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The Bristol Medical Simulation Centre

Simulation training has already been used extensively in many industries including aviation, nuclear power and rail. Repeated exposure to simulated crises has meant that airline crews, for example, are well prepared to face a rare disaster when it actually happens. The Bristol Medical Simulation Centre (BMSC) was the first training centre of its kind in the UK to offer a similar concept for medicine: training for medical emergencies using sophisticated manikins in very realistic medical settings.

Main picture: The operating theatre with full medical team carrying out a procedure on the Junior manikin

Medical simulators

The Bristol Medical Simulation Centre has a variety of simulators and medical training devices ranging from simple CD-ROM-based trainers to PC screen-based simulators, and manikin-based simulators. However it is the manikin-based simulators that make this type of centre unique. These simulators can be divided into non-model- and model-driven systems. Non-model-driven systems are less complex and tend to be operator driven. They can be stand-alone resuscitation-like manikins or else attached to a computer. Model-based systems attempt to represent faithfully the anatomy (manikin) and physiology of a human being. They are capable of functioning on their own.

Figure 1 Close-up of Stan with stack in the background

Model-driven simulators – the human patient simulator

The human patient simulators (HPSs) are called Stan (actually Stan D. Ardman – standard man) and Junior Stan (Figures 1 and 4). They are made and developed in the US by METI (Medical Education Technologies Inc, Sarasota, Florida). The HPSs act very much like 'real' patients. They can 'talk', breathe on their own or can be ventilated. They have pulses, blood pressure and heart waveforms. They respond to real anaesthetic gases and over 60 intravenous drugs. The eyes blink and the pupils react. Stan can be made female (Stanette) by changing certain anatomical parts.

The brains of the HPS is contained in a 'stack' (in the background of Figure 1, although normally the stack is hidden in the side room). This contains the driving electronics, the computer and microprocessors, the bellows for the lungs, the gas exchange and analysers, and the mass flow controllers. Multiple gas pipes (compressed air, oxygen, carbon dioxide, nitrous oxide and nitrogen) supply the stack. The manikin is connected to it via an 'umbilical' cord. This provides the correct proportion of gases for realistic breathing and all the air lines to control the various servos in the manikin.

The HPS takes in real anaesthetic gases from an anaesthetic machine, or

BMSC history

The centre was opened in the spring of 1997 by the former Chief Medical Officer Sir Kenneth Calman. It was established in a refurbished stand-alone building near the Bristol Docks and the Bristol General Hospital (Figure 2). By coincidence, the building was once a military training centre. In the autumn of 2001 it moved to new expanded and improved premises.

Figure 2 Outside the first BMSC building

Current BMSC

The current premises are located within the new United Bristol Healthcare NHS Trust (UBHT) education centre (the right of Figure 3), which is opposite the Bristol Royal Infirmary. Sadly the Infirmary has become well known in part for the Bristol inquiry, but it is hoped that the BMSC will bring a more positive association through innovative simulation-based training that will make medicine safer without any risk to patients.

The interest in medical education through simulation is growing. Since we opened nearly 7000 healthcare workers have been through the centre. A further seven centres have now opened in the UK and there are over 250 simulation facilities in the world, but these vary widely in sophistication from single-room facilities to purpose-built centres.

BMSC operation

BMSC is run on a commercial basis and is self-financing. A triumvirate of the University of Bristol, UBHT and the Charitable Trustees of the United Bristol Hospitals manages it. The centre has to balance its books and receives income from a variety of sources: grants (hospital, university and research) and revenue from courses. Running costs include building rental, consumables, course costs, upkeep of equipment, and payback of the initial set-up loan. The centre has one full-time member of staff – the centre manager. The rest of the faculty are staff (anaesthetists, operating department practitioners and clinical scientists) from the university and hospital who donate some of their time to the project. The education centre compliments the facilities of BMSC and provides clinical skills laboratories, basic resuscitation training laboratories, lectures theatres, tutorial rooms, and a fully stocked library, which delegates can use.

Figure 3 Current BMSC, showing BRI one side and education centre the other

Figure 4 Close-up of Junior in a theatre bed

oxygen from normal air and breathes out exhaled anaesthetic gases or CO_2 respectively. Servos and pneumatics are used for many functions: to provide chest movement; to provide pulses and blood pressure; to clamp down the airway when appropriate (to make putting down an artificial airway difficult!), and to provide hand movement.

All of these mechanical functions are controlled from the mathematical models in the system to give a huge degree of realism. For example, the hand-clenching movement in response to electrical stimulation (the Train of Four anaesthetic paralysis test) is stopped when the patient is given a muscle paralysis drug. Also the computer provides via its digital-to-analogue converters, various electrical signals such as the heart waveforms.

All of the signals from the HPS are monitored by normal (but-state-of-the-art) monitors. Most of the functions are necessarily complex to provide the realism. Sometimes huge realism can be provided with extreme simplicity, and one example of this is the speech function. Talking is an integral part of everyday life and the patient speaking, moaning or otherwise to the medical personnel and vice versa is essential for the training process. A simple speaker under the throat of the manikin provides speech and this is linked via an amplifier to the control room. The tutor in the control room therefore uses his or her voice and this is very effective. Some people visiting the centre are convinced that the speech process is complex using speech recognition and synthesis, and artificial intelligence. Normally they are told otherwise, but one person left the centre prematurely and has been heard telling people about this amazing speaking dummy!

Anaesthetic gases are recognised by the gas analyser in the stack, but the intravenous drugs are recognised by a bar-code reader (see Figure 5). Each drug syringe has a bar code on it, which relates to the strength and type of drug. The syringe also contains saline (so no actual intravenous drugs are used). When the syringe is 'injected' into the patient, the bar code reader relays to the computer what drug and concentration is being supplied. A flow meter notes the volume of saline supplied to the manikin, so that the computer can provide the correct dose response.

Figure 5 Bar-code reader by patient's head and drug syringe

Figure 6 The theatre team reviving Junior following a medical emergency

Mathematical modelling

Mathematical models simulate the patient physiology and pharmacology and provide responses in real time, to the therapeutic interventions to the patient. The models rely on software to predict the manikin's responses and have great flexibility for changing the model parameters. The human patient simulator contains 13 different models,[1,2] but they can be grouped into three groups, the cardiovascular (the heart systems), the respiratory (the lung systems), and distribution and pharmacology (drug systems). The complete models are shown in Table 1.

Cardiovascular	Respiratory	Pharmacology and reflex control
Uncontrolled cardiovascular system (blood volumes, pressures, flows, wedge)	Lung and chest wall mechanics (gas volumes, pressures, flows)	Distribution of anaesthetic gases
Myocardial oxygen balance	Respiratory rhythm (including respiratory muscle pressure generator)	Pharmacokinetics of intravenous drugs
Cardiac rhythm (including contractility and ECG generators)	Pulmonary gas exchange	Pharmacodynamics and control of circulation
Thermodilution cardiac output	Distribution of respiratory gases	Pharmacodynamics and control of breathing
		Pharmacodynamics of neuromuscular blockade and reversal

Table 1: Human patient simulator mathematical models

A schematic of a model in the system, the lung model, is shown in Figure 7. Most of the other models are similar in that they receive either inputs from the outside world, e.g. gas flow measurements from the lungs, or take outputs from another model. Many of the models, where appropriate, interact with each other. Most of the model parameters can be changed by user control from the control room terminal, and this can override the physical inputs.

Most of the models provide real outputs, e.g. breath sounds, electrical heart waveforms (ECG), various pulses around the body, pulse oximetery signals, blood pressure, thermodilution cardiac output and temperature.

Patient types

As the simulator is model-driven, the vast number of parameters that control a typical patient can be changed at the start of a simulation session to create many different patient types. The simulator comes supplied with many people types. Standard Man (70kg, 25-year-old male, standard fitness, non-smoker, standard height, standard physiology), standard Junior, Stanette (female Stan), and Truck Driver (very obese, heavy smoker, unfit, short male) are some examples. The basic physiological models can be changed to create different types and we have created many 'interesting people'. For example Grannie Frannie is a favourite 80-year-old lady who has ischaemic heart disease and we have also our urology patient, Mr I P Nightly.

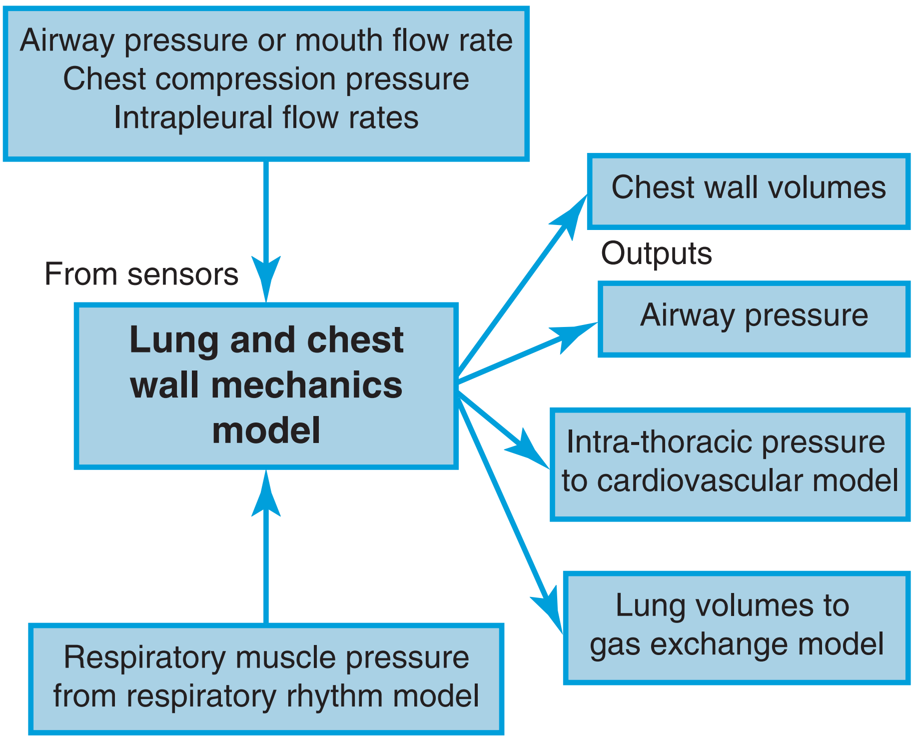

Figure 7: Block diagram of lung model

Anaphylaxis scenario

1 Baseline (a function)
2 Begin anaphylaxis
3 **Mild** anaphylaxis
4 Worsening anaphylaxis
5 Severe anaphylaxis
6 Adrenaline given
7 Complete recovery

2 Begin anaphylaxis

Increase breath sounds
Drop oxygen saturation
Decrease body fluid volume
Drop blood pressure (increase vascular resistance)
Increase left lung resistance (harder to ventilate manually)
Increase right lung resistance
IF adrenaline not given before 60 seconds GO TO **MILD** ANAPHYLAXIS

Figure 8 Anaphylaxis scenario

Scenario scripts

The simulator can be allowed to run freely on its own for tutorials on, for example, physiology and pharmacology. The models and other parameters of the simulation can be controlled in real-time by the user interface. However, the simulator is also a script-controlled system and computer programmes (similar to a high level languages, like C) can be used to control and modify physiological parameters automatically and give commands to the simulator to react or respond in a certain manner. The same sequence of events can be used time and time again for 'fair' testing of trainees.

For example a simple critical incident scenario such as anaphylaxis (huge abnormal reaction to a normally innocent material, drug or food stuff) uses a script as shown in Figure 8. The scripts are written by the course leader and can be complex or very simple. Each stage or 'state' of the script contains several procedures to produce the effect, and the begin anaphylaxis state is expanded to show this. The scenario will start at the baseline and can either progress manually or automatically. The operator can instruct the computer to jump to the next state. Or the script can automatically advance to the next state if a Boolean 'condition' is met, such as IF time > 60 seconds, or IF drug given.

There are numerous crisis events that can be programmed, for example malignant hyperthermia, asthma, and major haemorrhage. These can be as complex as the imagination and skill of the course designer allows. For example a severe multiple crisis can be made to develop. Oxygen can run out during a caesarean birth; complications can occur; there is a fire alarm; power failure, etc.

Scenarios

The scenario computer script must be accompanied by a 'story' or scenario to give some background so that the medical 'team' and controllers know what is happening. For example, to go with the anaphylaxis script, the following scenario might appear in one of our GP courses.

The delegates are told that an 18-year-old man has rushed into a GP surgery in a panic having accidentally eaten a sweet containing peanuts. The man has a known allergy to peanuts and carries an Epipen® (a single-use auto-injector device that administers epinephrine – an emergency drug used to treat severe allergic reactions). The delegates now attend to the manikin which has oral itching and swelling which rapidly progresses to severe stridor (high-pitched upper airway sounds). The patient cannot be intubated (putting an artificial breathing tube into the patient) and requires a surgical airway. The delegates have then to deal with this situation!

Figure 9 Operating theatre with operation in progress – view of surgical instruments and one-way window to control room

BMSC facilities

The human patient simulators, and all the other simpler simulators, are all based in realistic medically equipped rooms. Simulated operations can be carried out in the operating theatre (Figure 9). It is made as real as possible and ‘feels’ like a modern theatre. It contains ‘real’ equipment such as ventilators, defibrillators, state-of-the-art patient monitors, trolleys and drip stands. A control room is next to the theatre with a one-way viewing window (Figure 10). This is where the computer scenarios are controlled and the re-enactment is viewed and videoed. The tutors in the control room communicate with key personnel in the theatre using radio headsets. The advanced audio-visual facilities are housed here as well. There is a 24-channel video and audio matrix switcher, so that any of the cameras and microphones in any of the medical rooms can be switched to either the presentation/conference room, to the video recorders or to the broadcasting facilities. Also any of the AV feeds can be fed to the large lecture theatres in the education centre.

A debriefing conference/presentation room is provided which also contains a one-way viewing window to the theatre and real-time theatre physiological monitoring (Figure 11). There is also an intensive care side room (which can be converted to a GP surgery or a ward side room), and a six-bedded accident and emergency ward or general ward (Figure 12). The six-bedded ward is equipped with monitors, ventilators and similar equipment to that provided in the real situation. Although we do have just enough manikins to fill the beds, we can make (unrealistic?) situations of having empty beds in the ward!

Figure 10 Control room with tutor, with anaphylaxis scenario in progress

Figure 11 Presentation/debriefing room with tutor discussing points learnt from scenario

Courses at the BMSC

Because the centre has a number of these medical ‘rooms’, facilities and simulators, it has a high degree of flexibility making it ideal for training courses tailored to a wide range of delegates. Medical students, nurses, accident and emergency doctors, anaesthetists, general practitioners, dentists, pharmaceutical industry representatives, medical equipment manufacturers and pharmacists have all been through the centre. In fact most healthcare workers, except for surgeons, have been involved. The problem for surgeons is that our current manikins cannot be cut up (they break if they are) although there are current initiatives to involve surgeons in the centre.

Medical students and trainee nurses can have their routine teaching and training brought alive by using training through simulation. The simulator can help medical staff and the whole team involved deal with rare, medical crisis. These critical incident and human factor courses are very popular in the centre, but they do take a lot of manpower. Everyone dresses up in normal theatre clothing and there is usually a ‘hot seat’

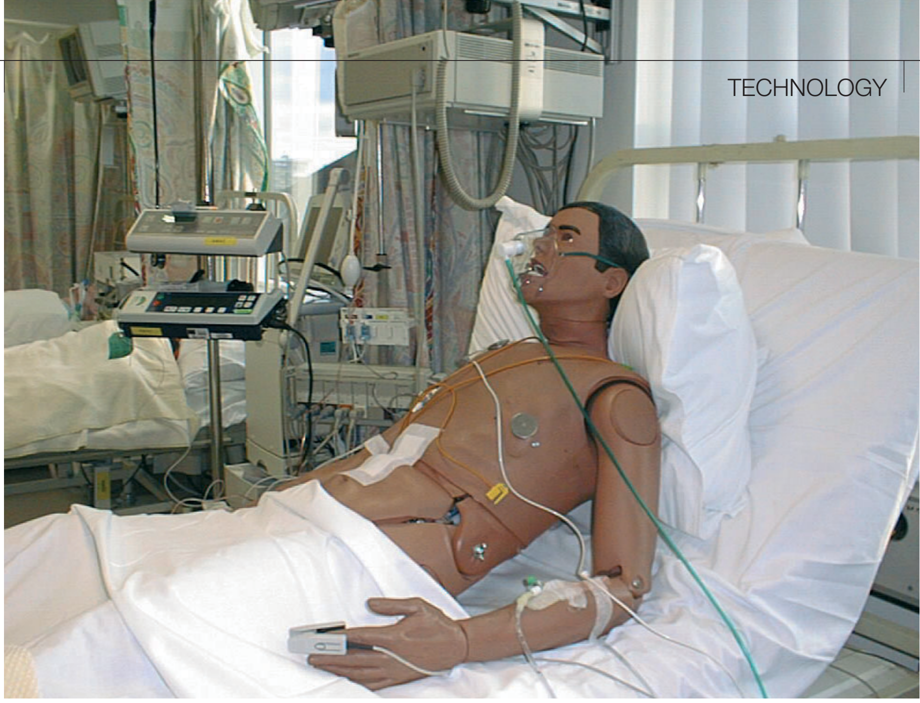

Figure 12 Six-bedded room photo, highlighting one of the beds with manikin

person who will be first to interact with the simulator. This might be the anaesthetist, but could be another key person. A rare critical event will occur, and the hot seat person will be watched and videoed. Other members of the team can be themselves, or actors (an operation is shown in Figure 9, where a crisis is about to happen). When the crisis does happen, however, the team is ready to deal with it. Delegates can watch their performance on video and be debriefed in the conference room. They are also given background lectures and prior simulator orientation in that room.

Courses are run for delegates locally and nationally. CPD (CEPD) recognition is given which is part of the present revalidation process of doctors. We run over 20 very different courses at the centre and are continually updating them and introducing new ones.

BMSC activity

The BMSC is busy. It runs (on average) courses 3.5 days a week, research 1 day a week, while maintenance/visits take up 0.5 day a week. It does not normally open at weekends, apart from occasional filming sessions where the media have used it as a realistic theatre environment, where things can be programmed to go wrong, without any danger to patients, or impact on the waiting lists.

Research and development

Research needs to be balanced with the courses that are run. The centre is reliant on course income to keep operational and ideally we would like to carry out more research. Presently the balance is tilted in favour of the courses. We have, however, carried out a variety of research projects and have others that are about to start.

One of the long-term objectives of the research programme is to determine whether training by simulation is effective and can improve the safety of medical practice. A consortium of the South West of England including input from the BMSC has recently been awarded a three-year grant from the Department of Health to investigate the impact of simulation-based training on reducing perinatal mortality. Also we are part of a national consortium seeking grant funding to start a major project to quantify improvement outcomes in operating theatre and ward situations after simulation-based training.

We have carried out many small research and development projects in the centre and to give a flavour of this, some are now very briefly described.

Medical student teaching

All Bristol medical students, as part of their anaesthetic placement, spend some time in the BMSC. We tried to find out objectively if their learning using the simulator was more effective than traditional learning. The medical students were split into two groups. The first group learnt about cardiovascular shock practically using the simulator, and the second group learnt about oxygen therapy practically using the simulator. Each group learnt about the other subject using traditional learning methods. Both groups sat their standard examinations. The results were analysed and there was no statistical difference in scores between the two groups. Although this was a surprising (and disappointing) result for us, further reflection suggested that the simulator groups maybe had less work to do to revise for the examination. We need in future to spring an un-revised examination on them. The simulator groups certainly preferred and enjoyed the learning experience using simulation more than traditional methods.[3]

Assessment of new anaesthetists

We looked at whether the human patient simulator could be used to assess new trainee anaesthetists' performance in doing a set task at the beginning of an operation (rapid sequence induction). With the simulator it is possible to have the same things 'go wrong' in each operation which would be difficult and non-ethical to activate in a real theatre. Each of the new anaesthetists were videoed and they were assessed or 'scored' using a specially devised marking system. All the anaesthetists showed similar 'classic' learning style curves of score against time. They all reached a plateau at around three months, but the plateau score was always less than that of the fully qualified anaesthetists. The difference was mainly due to the trainees not checking their equipment.[4] This work is being repeated to look at the effect of training operating department practitioners.

Effectiveness of human factors training

This research analysed all the feedback forms from all the human factor courses held at the BMSC over a three-year period. Eighty per cent reported that the training had a positive effect on their clinical practice. Fifty-five per cent reported that watching the scenario and debriefing in the conference room was as good as the 'hot seat' experience.

Improving paediatric modelling
Although the paediatric version of the simulator has been a very effective educational tool, administration of some drugs to the simulator created an unrealistic clinical response. We investigated 11 commonly used paediatric drugs, carried out full dose response relationships for these drugs on the simulator and then compared the results with the published literature. We then used the pharmodynamic and pharmokinetic drug editor of the simulator (which can actually create 'new' drugs) to modify the existing drugs, so that the 11 drugs are now correct. We are now clinically evaluating these 'new' drug profiles before introducing them into the courses.

Remote learning
We carried out a demonstration project (Multimed),[5] which used satellite broadcasting to transmit real-time anaesthetic courses from the centre to hospital and educational sites around the UK (and one in Bosnia). Remote users could watch a crisis incident in the centre and communicate via real-time text-transfer. Remote control of the cameras was possible. This project has now been extended into a new area – it is in a pilot phase looking at broadcasting interactive live courses and off-line tutorials to GP's surgeries.

Manikin development
We are starting a project to develop a manikin limb that will change colour and temperature according to physiological state, and that can be 'operated on' and cut to produce a proportional physiological output. This type of development will make the centre attractive to the surgeons.

Tired anaesthetists
We are half way through a project to study how anaesthetists who have been on call all night carry out complex operations. We can make their task progressively more difficult and determine at what stage they are too tired to carry out the difficult task. We can determine how the tired staff perform in a crisis situation. This is something that obviously could not be done in the real theatre! This research could be used to make recommendations for on-call working.

New initiatives
We have recently bought an ambulance, and intend to use this together with our new portable emergency patient model-driven simulator to provide training and simulation off-site. We would then have the possibility of staging, for example, a road-traffic accident and looking at how medical staff cope with the problem of moving injured patients around.

Conclusions

This article has described an example of simulation (the process of imitating the condition of a situation for training) used in the medical world. It has described the Bristol Medical Simulation Centre in detail and given some insight into how the complex human patient simulators work. Training by simulation seems to be enjoyable for the delegates, and will hopefully make better-trained medical staff which will in turn make medicine safer. Although Bristol was the first centre of its kind in the UK, there has been great expansion in simulation-based training in all areas of medicine, and it seems that as in other industries, it is here to stay. ■

For more details of the BMSC, please refer to the website, **www.simulationuk.com**

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