 8 hours is more than one-fourth sufficient time for the student to have in manikin practice. If a proper demonstration is given, and then the practice on the manikin is properly supervised, there is little doubt but that 30 hours can be most profitably utilized in this method of teaching. One of the most important fundamentals in the study of obstetrics is a perfect understanding of palpation, corroborated by an actual view of the various points considered in presentation and position, and a familiarity with the various manipulations to be acquired in prolonged work over the manikin. The average student has great difficulty in memorizing from lecture notes or textbooks the many points which can be made very practical and easy for him to remember, by a properly conducted manikin course. Less than twenty-five or thirty hours spent in this work will certainly leave much to be learned.*
>
> *The next question proposed was 'When, in the obstetric course, is the manikin practice started?'*
>
> *There was but little uniformity in the answers received, but there seemed to be very excellent reasons why this course should be delayed until late in the senior year, after the student has completed, or practically completed, the didactic lectures in obstetrics. In other words, after he has had a thorough course in the theory of obstetrics, the manikin instruction will be a supplementary, practical application of his theoretical knowledge; it will serve to emphasize by sight and touch those facts which have been presented didactically.*

Many obstetric simulators were available in the United States in the late 19th and early 20th centuries. The Clay-Adams Company advertised a new Adams ''OB'' Phantom in the *Bulletin of the New York Academy of Medicine*.[95] The simulator was made of hardwood with a triple layer of flesh-colored enamel, and there was an accompanying leather fetus doll with an umbilical cord and a placenta. The advert said that the company could also supply ''Schultze,'' ''Budin and Pinard,'' and ''Tramond and Selheim'' phantoms. The 1915 catalog of the Kny-Scheerer Corporation (New York) also lists a number of obstetric simulators and accessories with some illustrations.[96] A bladder and a uterus made from rubber for the Budin and Pinard simulator were priced at US $8.50 (Table 2), but there was a note that the war in Europe was affecting supply and cost.

Not everyone valued simulation. Explaining why the new (1909) edition of his obstetric textbook was so good, the author, Dr Farabeuf, declared,

> *How have I always observed and experimented? On pelves of bronze or wood? Never in my life. I am not so stupid. I have observed, manipulated, and experimented on dead bodies preserved in glycerine and consequently kept supple; and, when 'possible, on the dead bodies of eclamptic patients who were in labour.*[97]

TABLE 2. Obstetric Simulators and Accessories Listed in the 20th Edition of the Kny-Scheerer Catalogue (New York; 1915)

	Item	Net Price, $
Obstetric phantoms		
E/-2120	Plain pattern phantom with fetus	40.00
E/-2124	Budin and Pinard's phantom, with fetus	150.00
E/-2128	Edgar's phantom, complete leather-covered figure, with fetus	200.00
E/-2131	Schultze phantom, chamois covered, without fetus	75.00
Fetus		
E/-2124	French pattern artificial fetus, leather covered, with compressible head	20.00
E/-2156	Schultze's artificial fetus, chamois covered	16.50
E/-2160	Natural fetal skull	3.50
Accessories		
E/-2164	Vulva with perineum, soft rubber, for Budin and Pinard's phantom	10.00
E/-2165	Abdomen, soft rubber, for Budin and Pinard's phantom	10.00
E/-2166	Bladder and uterus, soft rubber, inflatable, for Budin and Pinard's phantom	8.50
E/-2167	Labia and vagina, soft rubber, Deshayes', for Budin and Pinard's phantom	10.00
E/-2168	Winckel's uterus, soft rubber	9.00
E/-2166	Schultze's set of 5 perforated discs, soft rubber for practicing touch	6.50

The catalog had been prepared before the war in Europe broke out. This had a big impact on the cost of materials, and a surcharge of 20% was applied to all items.

In a 1928 article describing an innovative fetal manikin for teaching obstetrics, Fist[98] noted that, despite great advances in mechanical knowledge over the previous 50 years, obstetric simulators had remained unchanged, and the "preserved fetal cadaver and leather manikin still serve to represent the fetus." There was, Fist[98] wrote,

> *…opinion that that the use of the manikin was old fashioned because the Germans, at that time the foremost authorities, were abandoning the manikin and studying live clinic patients.*

CIRCULATION SIMULATORS

In 1733, the surgeon Abraham Chovet advertised a *New Figure of Anatomy* in the London Evening Post.[34,99] The model was described as representing

> *…a woman chained down upon a table, suppos'd opened alive; wherein the circulation of the blood is made visible through glass veins and arteries: the circulation is also seen from the mother to the child, and from the child to the mother, with Systolick and Diastolick motion of the heart and the action of the lungs.*

This description suggests a sophisticated cardiovascular physiology simulator, but no illustration or example exists today. Chovet moved from London to Barbados and then to Pennsylvania and continued to teach anatomy. His models were acquired by the University of Pennsylvania when he died, but all were completely destroyed in a fire in 1888.[99]

In the 18th century, there were many attempts to simulate physiologic procedures with machinery.[100] In 1741, Jacques de Vaucanson presented a plan to the Académie de Lyon,

> *…to create an automatic figure whose motions will be an imitation of all animal operations, such as the circulation of the blood, respiration, digestion, the movement of the muscles, tendon, nerves and so forth … using this automaton we shall be able to carry out experiments on animal functions, and … draw conclusions from them which will allow us to recognise the different states of human health.*

Around the same time, the French surgeon, le Cat proposed to make an artificial man to test the effects of therapies.[100] Twenty years later, Vaucanson was still pursuing what he called "moving anatomy," but he now had the less ambitious goal of a hydraulic model of just the circulation. He planned to make the veins from "cutting edge" technology, the first use of elastic gum made into tubes.[100]

In the full text of *Proceedings of the Biological Society of Washington* is a report by Dr Cutler[101] of a visit to the house of Dr Benjamin Franklin in 1787,

> *He showed me a glass machine for exhibiting the circulation of the blood in the arteries and veins of the human body. The circulation is exhibited by the passing of a red fluid from a reservoir into numerous capillary tubes of glass, ramified in every direction, and then returning in similar tubes to the reservoir, which was done with great velocity, and without any power acting visibly upon the fluid, and had the appearance of perpetual motion.*

This brief note is all the information that we have on this cardiovascular simulator.

THE EARLIEST USE OF SIMULATION IN SURGICAL TRAINING

In 1890, Hamilton Bower purchased a Sanskrit-language text written on a birchbark that had been discovered on the Silk Road in Asia. When deciphered, it was found to be a comprehensive textbook of surgery and medicine ascribed to Sushruta, an Indian sage and scholar thought to have lived between the 4th and 6th centuries BC.[102] Bhishagratna, an Indian physician, translated the text into English and published it himself in 1907, and it is now freely available online.[101] The Bower Manuscript is a redaction text; that is, an additional material was inserted when the original was copied. The original text by Sushruta (sometimes referred to as Susruta or Sushrutha) has not survived, so we do not know what came directly from Sushruta and what was by the disciples of the school that he founded, but it is thought that he had discovered the basic surgical skills used today and undertook curative, trauma, and cosmetic surgery.[101]

The *Sushruta Samhita* is in 6 sections and has nearly 200 chapters on anatomy and dissection; pathology; toxicology; descriptions of a wide range of conditions; animal, mineral, and plant preparations; and surgical instruments and procedures. There are chapters that cover selection of students, teaching, and professionalism. It is clear that, around 2500 years ago, there was a curriculum-based medical course that included medicine and surgery and early exposure to clinical practice:

> *A physician skilled in the art of using surgical instruments, is always successful in his professional practice, and hence the practice of surgery should be commenced at the very outset of medical studies.*

It was recognized that clinical experience was important[103]:

> *A pupil otherwise well read, but uninitiated into the practice of medicine or surgery is not competent to take in hand the medical or surgical treatment of a disease.*

Alcohol and drugs were used to dull pain, but there was no effective anesthesia, so practice on simulators was advised to develop the speed required to undertake surgical procedures:

> *To give efficiency in surgical operations (trainees) were asked to try their knives repeatedly on natural and artificial objects resembling diseased parts of the body before undertaking an actual operation.*

How to make and use simulators for demonstration and practice of particular surgical skills and procedures (Table 3) and a whole-body patient simulator are clearly described[104]:

> *The art of bandaging or ligaturing should be practically learned by tying bandages round the specific limbs and members of a full-sized doll made of stuffed linen.*

The chapter on teaching surgical procedures concludes with the first recorded observation that simulation-based education leads to competence and confidence:

TABLE 3. Surgical Skills and Task Trainers Described in the Sushruta Samhita

- Incision on body of watermelon, cucumber, or gourd. It was noted that upward and downward cuts could be practiced
- Excision on leather pouches filled with mud or water and urinary bladders of dead animals
- Scraping on hides with hair
- Venesection on the veins of dead animals with the aid of lotus stalks
- Probing and stuffing on worm-eaten wood or bamboo or the mouth of a gourd
- "Secretion" on wooden planks smeared with beeswax
- Suturing on pieces of cloth, skin, and hides
- Enemas using tubes inserted into the mouth of a gourd
- Extraction by withdrawing seeds from the kernel of a jackfruit and extracting teeth from the jaws of a dead animal
- Cauterization or applying alkali on a piece of soft meat
- Tying up a severed ear lobe also on soft meat

> *An intelligent physician who has tried his prentice hand in surgery (on such articles of experiment as gourds, etc., or has learnt the art with the help of things as stated above), or has been instructed in the art of cauterisation or blistering (application of alkali) by experimenting on things which are most akin, or similar to the parts or members of the human body they are usually applied to, will never lose his presence of mind in his professional practice.*[103]

A picture of Sushruta's students using simulators has been published,[104] but its provenance is unknown. The *Sushruta Samhita* was translated into Arabic on the order of Caliph Mansur (AD 753–774), and this was then translated into Latin.[102] It has been claimed that both Arabic medicine and European medicine were founded on these translations.[105] Between the 4th and 8th centuries AD, surgery in India became a treatment of last resort mostly after trauma, and there is no evidence of simulation persisting in what surgical training continued.[106]

SURGICAL SIMULATORS

After the *Sushruta Samhita*, it was not until the 19th century that simulators for surgical procedures were next recorded. In 1868, at the New York Medical Journal Association meeting, Dr Howard[107] gave a lecture "On the Radical Cure of Hernia" and used a canvas manikin to demonstrate a new hernia operation. A year later, at the 1869 meeting of the Medical Society of the State of New York, Howard said,

> *…he had no paper to present before the Society, but he would simply illustrate from a manikin, devised for the purpose of illustrating the anatomy of hernia to students, and a new truss which he had devised. He said, in common with all other teachers of surgical anatomy, he had experienced the difficulty of clearly impressing the student with the relations of these parts. The manikin he exhibited he had used in his lectures at the University of New York, and found it obviated the chief difficulties of the case.*[108]

The simulator was advertised in the September 1870 issue of the *International Record of Medicine*:

> *Dr Howard's Hernia Manikin, for demonstrating Surgical Anatomy, and treatment, and for illustrating its descent and protrusion. Price, $12.*[109]

Between 1870 and 1888, the US government published the *Medical and Surgical History of the War of the Rebellion*. The series detailed tens of thousands of surgical cases and diseases that occurred during the recent civil war (1861–1865) and drew lessons from the outcomes. Part 2 volume 2 was published in 1876 and covered injuries of the abdomen and pelvis, flesh wounds of the back, and wounds and injuries of the upper extremities.[110] The chapter on wounds penetrating the abdomen included a section on intestinal suturing with the advice that it

> *…should not be attempted on the living subject until the operator has acquired some experience by practicing, as [M. Enno] used to require his pupils to do, either using the fingers of a glove, or, better still, upon a recent subject, or on intestines placed in a manikin.*[110]

The hybrid of a manikin with body parts to enhance fidelity of the simulator was also used to practice ophthalmic surgery in the 19th century. The ophthalmophantom is a half- or full-face mask or a bust that has a carrier (called the *porte-oeil*) for an animal or cadaveric eye (Fig. 4) and is thought to have been developed by Sachs around 1820.[111,112] The 1896 *Annual of Universal Medical Sciences* included instructions on how to preserve "…human eyes for operative practice on the phantom," while maintaining transparency of the media.[113] Harman[114] described how to make an inexpensive phantom in his book *Aids to Ophthalmology*.

> *Practice on globe operations may be made with pig's or sheep's eyes. Pig's eyes are nearly the same size as human, but are too tough; sheep's eyes are large, but more nearly of human texture. A convenient phantom in which to secure the eye may be made as follows: Take a cardboard box 4 × 2 × 2 inches; cut a piece of bar yellow soap to fit inside; scoop out a cavity from one side of the soap just large enough to take an eye, yet leave the cornea standing well out; cut a hole in the lid of the box just a little larger than the cornea, to correspond with the cavity in the soap; put the lid on and secure with elastic bands. The eye in its soapy bed slips about as readily as it does in life even under an anaesthetic."*

Harman[114] also designed a simulator for strabismus surgery.[115] The ophthalmoscope was invented in the middle of

FIGURE 4. Detail of the porte-oeil (eye carrier) of an ophthalmophantom (Alex Peck Medical Antiques, Charleston, IL).

the 19th century, and the early simulators to practice ophthalmoscopy were known as skiascopic eyes.[116]

Around 1880, George Tiemann and Company produced a phantom or teaching aid for practicing litholopaxy,[117] which was the beginning of minimally invasive surgery. An example is on display at the Dittrick Medical History Center in Cleveland, Ohio. A cystoscopic phantom was listed in a catalog of medical instruments for the Columbian Exposition held in Chicago in 1893.[118]

In 1879, Bacchi[119] described a *laryngo-fantome* made by Labus[120] for practicing laryngoscopy that had an electric bell to give feedback to the user. Two years later, Labus[120] published a comprehensive description of the model and an illustration of it. Over several years, a number of modifications were made to the original model to make it easier to use or extend its features.[121–123]

At Columbia University College of Physicians and Surgeons in the 1890s, the course book for 1896 to 1897 stated that laryngology was taught over 12 lessons in the Vanderbilt Clinic students and that students had to practice on a "laryngoscopic phantom," until they had acquired the use of reflected light with the aid of the concave head mirror.[124] There was a note in the 1894/1895 catalog that students received practical instruction "…in the use of the laryngoscope and rhinoscope upon the phantom" and that the clinic had "…twelve laryngoscopic phantoms, by Bock of Leipzig, for exercising the students in the use of the various instruments preliminary to the examination of the living subject."[125]

There was the by-now-traditional debate between those who used simulation in teaching and those who did not with Bruck[126] claiming,

> *Practice on the artificial larynx (phantom) is of no real practical value, and it is best to practice on a willing person of slight sensitiveness.*

In contrast, Behnke and Behnke[127] thought that students should first develop skills on an artificial larynx and then practice laryngoscopy on themselves writing,

> *I close this chapter by again reminding amateur laryngoscopists that in [sic] of cases where the touch of the mirror causes retching and gagging, it is due less to the sensitiveness of the person operated upon than to the want of skill on the part of the operator. He should in that case renew his experiments upon himself, and continue them until he has fully mastered the use of the instrument, as it is not fair to make others suffer for his own clumsiness.*

It was recognized that practice on a phantom had use beyond initial training. Tilley[128] reported on the contribution of Donellan, a London surgeon, to a public discussion about anesthesia for laryngoscopy,

> *Reference had been made to the great skill of Morell Mackenzie in the indirect method. As one intimately associated with Mackenzie's private work, he had known him to regularly practise with a phantom larynx, or even at the removal of small objects from the bottom of a dice-box by the indirect method. If the new generation had similar perseverance, they would find there was little they could not accomplish in the examination of the air passages and operations therein.*

The previously mentioned reference is to the indirect method of laryngoscopy that uses a mirror. At the end of the 19th century, Killian[129] developed a rigid bronchoscope to directly visualize the larynx and airways.[130] He quickly realized that it could be used for removing foreign bodies and developed a bronchoscopy simulator that was used both for skills training and to prepare for difficult cases.

> *With regard to the manipulation of probes and forceps it may be said that the difficulty in judging distances and excluding the disconcerting sensations which arise from the necessary contact with the metal tube can only be overcome by frequent practice upon a rubber phantom, such as that devised by Killian, or a set of branching rubber tubes, which serve much the same purpose. When the nature of the foreign body is known, actual practice should be made with its duplicate placed in the phantom.*[131]

A Killian's phantom cost $30.00 from Kny-Scheerer Company in 1915.[132]

The final simulator in this review is the first simulator for learning tracheal intubation. Schlossarek reported on a medical society meeting held on January 5, 1894, in Vienna, where professor Otto Heubner demonstrated a simulator based on a preserved cadaveric larynx for inserting and extracting O'Dwyer tubes.[133] There was a brief reference to the simulator published in *The Journal of Laryngology, Rhinology, and Otology*.[134] Some comments in Schlossarek's report on using a simulator to learn the new technique are as relevant now as they were in the 19th century; to perform the skill quickly and without causing injury requires a lot of practice, and if you do not practice on a simulator, the first unlucky patients whom you treat will suffer.

CONCLUDING COMMENTS

Simulation for demonstration and skill acquisition and maintenance in health care has a long history. Some early educational aids and simulators were simple carvings or castings, but many simulators were made of materials to have the look, feel, and compliance of human tissues and were used in immersive and interactive experiences that we would call simulation.[135] Simulation was embedded in a surgical training program around 2500 years ago, so that students had developed a wide range of skills before commencing clinical practice. There was a national simulation-based training curriculum for midwives more than 300 years ago, and just like today, these simulators could be optioned up to bleed and leak amniotic fluid. Some of the simulators were made from metal, leather, and wood, but some used human or animal body parts or whole corpses. Not all simulation was good; using bodies was biologically unsafe and was sometimes associated with increased mortality.

It is interesting to note that, more than 200 years, there was a concern that students know too little anatomy and simulation was proposed to address this deficiency.

The early adopters of simulation described how it facilitated development of procedural skills without risk to patients, that skills could be practiced repeatedly to become expert, that experts could maintain skills, and that uncommon

events could be prepared for using simulation. Simulation was used for high-stakes assessments in the 18th and 19th centuries with students required to demonstrate competence on simulators. Simulation was used in demonstrations to improve learning and to practice new or difficult procedures. Simulation was even used to investigate or guide treatment, and the only new use for simulation in the last 250 years appears to be teamwork training.

Bronchoscopy is a case study for collective amnesia about simulation in training health care professionals. When Killian[129] developed direct bronchoscopy for removal of foreign bodies, he also developed a bronchoscopy simulator because it needed practice. In his 1902 lecture to the British Medical Association, he said,

> *For the removal of foreign bodies from the bronchi a good view, great care, and quietness in procedure are essential. Slender tubular forceps, blunt hooklets … are the instruments of most use. Their manipulation at so great a depth is not an easy matter, but may be learned and practised on a phantom. I have constructed one for this purpose.*[129]

A history of bronchoscopy and esophagoscopy published[130] in 1926 made no mention of simulation. In 2006, Ouellette[136] published a study of bronchoscopy training in a pulmonary fellowship program, which found an increased rate of complications among novice bronchoscopists. Attempting to explain why an earlier study showed an even higher complication rate,[137] Ouellette[136] suggested that it was because it was "…published > 25 years ago at a time when bronchoscopy and bronchoscopy training might be considered to have been in an early stage of evolution." However, that was actually 75 years after a bronchoscopy simulator had been reported in a mainstream journal.[129] Ouellette,[136] 100 years after Killian[129] had made a simulator and 25 years after learning on patients was reported to be harmful, concluded,

> *Future research is needed to determine the role of advanced educational techniques, including the use of simulators, in facilitating bronchoscopy education.*

It was not that Killian's simulator was too expensive, it was listed in the 1915 Kny-Scheerer catalog for $30.00,[132] which is around US $650 today.[138]

The main aim of this article was to discover what simulators were used in education of health care professionals from the earliest times up to the modern era of Resusci Anne and SimOne. Information on early simulators has come from a wide variety of sources including reports of meetings and visits, trade catalogs, museums, correspondence, biographies, and even hospital accounts. Terms used for the early simulators are listed in the Appendix. The simulators and teaching aids discovered were older, were made for a wider range of procedures, and were much more sophisticated than anticipated, but only a few have survived. One of the most amazing survivors is Giovan Galli's obstetric simulator that had a glass uterus (Fig. 2). Some simulators were destroyed deliberately[34]; and others, by neglect[35] or accident.[99] Occasionally, simulators could be tracked through time and place before the trail went cold. For example, who inherited Smellie's simulators, who bought one when they were auctioned and when he sold it, who bought it, and where it was used for teaching. Although there were some simulators that were described in detail (eg, Ozenne[68]), most references to simulators have very little or no information about them (eg, Edmonson[71]). It is hoped that this article will lead to some of these models being rediscovered in medical school storerooms or college archives or at least some illustrations of them.

Flexner[93(p124)] had specifically recommended simulation in obstetrics in his 1910 report on reform of medical education, and some years after that, Meldenhall[94] recommended 30 hours of manikin practice. Unfortunately, although simulation was used in Europe and in the United States from the 17th to the early 20th century and despite great advances in medicine and technology, much of the 20th century was a "dark age" for simulation, where students and trainees followed a learning curve on patients with inevitable results. The role of simulation in quality and safety in health care professional training has had to be rediscovered. The history of simulation in training health care professionals is important because "Those who cannot remember the past are condemned to repeat it."[139] Many patients still experience the collateral damage that arises from using them to gain experience on them, although it has been known for a very long time that patient harm can be minimized through using simulation.

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APPENDIX: LIST OF TERMS USED FOR PATIENT SIMULATORS IN HEALTH CARE PROFESSIONAL EDUCATION IN DIFFERENT TIMES AND PLACES:

Birthing machine
Doll
Laryngophantom
Machine
Manakin
Manikin
Maniken
Mannequin
Maniqui
Mauniquin
Medical model
Ophthalmophantom
Part-task trainer
Patient simulator
Phantom
Phantome
Poupée
Puppe
Fantoom
Fantome
Simulator
Simulatoren
Task trainer