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REVIEW ARTICLE

Simulators for use in anaesthesia

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Summary
There are many simulators available for use in anaesthetic-related education and research. Those who wish to purchase a simulator or to establish a simulation facility face a daunting task in understanding the differences between simulators. Recent reviews have focused on narrower areas of simulation, such as airway management or basic life support, or on the application of simulators. It would be difficult to deal in detail with every simulator ever made for anaesthesia, but in the present review we cover the spectrum of currently available anaesthetic simulators, provide an overview of different types of simulator, and discuss a selection of simulators of particular interest, including some of historical significance and some examples of 'home made' simulators. We have found no common terminology amongst authors for describing or classifying simulators, and propose a framework for describing (or classifying) them that is simple, clear and applicable to any simulator.

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Simulation has its roots in medieval times, when knights used a mounted figure (or quintain) for lance practice [1], and has been an integral part of the airline industry since the early 1940s [2, 3]. Medical simulators were introduced in the early 1960s, in the form of manikins designed to aid in teaching mouth-to-mouth resuscitation, and the first computer-controlled simulators were seen in the mid-1960s [4]. A number of societies have now been established in response to the expanding interest in this broad, interdisciplinary field. The inaugural issue of *Simulation in Healthcare: the Journal of the Society for Simulation in Healthcare* was published in January 2006; the Society for Simulation in Healthcare was established in January 2004; and the Society in Europe for Simulation Applied to Medicine was established in August 1994.

A simulator is a device or product that is used in simulation. Anaesthetic simulators are often thought of as full scale manikins connected to computers in an operating room environment [5], but they can be as simple as a folded paper cup (used to assist in teaching tube rotation manoeuvres in tracheal intubation) [6]. Some authors refer to simpler simulators as 'training devices' [7, 8]. Not all simulation necessarily requires a simulator: role playing is an example of simulation that can be undertaken without any physical aids [9]. In this paper we focus on the simulators rather than the simulation.

A framework for describing (or classifying) simulators

Simulators have been categorised in a number of ways [10–14]. A common approach would be valuable and would reduce ambiguity and confusion when discussing simulators. We propose a classification based on three attributes of the simulators: how the user interacts with the simulator; its simulated physiology; and its use.

Interaction

Simulators may be categorised as screen-based, hardware-based or virtual reality-based. A screen-based simulator runs on a computer with no additional hardware. People interact with it through conventional devices (such as its keyboard or mouse). People interact with a hardware-based simulator in much the same way they would interact with a real patient. Virtual reality simulators simulate aspects of the physical environment via specialised equipment like headsets facilitating three-dimensional imagery, and haptic devices which provide physical feedback to the user (e.g. the cannula for intravenous insertion in the Virtual I.V.™ (Laerdal®, Stavanger, Norway)).

Physiology

For the purposes of our classification, physiology includes pathological events (such as bronchospasm) and responses to pharmacological interventions as well as normal physiology. Many simulators have no physiological attributes. For those that do, the physiology is generally computerised, and either script-controlled or model-controlled. Script-controlled physiology depends on a set of commands (a script) specifying physiological responses. Complex sets of responses may be predetermined but some decision making in real time is required of the operator to provide realistic responses to unpredictable events such as the administration of a drug. Model-controlled physiology depends on the use of mathematical models to determine the physiological responses to various interventions [15]. Manual override of the autonomous modes of model-controlled physiology is usually possible.

Use

A simulator may be used to teach skills (psychomotor or cognitive) or to impart knowledge. An example of a cognitive skill is the ability to make a diagnosis on the basis of a given set of clinical data. This is distinct from knowledge of the features of a disease, although such knowledge may be necessary for diagnosis. For the purpose of this classification, we will assume that knowledge is to a greater or lesser extent part of any skill, and categorise as knowledge-based only those simulators that do not provide the opportunity actually to practise the skill in question. Thus a screen-based simulator could not be used to teach a psychomotor skill (such as the ability to insert a pulmonary artery catheter), although it could be used to impart the knowledge underpinning that skill. Sinz [16] referred to 'procedure training', 'cognitive learning', and 'behavioural enhancement'. Other authors have used terms such as 'low fidelity' and 'high fidelity' or 'realistic' to describe such differences in simulators [11–13]. However, a plastic model head may be very realistic, with high fidelity in relation to a real head, but would not normally be thought of as a high fidelity simulator. Fidelity, realism, and 'behavioural enhancement' have as much to do with the environment and the participants as with the simulator [12, 17].

This framework can be used to describe any simulator (Table 1). For example, the folded paper cup [6] is a hardware-based, non-physiological simulator for teaching a psychomotor skill.

Table 1 Attributes of simulators according to the proposed classification system.

Interaction	Physiology	Used for teaching
Hardware-based	No physiology	Knowledge
Screen-based	Script-controlled	Cognitive skills
Virtual reality-based	Model-controlled	Psychomotor skills

Methods

We searched PubMed for 'simulat* and (anaesthe* OR anaesthe*)' with limits on 'English' and 'Human' results. These publications were used as a primary source from which other publications were identified. A search of the world wide web for the same terms was also conducted using Google™ Scholar (http://scholar.google.com) and contact was made with manufacturers and distributors for further information about their products. We eliminated all simulators that did not obviously lend themselves to the teaching of a skill required by anaesthetists, and where there was doubt about the skills needed by anaesthetists, the Australian and New Zealand College of Anaesthetists curriculum was consulted [18].

Results

The PubMed search returned 1440 results of which 313 papers mentioned at least one simulator. Through following these references, a further 54 papers were identified. In total, 83 commercially available simulators were identified and these are listed in Table 2 with a brief description, a rough price guide and a selection of references for each. CathSim® (Immersion Medical, San Jose, CA) [19] has recently been taken off the market [20] and is therefore not included in Table 2. Commercially available simulators of particular interest and some non-commercial simulators are discussed in greater detail below. In the following descriptions, each simulator is categorised according to our framework.

Simulators of interest that are not commercially available

Sim One (hardware; script, psychomotor and cognitive)

The very first anaesthetic simulator, Sim One, was created by an engineer, Dr Stephen Abrahamson, and a physician, Dr Judson Deneson, in the mid-1960s [21]. Only one of these was constructed and nothing remains of it today [4].

Table 2 Simulators identified in the literature arranged by their method of interaction, with a rough price guide: X < £55 (<€80; <$US100); XX £55–550 (€80–800; $100–1000); XXX £550–5500 (€800–8000; $1000–10 000); XXXX £5500–27 000 (€8000–40 000; $10 000–50 000); XXXXX > £27 000 (> €40 000; > $50 000).

Type	Physiology	Usage	Website	Skill(s) taught	Price
Virtual reality simulators					
MedSim UltraSim [34]	None	Psychomotor	http://www.medsim.com/products/products.html	Ultrasound	XXXX
Laerdal Virtual IV [35]	Unknown	Psychomotor	http://www.laerdal.com/document.asp?subnodeid = 6473945	Cannulation training	XXXX
Screen-based simulators					
Cardionics Cardiosim® [36]	None	Cognitive	http://www.cardionics.com/productname/	Auscultation	XXX
Cook Critical Care Management of the difficult airway CD-ROM [29]	None	Cognitive	http://cookcriticalcare.com/education/cd_rom/C-DAB-CD.pdf	Airway management	X
Diagnostic reasoning cases [32]	None	Cognitive	http://www.dxrgroup.com/	Pathology diagnoses	XX
Laerdal HeartSim® 4000 [37]	None	Cognitive	http://www.laerdal.com/document.asp?subnodeid = 7320318	Advanced life support skills	XXX
TEECHER™ [38]	None	Cognitive	http://www.anest.ufl.edu/tds/	Echocardiography	X
Umedic [36,39]	None	Cognitive	http://crme.med.miami.edu/umedic_about.html	Bedside cardiology	X
AlgoSim® [40]	Script	Cognitive	http://www.gasnet.org/software/files/AlgoSim/	Airway management	X
Anesoft ACLS simulator [11, 32]	Script	Cognitive	http://www.anesoft.com/Products/acls.asp	Advanced life support skills	X
MadScientist BloodGas [41]	Script	Cognitive	http://www.madsci.com/physicians.html	Blood gas interpretation	X
MadScientist Cardiac Arrest [41]	Script	Cognitive	http://www.madsci.com/physicians.html	Advanced life support skills	X
MadScientist Chest Pain [41]	Script	Cognitive	http://www.madsci.com/physicians.html	Chest pain diagnosis and treatment	X
MadScientist MicroEKG [41]	Script	Cognitive	http://www.madsci.com/physicians.html	ECG interpretation	X
MadScientist Trauma One [32, 41]	Script	Cognitive	http://www.madsci.com/physicians.html	Multiple-trauma management	XX
PAC simulator [16, 42]	Script	Psychomotor	http://www.manbit.com/	Cannulation training	X
Anesoft Anaesthesia simulator [32, 41]	Model	Cognitive	http://www.anesoft.com/Products/as.asp	Anaesthesia	XX
Anesoft critical care simulator [11]	Model	Cognitive	http://www.anesoft.com/Products/cc.asp	Advanced life support skills	X
Anesoft Hemodynamics simulator [11]	Model	Cognitive	http://www.anesoft.com/Products/hsasp	Cardiovascular physiology and pathology	X
Anesoft Sedation simulator [11]	Model	Cognitive	http://www.anesoft.com/Products/ss.asp	Pharmacology	X
BODY [14, 43]	Model	Cognitive	http://www.advsim.com/biomedical/body_simulation.htm	Anaesthesia	XX
BreathSim© [44]	Model	Cognitive	http://www.breathsim.com/	Anaesthesia machine	X
Cardiovascular interactions: an interactive tutorial [45]	Model	Cognitive	http://advan.physiology.org/cgi/content/full/26/2/98/DC1	Cardiovascular physiology	X
Gasman® [32, 46]	Model	Cognitive	http://www.gasmanweb.com/	Pharmacology	XX
HeartSim© [47]	Model	Cognitive	http://www.columbia.edu/ccnmtl/projects/heart/	Cardiovascular physiology	X
javaMan [48]	Model	Cognitive	http://www.health.adelaide.edu.au/paed-anaes/javaman/	Full body physiology	X
MacDope [49]	Model	Cognitive	http://www.chime.ucl.ac.uk/resources/Models/macdope.htm	Pharmacology	X
MacMan [50]	Model	Cognitive	http://www.chime.ucl.ac.uk/resources/Models/macman.htm	Cardiovascular physiology	X
MacPee [51]	Model	Cognitive	http://www.chime.ucl.ac.uk/resources/Models/macpee.htm	Full body physiology	X
MacPuf [52]	Model	Cognitive	http://www.chime.ucl.ac.uk/resources/Models/macpuf.htm	Respiratory physiology	X
Nottingham physiology simulator [53, 54]	Model	Cognitive	http://www.jghardman.plus.com/NPS/	Cardiovascular physiology	X
PKPD hydraulic analogue [55]	Model	Cognitive	http://www.anest.ufl.edu/tds/	Pharmacology	X
Relax [11, 56]	Model	Cognitive	http://www.anest.ufl.edu/tds/	Pharmacology	X

Table 2 (*Continued*).

Type	Physiology	Usage	Website	Skill(s) taught	Price
SimBioSys [41]	Model	Cognitive	http://www.eurca.org/res_desc.asp?EdID = 554348	Full body physiology	XX
Virtual Anaesthesia Machine (VAM) [11, 32]	Model	Cognitive	http://vam.anest.ufl.edu/	Anaesthesia machine	X
Hardware-based simulators with no physiology					
Adam,Rouilly cricothyrotomy trainer [57]	None	Psychomotor	http://www.adam-rouilly.co.uk/productdetails.php?id=541&catid = 46	Cricothyrotomy	XXX
Ambu adult airway trainer [58, 59]	None	Psychomotor	http://www.ambu.com	Airway management	XXX
Ambu baby manikin [60]	None	Psychomotor	http://www.ambu.com	Infant CPR skill	XX
Ambu CPR Pal [61]	None	Psychomotor	http://www.ambu.com	CPR skill	XX
Ambu man [61]*	None	Psychomotor	http://www.ambu.com	CPR skill	XXX
Armstrong medical Actar D-fib® CPR/AED Manikin [61]	None	Psychomotor	http://www.armstrongmedical.com/ami/item.cfm?sction = 2&sbsection = 11&category = 28&itemid = 1767	Basic life support skills	X
CLA Intubation manikin [57, 58]	None	Psychomotor	http://www.coburger-lehrmittelanstalt.de/englisch/CLA/Produkte/Phantome/Ubungsphantome/E_Gstck_Intub1.htm	Airway management	XX
CLA scorpio-bronco-boy [57]	None	Psychomotor	http://www.coburger-lehrmittelanstalt.de/englisch/CLA/Produkte/Phantome/Ubungsphantome/E_Gstck_Scopin1.htm	Bronchoscopy	XX
CPR Prompt® [61]	None	Psychomotor	http://www.cprprompt.com/tmtman.html	Basic life support skills	X
Dexter endoscopy [29, 42, 62]	None	Psychomotor	http://www.dexterendoscopy.com/home.htm	Bronchoscopy	XX
Flinders MediTech cricoid pressure trainer [63]	None	Psychomotor	http://www.flindersmeditech.com/products/CPT/cpt_features.php	Cricoid pressure	XXX
Flinders MediTech epidural injection trainer [64]	None	Psychomotor	http://www.flindersmeditech.com/products/EIS/eis_features.php	Epidural injection	XXX
Gaumard maternal and neonatal 'Noelle™' [17, 57]*	None	Psychomotor	http://www.gaumard.com/customer/product.php?productid = 16247&cat = 0&page = 1	Airway management	XXX – XXXX
Gaumard Simon® airway [57, 58]	None	Psychomotor	http://www.gaumard.com/customer/product.php?productid = 16325&cat = 0&page = 1	Airway management	XX
Laerdal Airman [29, 65]	None	Psychomotor	http://www.laerdal.com/simman/airman.htm	Airway management	XXXX
Laerdal Airway Management Trainer [59, 66]	None	Psychomotor	http://www.laerdal.com/document.asp?subnodeid = 7423513	Airway management	XXX
Laerdal cricoid stick trainer [57]	None	Psychomotor	http://www.laerdal.com/document.asp?subnodeid = 18795213	Cricothyrotomy	XX
Laerdal delux difficult airway trainer [57]	None	Psychomotor	http://www.laerdal.com/document.asp?subnodeid = 7423533	Airway management	XXX
Laerdal Little Anne™ [61]	None	Psychomotor	http://www.laerdal.com/document.asp?subnodeid = 7595379	Basic life support skills	XX
Laerdal Rescusci® Anne [16, 36]	None	Psychomotor	http://www.laerdal.com/document.asp?subnodeid = 11690683	Advanced life support skills	XX–XXX
Laerdal trauma head [58]*	None	Psychomotor	http://www.laerdal.com/document.asp?subnodeid = 7423393	Airway management	XX
Medic Vision epidural injection trainer [67]	None	Psychomotor	http://www.medicvision.com.au/assets1/Epidural4.pdf	Epidural injection	XXX
Nasco life/form® advanced airway Larry [57, 58]	None	Psychomotor	http://www.enasco.com/healthcare/ProductDetail.do?sku = lF03669U	Airway management	XX
Nasco life/form Basic Buddy [61]	None	Psychomotor	http://www.enasco.com/healthcare/ProductDetail.do?sku = lF03693U	Basic life support skills	X
Nasco life/form central venous cannulation [42]	None	Psychomotor	http://http://www.enasco.com/healthcare/ProductDetail.do?sku = lF01087U	Cannulation training	XX
Nasco life/form CPArlene [58]	None	Psychomotor	http://http://www.enasco.com/top/190/Manikins/CPARLENE%26%23174%3B/	Basic life support skills	XX
Nasco life/form cricothyrotomy simulator [68]	None	Psychomotor	http://www.enasco.com/healthcare/ProductDetail.do?sku = lF01082U	Cricothyrotomy	XX
Nasco life/form fat old Fred [61]	None	Psychomotor	http://www.enasco.com/healthcare/ProductDetail.do?sku = lF03750U	Basic life support skills	XX
Pharmabotics Oxford fiberoptic trainer [16, 62]	None	Psychomotor	http://www.pharmabotics.com/products/OXB100.asp	Bronchoscopy	XXX

Table 2 (*Continued*).

Type	Physiology	Usage	Website	Skill(s) taught	Price
Pharmabotics tracheotomy trainer [57]	None	Psychomotor	http://www.pharmabotics.com/products/CYT100.asp	Cricothyrotomy	XX
Simulaids adult airway [57, 58]	None	Psychomotor	http://www.simulaids.com/print/086p.htm	Airway management	XXX
Simulaids David ⁄ african American [61]	None	Psychomotor	http://www.simulaids.com/2000.htm	Basic life support skills	XX
Simulaids economy adult sani-man [61]	None	Psychomotor	http://www.simulaids.com/2131.htm	Basic life support skills	X
Simulaids trauma head [58]	None	Psychomotor	http://www.simulaids.com/069.htm	Airway management	XX
Trucorp airsim [59]	None	Psychomotor	http://www.trucorp.co.uk/sections/?cms = Products_Airsim&cmsid = 4–21&id = 21&secid = 4	Airway management	XXX
VBM Bill airway trainer [57, 59]	None	Psychomotor	http://www.vbm-medical.com/files/vbm_ansthesie2.0–1005_gb.pdf	Airway management	XXX
Hardware-based simulators with physiological capability					
Ambu Cardiac Care Trainer [69]*	Script	Psychomotor and cognitive	http://www.ambu.com	Advanced life support skills	XXX
Harvey [17, 47]	Script	Psychomotor and cognitive	http://www.crme.med.miami.edu/harvey_changes.html	Cardiology	XXX–XXXX
Laerdal ALS simulator [70]	Script	Psychomotor and cognitive	http://www.laerdal.com/document.asp?subnodeid = 16358619	Advanced life support skills	XXXX
Laerdal ALS skillmaster [58, 71]	Script	Psychomotor and cognitive	http://www.laerdal.com/document.asp?subnodeid = 7320320	Advanced life support skills	XXX
Laerdal SimBaby [72]	Script	Psychomotor and cognitive	http://www.ambu.com	Infant anaesthetic	XXXX
Laerdal SimMan® [73, 74]	Script	Psychomotor and cognitive	http://www.laerdal.com/simman/simman.htm	Anaesthetic	XXXX
METI ECS™ [17, 39]	Script	Psychomotor and cognitive	http://www.meti.com/Product_ECS.html	Anaesthetic	XXXX
Simulator K [36]	Model	Psychomotor and cognitive	http://www.kyotokagaku.com/products_medi_cpsk.html	Cardiology	XXXX
METI HPS [75, 76]*	Model	Psychomotor and cognitive	http://www.meti.com/Product_HPS.html	Anaesthetic	XXXXX
METI PediaSIM® [17, 77]	Model	Psychomotor and cognitive	http://www.meti.com/Product_Pedia.html	Infant anaesthetic	XXXXX

*These references may refer to earlier or modified models of the simulator.
CPR, cardiopulmonary resuscitation.

ACCESS (hardware; script; psychomotor and cognitive)
The Anaesthesia Computer Controlled Emergency Situation Simulator was developed at the University of Wales in 1994 [22] by incorporating computerised physiology into a commercially available manikin.

PATSIM (hardware; script; psychomotor and cognitive)
The PATSIM system was developed in Norway in 1996. It is similar to ACCESS, with a number of parameters that can be altered by an instructor or by scripts [13, 23, 24].

SIMA (hardware; model; psychomotor and cognitive)
The Sophus group was founded in Denmark in 1991 to study human error in anaesthesia [25, 26]. The group was not satisfied with the available simulators at the time and began developing their own simulator in 1992 [27]. The result was the Sophus simulator, which later became the SIMA (SIMulation in Anaesthesiology) simulator and was commercialised by Math-Tech [28], Denmark [25, 29]. In 2003, Laerdal acquired Sophus [30].

LAS (hardware; model; psychomotor and cognitive)
Following a similar approach to that used for ACCESS, a group led by Dr Vimil Chopra in Leiden, Netherlands, produced the Leiden Anaesthesia Simulator (LAS) in 1994 [13, 31].

Eagle Patient Simulator (hardware; model; psychomotor and cognitive)
Dr David Gaba, at Stanford University, created this simulator which was commercially available for a number of years. The original simulator, CASE (Comprehensive Anaesthesia Simulation Environment), underwent a number of improvements before being licensed to CAE-Link, a descendent of the original Link Aeronautical Corporation which produced the first significant airline simulator [4]. CAE-Link evolved into Medsim-

Eagle and the simulator was renamed the Eagle Patient simulator [4, 13, 32]. The company has abandoned the product and only a few of these simulators are in existence today (Gaba DM, personal communication). It is still use in Dr Gaba's unit for teaching and research [33].

Commercially available virtual reality simulators

All of the virtual reality simulators identified were designed for teaching specific psychomotor tasks. Most current applications of virtual reality in medicine are primarily for surgical training, but some of these simulators are also applicable to anaesthesia [78], notably for training in needle or catheter insertion [35, 79, 80] and in the use of ultrasound imaging [81].

Virtual I.V. (virtual; physiology unknown; psychomotor)

Developed by Laerdal, this system comprises a specialised force-feedback needle device and software to teach students to start an intravenous infusion or draw blood [30].

UltraSim® (virtual; no physiology; psychomotor)

A modified ultrasound machine stores patient data in three-dimensional images, and by scanning on the UltraSim (MedSim, Kfar Sava, Israel) manikin the student can reconstruct images of structures, such as the carotid artery and thyroid gland, in real time [81, 82]. Currently, invasive procedures cannot be performed on this simulator.

Commercially available screen-based simulators

We identified a multitude of websites and programmes, ranging from simple interactive tutorials (such as a transoesophageal echocardiogram simulator [83]) to whole-body simulations like JavaMan [84].

The technology behind the world wide web and its use for distributing information was reviewed in 1996 [85]. In 1980, Tunnicliffe Wilson [86] found over 200 papers in which examples of the application of computer simulation to health care problems were identified. There are too many websites and small applets (i.e. programmes that can be run in a browser such as Internet Explorer) devoted to the simulation of some aspect of anaesthesia to list them all within this review. Many are free, but several companies sell screen-based, cognitive simulators (with no physiological capabilities) [87, 88], one example being MADSCIENTIST Software [89]. The price of these varies with complexity amongst other factors. We have listed software packages mentioned in the literature in Table 2, and five examples of screen-based simulators not found in the literature in Table 3.

More sophisticated screen-based simulators include script-controlled physiology for teaching skills such as airway management [40] or pulmonary artery catheterisation [90]. We identified two programmes with model-controlled physiology for simulating the administration of anaesthetics: Anaesthesia Simulation (Anesoft, Issaquah, WA) and BODY (Advanced Simulation Corporation, Point Roberts, WA) [91, 92].

Anaesthesia Simulation (screen; model; cognitive)

Anesoft Corporation software provides sophisticated, interactive simulations of anaesthesia using mathematical models of physiology and pharmacology developed from work by Dr Howard Schwid [91].

BODY (screen; model; cognitive)

The BODY (Advanced Simulation Corporation, Point Roberts) is similar to the Anesoft product [92]. The models used have been developed by Dr N. Ty Smith from the University of California, San Diego, together with Advanced Simulation Corporation (which is also involved in aviation simulation and instrumentation).

Commercially available hardware-based, no-physiology simulators

A number of basic hardware simulators are designed for teaching anatomy. Prices depend, in part, on the complexity of the simulator (Table 4); interesting examples are shown below. Companies producing these

Table 3 Examples of screen-based simulators not found in the literature, their categories and a brief description of the website.

Website	Category	Brief description
Capnography.com http://www.capnography.com/	None; cognitive	A simple website aimed at teaching the interpretation of the capnograph.
Hypertext Adaptation of ASA Difficult Airway Algorithm http://www.oyston.com/anaes/airway	None; cognitive	A 'pick-a-path' type site for the ASA difficult airway algorithm.
Interactive Biochemistry http://cti.itc.virginia.edu/~cmg/Demo/front.html	Model-controlled; cognitive	A comprehensive site on biochemistry.
AUC http://www.chm.davidson.edu/erstevens/AUC/AUC.html	Model-controlled; cognitive	A pharmacology applet for C_p and area under the curve (AUC).
Human Anatomy Online http://www.innerbody.com/index.html	None; knowledge	An interactive anatomy website.

Table 4 A rough guide to prices for hardware-based, no physiology, psychomotor-focused simulators based on their specific task. X < £55 (<€80; <$US100); XX £55–550 (€80–800; $100–1000); XXX £550–5500 (€800–8000; $1000–10 000); XXXX £5500–27 000 (€8000–40 000; $10 000–50 000); XXXXX > £27 000 (> €40 000; > $50 000).

Task	Cost range
Anatomical only	X–XXX
Ultrasound phantoms	XX–XXX
CPR manikins	X–XX
Injection trainers	XX–XXX
Airway management	XX–XXX
Auscultation	XX–XXX

models include 3B Scientific® (Hamburg, Germany) [93], Adam, Rouilly (Sittingbourne, UK) [94], Berlin Anatomy (Montreal, Canada) [95], Denoyer-Geppert (Skokie, IL) [96] and Laerdal [30]. Of particular interest are 'phantoms' used in teaching ultrasound anatomy. These are synthetic models that mimic the anatomy such that images produced with conventional ultrasound machines are realistic. Companies producing phantoms applicable to anaesthesia are Blue Phantom™ (Kirkland, WA) [97], Limbs and Things (Bristol, UK) [98], and Shelly Medical Imaging Technologies (Ontario, Canada) [99].

There are a number of companies that produce manikins for teaching medical skills (Adam,Rouilly [94], Ambu® (Baltorpbakken, Ballerup, Denmark) [100], Gaumard® (Miami, FL) [101], Laerdal [30], Limbs and Things [98], Mitaka Supply Company (Osaka, Japan) [102], Nasco (Fort Atkinson, WI) [103] and Simulaids (Saugerties, NY) [104]). Most of these products are for teaching cardiopulmonary resuscitation, airway management, auscultation or injection techniques.

Giant Heart (hardware; no physiology; knowledge)
Most anatomical models are life-sized or slightly enlarged, but the giant heart from 3B Scientific (£550–5500 (€800–8000; $1000–10 000)) [93] is eight times real size and stands 1 m tall. It is intended to be used as a teaching aid in a large lecture room. Considerable anatomical detail is shown and cut-away sections reveal the atria and ventricles.

C.V. Access Phantom (hardware; no physiology; psychomotor)
Blue Phantom [97] have developed a head and torso manikin (£550–5500 (€800–8000; $1000–10 000)) for practising cannulation of blood vessels under ultrasound guidance.

Fat Old Fred (hardware; no physiology; psychomotor)
This manikin (£55–550 (€80–800; $100–1000)), designed to teach cardiopulmonary resuscitation on overweight people, was developed by Nasco [103].

Ambu I.V. Trainer (hardware; no physiology; psychomotor)
The Ambu I.V. Trainer (£55–550 (€80–800; $100–1000)) [100] has a feedback panel to indicate which blood vessel has been cannulated.

Tracheal Intubation (hardware; no physiology; psychomotor)
The Sakamoto tracheal intubation trainer (Mitaka Supply Company; £550–5500 (€800–8000; $1000–10 000)) [102] comes with the unusual feature of breakable (but replaceable) teeth.

Heart and Lung Sounds (hardware; no physiology; cognitive)
This intubatable paediatric simulator from Gaumard ((£55–550 (€80–800; $100–1000))) [101] has an external speaker for the instructor and observers to hear breath and heart sounds at the same time as the trainee auscultates with a stethoscope.

Commercially available hardware-based, computer-controlled simulators

The most complex hardware-based, computer-controlled adult simulators have been called 'full scale' [12, 14], 'high fidelity' [11] or 'realistic' [12, 13]. If such simulators are placed in a suitable environment (e.g. a simulated theatre) with people to play the roles of appropriate staff (e.g. nurses and surgeons), situations closely resembling that of the real working environment can be created.

PDA STAT (hardware; script; psychomotor and cognitive)
Simulaids [104] have a portable manikin for advanced life support training (£550–5500 (€800–8000; $1000–10 000)) that can be controlled by a personal digital assistant (PDA). Changes can be made to features such as lung sounds or tongue oedema. Scripts can be used to make multiple changes at predefined times to create scenarios. Events (e.g. procedures performed and drugs administered) can be logged for later review.

HAL® Interactive (hardware; script; psychomotor and cognitive)
Gaumard [101] have adult, paediatric and neonate manikins (£550–5500 (€800–8000; $1000–10 000)) adapted to detect events such as tracheal intubation and positive pressure ventilation. There are a number of variables which can be controlled by the instructor and scenarios that can be constructed by scripting. Trainees' actions can be logged.

Laerdal SimMan® (hardware; script; psychomotor and cognitive)
Laerdal began as a plastic toy manufacturing firm in the 1960s, and now produces an extensive range of products associated with the practice and teaching of resuscitation. This includes hardware-based, script-controlled adult,

paediatric and infant simulators [30]. SimMan (£5500–27 000 (€8000–40 000; $10 000–50 000)) is a full sized manikin with a monitor display but does not lend itself to the use of standard anaesthesia monitors.

METI™® HPS™ (hardware; model; psychomotor and cognitive)
A group lead by Dr Michael Good at the University of Florida in Gainesville developed a simulator at the same time as the CASE system was being developed in Palo Alto. It was aptly named 'GAS' (Gainesville Anesthesia Simulator) [4]. This was commercialised with Loral Data Systems which became Medical Education Technologies, Inc. (METI; Sarasota, FL). The latter has produced a range of infant, paediatric and adult patient simulators [105]. The HPS (> £27 000 (> €40 000; > $50 000)) is the most frequently mentioned in the papers identified in our literature search. A full sized manikin is supported by a gas module (which physically simulates the absorption and release of gases and vapours) and computer models for physiological and pharmacological events [105]. A comparison between the precursor to the HPS and the Eagle simulator (CAE, Binghamton, NY, USA) can be found in Norman and Wilkins [5]: even in their early stages of development, both these simulators were complex and comprehensive. The HPS simulator can be connected to conventional anaesthetic machines and monitors.

'Home made' simulators

Palm-LM (hardware; no physiology; psychomotor)
One's own palm can be used to teach aspects of laryngeal mask airway insertion, to emulate the hard and soft palate, and to demonstrate how the mask folds against the posterior pharyngeal wall [106].

Elastoplast cricoid (hardware; no physiology; psychomotor)
A roll of adhesive tape has been employed by Kopka and Crawford [107] and Cook et al. [108] to simulate the cricoid cartilage.

Model larynx (hardware; no physiology; psychomotor)
Meek and colleagues [109] made a model larynx with a pressure transducer to assess cricoid pressure. The model used a 4-cm diameter Perspex universal container with a collar of oxygen tubing to simulate the cricoid cartilage, all covered with a bandage.

Gasoline bronchoscope (hardware; no physiology; psychomotor)
Colley and Freund used a plastic petrol can to simulate the trachea in fibreoptic bronchoscopy simulations [110].

Needle insertion with feedback (hardware; no physiology; psychomotor)
A simulator that includes haptic feedback for epidural needle insertion has been developed by Magill and associates [111].

Oil-based lung model (hardware; no physiology; cognitive)
Loughlin et al. designed a lung model comprising plastic boxes of varying capacities to represent different body compartments [112]. The volume and absorption characteristics of these compartments are simulated by altering the volumes and flow rates of olive oil added to the boxes.

Modified anaesthesia machine (hardware; no physiology; psychomotor and cognitive)
Instead of focusing on simulating the patient, Berge et al. [113] modified an anaesthesia machine to recreate machine failures. The machine was configured to have an inbuilt range of failures, controlled by a computer.

Phantoms (hardware; no physiology; psychomotor and cognitive)
Chantler et al. inserted a length of ventilator tubing into a Perspex cylinder filled with chlorhexidine 0.5% to assist in central line placement under ultrasound guidance [114]. Farhig et al. constructed a geometrically accurate phantom for visualising cerebrovascular flows [115].

Sydney perfusion simulator (hardware; model; psychomotor and cognitive)
This is a model-controlled hydraulic device for simulating physiology and pharmacology to train perfusionists and anaesthetists in cardiopulmonary bypass and the management of perfusion related crises [90]. The idea was first suggested by Dr Richard Morris [90]. It has become commercially available through Ulco Technologies (Marrackville, Australia) [116] as the 'Orpheus perfusion simulator'.

Discussion

We have reviewed simulators for use in anaesthesia and have proposed a classification system for simulators in general. There is an abundance of simulators for teaching aspects of anaesthesia from simple anatomy to crisis management in simulated anaesthetics in replicated operating theatres. The majority of the simulators identified are screen-based for teaching knowledge or cognitive skills, or hardware-based for teaching psychomotor skills. A smaller number of advanced simulators can be used to simulate the administration of anaesthetics. We have focused on adult simulators but paediatric and neonatal simulators are also available, and we have discussed some of these.

An overview of simulators and their applications by Maran and Glavin in 2003 [17] deals with simulation rather than simulators per se. Similarly, a systematic review conducted by Issenberg et al. in 2005 [117] focused more on the educational aspects of simulation than on the simulators. We have focused on the simulators themselves, to provide a guide to the range of currently available simulators. A website maintained by the Simulation Development and Cognitive Science Laboratory at Penn State College of Medicine (http://www.hmc.psu.edu/simulation/available/index.htm) may supplement this guide. Our classification system should make it easier to describe simulators unambiguously.

Researchers at Flinders University, Australia, have reviewed and tested simulators used for teaching difficult airway management and basic life support skills [57, 61] and Eason reviewed simulators for cardiothoracic and vascular anaesthesia in 2005 [42]. Lane et al. [118] and Maran et al. [17], on the other hand, included all medical simulators in their reviews. We have restricted our review to simulators related to anaesthesia. Reviews by Schwid [11] and Doyle [32] focused on anaesthetic simulators. Our review brings their work up-to-date and is systematic.

Virtual reality is perhaps the most exciting area in simulation, though it is still in its infancy. With increasingly sophisticated technology, particularly in the fields of haptics and artificial intelligence, supported by progressively more powerful computers, it may become possible to create virtual operating theatres, complete with staff, in which 'patients' can be 'anaesthetised' and undergo 'surgical operations'.

The most obvious advantage of screen-based simulators over hardware-based simulators is their low cost. Not only are these simulators themselves much cheaper (hundreds of pounds vs tens of thousands) but hardware-based simulators usually require more space, as well as other equipment (such as anaesthetic machines and defibrillators). The ongoing costs, such as repairs and maintenance, are therefore higher for hardware-based simulators. For a simulation centre complete with staff and simulators, the set-up cost has been estimated at approximately £482 000 (€700 000; $876 000) and the fixed annual costs at £200 000 (€289 000; $361 000) [119]. Screen-based simulators can more readily be used by a trainee alone, without the need for a tutor or actors, which also reduces cost. The disadvantage of screen-based simulators is that they cannot be used to practise psychomotor skills or teamwork. In the end, one's choice of simulator will depend on the intended application and the available budget.

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