Chapter 2
Early Examples of Simulation in Training and Healthcare

"The art is long, life is short; the crisis fleeting; experience perilous, and decision difficult". Hippocrates

Everyone about to undergo a healthcare procedure wants the health professional to be knowledgeable, well-trained, and experienced so that a complication would be unlikely but if one did occur it would be managed quickly and effectively. Practical experience is essential for learning a skill and it may take hours or days to develop competence and learning all the skills of a craft or a profession may take several years. The Greek philosopher Aristotle (384–322 BCE) taught in his *Nichomachean Ethics* that we learn skills and behaviors through repetitive actions (habituation) and development of expertise, like virtuous behaviors, requires guidance and feedback:

> For we learn a craft by producing the same product that we must produce when we learned it; we become builders, for instance, by building, and we become harpists by playing the harp. Similarly, then, we become just by doing just actions, temperate by doing temperate actions, brave by doing brave actions. [1]

There are two parts to learning a skill; learning what to do when everything is normal and working as it should and learning what to do when there is an abnormal condition. Hippocrates (c. 460—c. 367 BCE), known as the father of medicine, summed this up in the *Aphorismi*, which starts with the phrase, *Ars longa, vita brevis*. The English rendering of the complete aphorism explains exactly why simulation has to be at the core of practical training of health professionals.

> Life is short, the Art is long; the crisis fleeting; experience perilous, and decision difficult. The physician must not only be prepared to do what is right himself, but also to make the patient, the attendants, and externals cooperate. [2]

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In some areas of healthcare the transition from normal to abnormal can be quick and the crisis needs rapid intervention to avoid harm. In these cases "learning by doing" would risk of adverse outcome or in the words of Hippocrates "experience perilous." The correct procedure to manage these events should be practised through simulation in which the real-world activity is substituted for one in an artificial setting that is realistic but safe. Flight simulation is a well-known example of this way of training where novices can learn the basics of flying and trained pilots can practise managing events that happen rarely but have serious consequences if not dealt with promptly and appropriately. In commercial aviation simulation has become increasingly important in the last 50 years and has been embedded in flight crew training and is used in regular assessment of competence. This was not the case in healthcare.

In the last 50 years simulation has not been routinely used in the education or training of health professionals despite ample evidence that the amount of preventable error and harm from medical care [3] makes admission to hospital many times more dangerous than air travel [4]. Plane crashes are expensive and receive a lot of attention and companies and professional organizations have been willing to cooperate and develop rules and requirements for training using simulation. Pilots would prefer not to be involved in a crash and have actively participated in this development. Healthcare seems to be different partly it seems because patients are injured or die individually and discretely and partly because the risk is borne only by the patient as healthcare providers are not physically harmed by the event. Administrators have been complicit in this failure of training through being overly focused on service provision and less on preventing harm.

Recently there has been increased interest in simulation to improve performance of healthcare professionals but its use has been patchy and uncoordinated. It shouldn't be this way because more than a hundred years ago simulation was widely used by students and practitioners wanting to learn new techniques and how to avoid loss of life when an uncommon but serious complication presented. This book documents the origins and development of simulation in health professional education and the technology used to create realistic simulators. This has required an exploration of simulation and simulators used as aids for training and education generally. Teaching aids have been included because whilst they were not used in immersive learning they were used to simulate body part or physiological process that would otherwise be hard to see or learn and many were used in experiential learning.

We shouldn't be surprised that simulation in healthcare has a long history because the value of simulators and simulation was recognized and understood in other fields. What is surprising is that whilst health professionals are generally thought to be smarter than average they have been more than willing to teach and learn on patients. The resurgence in interest in simulation in healthcare education has been broadly met with indifference by healthcare providers and funders.

Liver Simulators

Haruspicy, the inspection of the liver of a sacrificial animal[1] for blemishes that could be interpreted as having meanings has been a component of the belief system of many cultures. Clay models of livers (see Fig. 2.1) have been found along a geographical corridor from the Euphrates through Syria and Cyprus to Etruria in what is now Italy. A clay liver model from Babylonia, now in the British museum, dated to 1900–1600 BCE, is thought to have been used in Mesopotamia to forecast the outcome of an illness. Wooden pegs were placed in holes in the model to record the markings on the liver being read.

A bronze model of a sheep's liver of Etruscan origin was discovered in 1877 near Piacenza in the north of Italy [5]. This simulator is made of bronze and has the gall bladder, caudate lobe, and part of the posterior vena cava sculpted on the inferior surface of the liver which is inscribed with an astrological star map. An accurate interpretation was very important because decisions of great importance were based on the findings. This model ensured consistency of readings and would have been useful for teaching and as a cognitive aid. The Etruscans were thought to be skilled in divination but despite this apparent advantage their culture still experienced a

Fig. 2.1 Clay model of a sheep's liver 1900–1600 BC (Credit: British Museum)

[1] Haruspicy is sometimes referred to as hepatoscopy. Inspection of the entrails is called extispicy.

decline from around 500 BCE and they were conquered by the Romans around 100 BCE. The Romans adopted haruspicy and the haruspex (diviner) Spurinna warned Julius Caesar to beware the Ides of March.

Simulation in Roman Military Training

The assassination of Julius Caesar marked the transition of the Roman Republic to the beginning of the Empire. The Republic of Rome had raised armies as required to counter specific threats to the republic and they had a poor record. Reforms instigated by General Gaius Marius led to the creation of a professional standing army that was able to devote time and resources to training. Publius Rutilius Rufus introduced methods of training used in gladiatorial schools including regular fitness training and practise using their swords, spears, and shields on a simple simulator known as the *palus*. Publius Flavius Vegetius Renatus described how the *palus* was used in legionary training in *De Re Militari* (On Military Matters):

> They wove their shields from withies, of hurdle-like construction, and circular, such that the hurdle had twice the weight that a government shield normally has. They also gave recruits wooden foils likewise of double weight, instead of swords.
>
> Each recruit would plant a single post in the ground so that it could not move and protruded six feet. Against the pot as if against an adversary the recruit trained himself using the foil and hurdle like a sword and shield, so that now he aimed at as it were the head and face, now threatened the flanks, then tried to cut the hamstrings and legs, backed off, came on, sprang, and aimed at the post with every method of attack and art of combat, as though it were an actual opponent. In this training care was taken that the recruit drew himself up to inflict wounds without exposing any part of himself to a blow. [6]

In training schools the palus could be more substantial and have a carved head (see Fig. 2.2) [7]. The *palus* offered a safe environment for training and meant that one trainer could supervise several trainees and correct mistakes in technique. There were doubters who thought simulation was inferior to earlier methods of preparing for battle. Valerius Maximus, for example, expressed concern that the quality of training at the *palus* was inferior to live training [8]. Instead, with the benefit of simulation, the Roman legions became an unstoppable force although this had an unexpected outcome, an empire that was unsustainable. When Vegetatius wrote *De Re Militari* at the end of the fifth or the beginning of the sixth century CE, the Empire was in serious decline.

A Battle Simulation and Cadaver Simulators

The *palus* continued to be used for training in many countries that had been under Roman control and in medieval Europe it was developed into the *pell* or *quintain* [9]. In this development the post was replaced by a target or a carved wood figure,

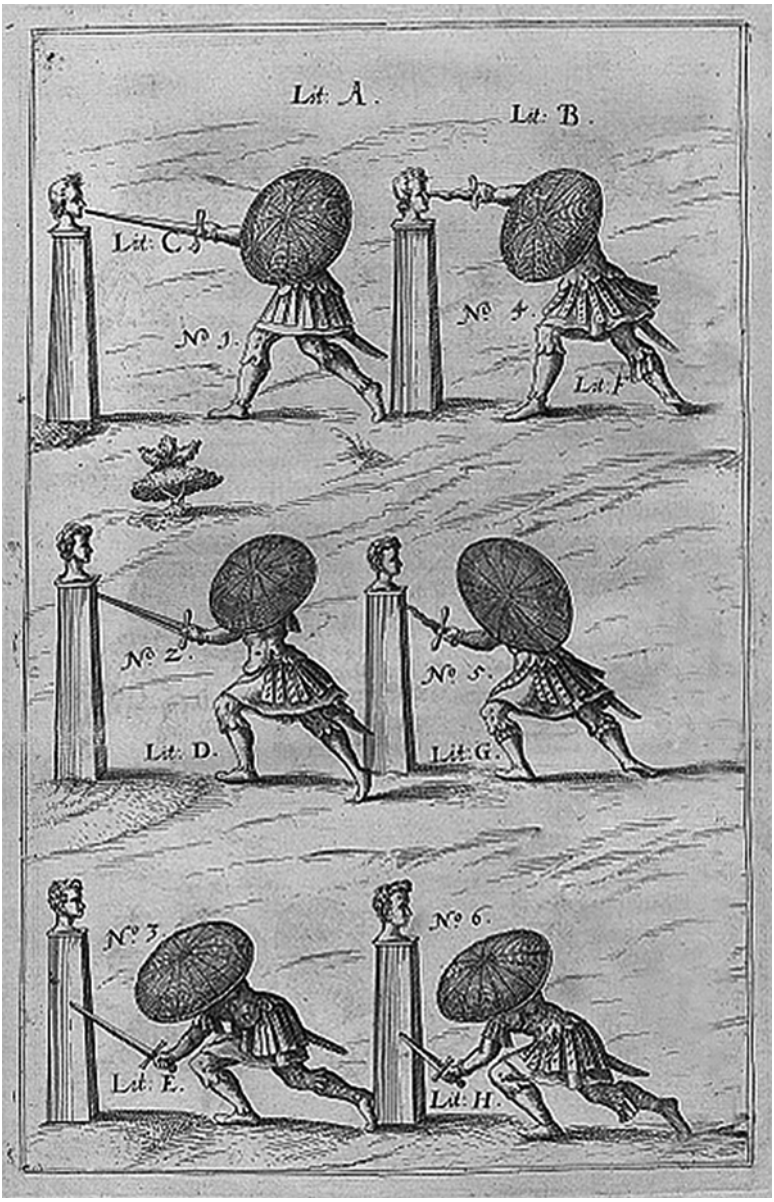

Fig. 2.2 Fighting exercises with sword and protective shield—*Kampfübungen mit Schwert und Schutzschild* [26]

typically a Saracen or Turk holding a sword, that could be moved or pivoted when struck. In various guises the quintain was a part of infantry training until rifles made swordsmanship irrelevant [8] although it was still used in cavalry training at the beginning of the twentieth century.

Fig. 2.3 A novice knight learning to joust using a quintain and horse simulator from Joseph Strutt's *Sports and Pastimes of the People of England* [27]. The opponent has been reduced to a stationary target and the "horse" is slow and easy to control

In the Middle Ages jousting developed as a stylised exhibition of prowess by knights on horseback. The quintain was often used competitively but the ultimate test was between one knight on a warhorse against another. Participating in a joust brought high prestige but it required years of training (see Fig. 2.3), was very expensive and was a high-risk activity. Geoffrey Chaucer (1342–1400) described many injuries from jousting in The Knight's Tale, one of a collection of stories called the Canterbury Tales. He also referred to a recommendation that Knights run only one course (joust) at a tournament [10].

In 1559 Henry II, King of France, ran two courses at a tournament and after nearly being unhorsed was advised to retire. Henry, probably suffering concussion from the earlier runs and impacts [11], ignored his advisors and challenged Gabriel Count of Montgomery, the captain of his Scottish Guard.[2] Contemporary accounts report that Henry then made a spectacular example of poor decision-making and charged with his visor not properly fastened closed. When the riders met Montgomery's lance was on target, the right shoulder of his opponent, but it broke on impact. A broken lance was dangerous and in a joust a knight was supposed to drop a lance as soon as it broke. In the moment, Montgomery forgot his training and held on to the lance so the splintered end which was deflected up, pushed open the king's visor and went into his right eye [11]. The largest splinters were removed from the orbit but many small ones remained and the king's physicians sought the advice of the surgeon Ambroise Paré. King Philip II of Spain also sent the anatomist-surgeon Andreas Vesalius to consult.

Paré thought it would be helpful to understand the mechanism of the injury and the Queen arranged to have four criminals executed and beheaded to provide simulators for a series of experiments. When Paré received the heads he pushed the broken end of Montgomery's lance into the eyes at the angle it had struck the king

[2] France had an alliance with Scotland at this time and Henry's son married Mary, Queen of Scots. Henry's family did not have much luck in sport as Henry II had become king after his elder brother died during a game tennis.

to see if it would penetrate the roof of the orbit [12]. Unfortunately the simulation did not offer any insight into how the king should be treated and on the fourth day after the injury a primitive neck flexion test performed by Vesalius indicated the king had developed meningitis and would surely die [13]. The king died on the eleventh day after the injury and Vesalius performed an autopsy that confirmed infection had travelled from the orbit to the brain [11].

A Dragon Simulator

> The knight Dieudonné de Gozon made a dragon simulator to accustom his horse and dogs to the monster. ("il fit faire un fantôme representoit ce dragon") [14]

When the Knights Hospitaller of the Order of St John of Jerusalem were forced out of the Holy Land early in the fourteenth century they established a base on the island of Rhodes. Some years later a monstrous dragon began living in an area near the city of Rhodes and terrorized the local inhabitants and ate their livestock. The dragon was powerful and was well protected by scales and killed several knights who attacked it. One knight, Dieudonné de Gozon, gathered all the information he could on the dragon and deduced its belly was the most vulnerable part but it would be hard to reach. First de Gozon went to his father's castle in Languedoc, France where he made a *simulacra*, a mechanical dragon that resembled the monster [15].

The historian Giacomo Bosio (1544–1627) wrote that "the dragon [simulator] was made of canvas stuffed with tow [fibers of flax or hemp], of the same size, form, and figure and of the same colors as the beast itself and so devised that it could be moved mechanically, and made hideous noises when it did so" [16, 17]. Charles Owen, an expert on dragons, wrote that Gozon "contrived the resemblance of a Dragon by a Machine of Pasteboard, of equal bulk with the Dragon, and by certain Springs made to leap like a true Dragon" [18]. Over several months Gozon used the simulator to accustom his warhorse to the dragon and not be frightened by its movements and to train two strong mastiffs to attack the dragon's underbelly [16]. Finally, when he thought the simulation training was complete, de Gozon returned to Rhodes to fight the dragon.

In one account, when de Gozon attacked the dragon its smell and cries startled the horse [19] but in others the horse carried de Gozon to the dragon and his lance broke against the scales [20]. On foot but with the help of the dogs de Gozon was able to kill the beast, for which he was given the title *Draconis Extinctor* [21]. Many

countries and cultures have stories about knights killing dragons, including England's St George, and most represent the triumph of good over evil. The story of Dieudonné de Gozon is unique in featuring a simulator [15, 17] and if it is not an account of a real event then there must have been a reason for the chroniclers to include simulation in the story. Perhaps it was to send a message to trainees on the benefits of simulation.

First Recorded Use of Simulation in Health Professional Education

It is clear from the above examples that the concept of simulation as a tool for learning and preparation for future actions and events was well understood and utilized, particularly when it was important to be quick and there was only one opportunity. The oldest description of simulation in healthcare professional education was in the *Sushruta Samhita*, a collection of texts on medicine and surgery written around 500 CE [22]. This ancient work written on birch-bark leaves in a previously unknown language was discovered in a ruined stupa near Kucha on the Silk Road. It was acquired by Hamilton Bower (1858–1940) a British agent in Central Asia on a mission to capture an Afghan accused of killing a Scottish trader in a remote area between India and Afghanistan in 1888.[3]

The *Sushruta Samhita* described more than 1100 illnesses and their management and many surgical procedures. It also included a section on how to make and use simulators for surgical skills training. In ancient times new material was sometimes inserted when a professional text was copied so although we know simulation was being used when this *Sushruta Samhita* was copied we do not know when simulation was first introduced in surgical training. The simulators described in the *Sushruta Samhita* were mostly based on natural materials or objects that happened to have features that could be used to practise skills, for example, using the holes in "moth eaten" wood to learn how to probe a wound.

Students were expected to use the simulators to develop surgical skills so that they could be quick, which was important when operating on patients without the benefit of anaesthesia. Most of the simulators described in the *Sushruta Samhita* would now be called part-task trainers but a whole-body patient simulator for learning a skill in context was also described. Clearly, it was recognized that skills learnt on simulators would transfer to clinical practice. Without effective anaesthesia or the ability to manage infection interest in surgery in India waned and this knowledge and experience of simulation was lost.

[3] When Hamilton Bower was tasked with finding the rogue Afghan he was already in the area on a spying mission in support of the "Great Game" between Britain and Russia. Bower heard of the manuscript whilst gathering intelligence on the fugitive's whereabouts. Bower's agents successfully tracked Mohammed to Samarkand but he died before he could be tried.

Acupuncture Simulators

Around a thousand years ago patient simulators were used in China in teaching acupuncture and for assessment of learning [23]. The different schools of acupuncture across China had been a cause of some confusion so in 1023 Song Emperor instructed Wang Weiye, a court physician, to develop a standardized system of acupuncture. Wang worked on the project for 3 years and eventually fixed 359 acupoints arranged along 14 channels. He had two life-size hollow bronze figures cast and inscribed with the channels and points to be used for teaching and published an accompanying manual, *Tong Ren Shu Xue Zhen Jiu Tu Jing* (Illustrated Classic of Acupuncture and Moxibustion Points as demonstrated on the Bronze Figure) [23]. The centralized government health bureaucracy[4] distributed a copy of the text to every prefecture and had a master copy carved in stone in the capital which was the ultimate reference for students. The channels along which the acupuncture points are located do not align themselves to any body structure because dissection was forbidden and the subject of anatomy didn't exist [24].

The earlier Tang dynasty (618–906) had introduced examinations for physicians but the Song government had another innovation, practical examinations. The bronze figures were covered in wax and filled with water and students were asked to needle particular acupuncture point. The drops of water on the surface of the figure when the needle was removed provided an objective end-point for assessment of competence [23]. Around 500 years later acupuncture was revisited by a government of the Ming dynasty when it was incorporated in the Imperial Medical Academy, the bronze figures were recast in 1443 and the stone tablets were re-engraved to make them current. These acupuncture points on the figures were those still used today [24].

The Beginning of the Modern Era of Simulation in Healthcare

More than 250 years ago simulation was advocated to reduce risk of injury caused by students learning on patients and to prepare students to manage unusual events that endangered life.

Systematic and sustained use of simulation in health professional education can be traced to the start of the eighteenth century, the beginning of an era historians call the Enlightenment. At this time Hermann Boerhaave (1668–1738) was a prominent medical educationalist at the University of Leiden who advocated a broad-based scientific foundation for students of physick (medicine) [25]. He taught that much

[4] Song government regulations also required physicians to keep standardized case notes.

medical opinion was the result of imagination and that progress would require frequent experiment and careful observation. He also recommended "mathematical inquiry" to improve understanding of diseases and the use of "mechanicks in the science of physic."

At this time the Chamberlen family had lost their monopoly on instrumental deliveries many more men developed an interest in attending births. These new professionals came to be known as men-midwives to differentiate them from the women midwives who generally could not use the forceps. The training of midwives varied greatly at different times and in different countries as did the training of men-midwives (the prototype obstetricians). At the beginning of the eighteenth century simulators started to be used for teaching midwives and men-midwives how to manage normal deliveries and complicated births.

Use of simulation increased over the next 200 years which covers the transition to early modern medicine and the recognition that appropriate training can lead to better treatment outcomes and included wide acceptance of using a replica of a body or body part as a training aid or simulator. Despite this, as the twentieth century progressed use of simulators in healthcare education with the exception of dentistry and to a lesser extent midwifery, seems to have declined so much that when it was rediscovered at the end of the twentieth century, it was thought to be new.

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