ASWAN HEART CENTRE
SCIENCE & PRACTICE SERIES
A Qatar Foundation Academic Journal

Research Article

Modelling transoesophageal echo

Susan Wright*

Department of Anaesthetics, The Heart Hospital, University College London Hospitals, London, UK

* Email: sue.wright@doctors.org.uk

ABSTRACT

Background: Achieving competence in transoesophageal echocardiography (TOE) requires a clear understanding of cardiac anatomy as well as an ability to correlate two-dimensional (2D) echocardiographic images with the three-dimensional (3D) structures which they represent. Training in the technique is a long process, which may also be hampered by insufficient access to teaching in the clinical environment. These challenges would be met by a simulator which demonstrates detailed cardiac anatomy with a previously unavailable degree of accuracy.

Methods: A TOE simulator system was created by collaboration with a wide range of clinical specialists and a post-production company skilled in the generation of computer graphics and special effects for the film industry. The core of the system is an animated, accurate and detailed virtual heart. Echocardiographic simulation was developed to provide a real-time display of ultrasound images alongside the 3D anatomical correlate of the imaging plane.

Results: A freely interactive animated model of the heart was created as the basis for ultrasound simulation. Creation of a mannequin simulator which drives the software allowed reproduction of the practical experience of the TOE procedure.

Conclusions: Partnership with groups with a wide diversity of skills can result in a simulator teaching tool of high fidelity.

Keywords: transoesophageal echocardiography, simulation, education

DOI: 10.5339/ahcsps.2011.2

Published: 14 April 2011

Cite this article as: Wright, S. Modelling transoesophageal echo, *Aswan Heart Centre Science & Practice Series* 2011:2 doi: 10.5339/ahcsps.2011.2

BACKGROUND

An explosive rise in the use of ultrasound in clinical practice has led to the need for clinicians from a wide range of specialties to develop practical and interpretative skills in ultrasound scanning. In the practice of cardiac anaesthesia, ultrasound technology has been applied to the intraoperative management of cardiac surgical patients in the form of transoesophageal echocardiography (TOE) [1]. Over the last two decades this has become a standard intraoperative monitor in the cardiac operating theatre [2].

Training in the technique is time consuming and labour intensive [3]. Fundamental to learning the practice of TOE is a sound understanding of cardiac anatomy and physiology. Furthermore, an ability to interpret a 2D image in the context of the 3D structure from which it has been derived is critical to the accurate interpretation of ultrasound images. Currently, training in TOE image acquisition and interpretation is derived from supervised scanning of patients and video image review, a process which is frequently hindered by limited access to patients in the clinical setting.

At The Heart Hospital in London our group (Dr's Andrew Smith, Bruce Martin and Sue Wright) directs training courses in perioperative TOE. The paucity of accurate teaching material with which to illustrate accurate cardiac anatomy to students presented us with an opportunity to create our own model of the heart. Subsequent incorporation of an animated, accurate model of the heart into a simulator with 'true-to-life' TOE probe controls and realistic screen images would allow training in practical image acquisition that was independent of access to patients in a clinical setting and would entail no risk to patients from procedure-related complications.

This concept developed into a plan to create an accurate, detailed and freely interactive virtual heart, which could be tumbled and sliced to reveal intracardiac anatomy and enlarged to enhance clarity. Ideally, the model needed to be animated and labelled. The simultaneous display of simulated ultrasound images corresponding to any given slice through the heart would have obvious educational value, and ultrasound simulation was incorporated into the specification presented to potential software developers.

Impressed by the realism of computer graphics they had created for the film industry, we engaged a post-production company (Glassworks Ltd., London) to develop the virtual heart. The software team had no prior medical knowledge but a strong track record in the research and development of unusual projects within advertising and the film industry. We believe that their background was fundamental to the creation of a model with an unprecedented degree of realism.

METHODS

The creators of the model faced the challenge posed by the fact that the heart is one of the most complex organs in the human body to model as a static structure, its complexity then compounded by the fact that it moves. The foundation for the creation of the 3D structure was a latex cast taken from a cadaveric normal heart (Fig. 1), which was processed by a 3D scanner to produce a dataset representing the basic shape of the cavities of the heart (Fig. 2). This relatively low-resolution dataset was developed by manual modelling to create detailed intracardiac structures and a separate, concentric external cardiac surface. Reference data in the form of a range of cardiac imaging modalities (CT, MRI, angiography, echocardiography) complemented access to cadaveric specimens to inform this process.

Oblivious to the clinical significance of any particular intracardiac structure, the developers applied as much attention to the detail of regions of the heart rarely focussed upon by clinicians as they did to structures of greater clinical importance. In addition, the 'hand-modelled' nature of the virtual heart allowed us to incorporate contributions from a wide range of eminent clinicians, morphologists and imaging specialists, all of whom have specialist knowledge of differing aspects of cardiac anatomy. Although it is frowned upon by intellectual property lawyers, we believe that the practice of broad collaboration strengthened the accuracy of the model significantly.

The result was a 3D polygonal mesh comprised of over 340,000 triangles. (Fig. 3). The cardiac surfaces were textured with reference to a large amount of video and still images of live human hearts (Fig. 4), with careful attention to the light-reflecting properties of different tissues. The need to display the cut edge of the heart, when sliced, as a solid structure (in reality two concentric shells with an intervening hollow space) and the generation of the 2D ultrasound image from that cut surface presented further software challenges, which were met by the development of custom software by the team.

Animation of the 3D mesh was also achieved manually, on a frame-by-frame basis, with visual reference, as before, to other cardiac imaging modalities and meticulous attention to details of the timing of the cardiac cycle.

The software was written *de novo* in C++ with minimal reliance on third party software. The graphics pipeline is OpenGL, using GLSL as the high level shading language. The cumbersome nature of the deforming mesh stretched the processing capabilities of available graphics cards to their extreme; on average the application processes approximately 4 million (deforming) triangles every frame. This is because the 3D polygonal model is only a fraction of the data needed to generate the resulting image. The addition of the surface textures and the volumetric data required for motion description created a massive dataset which required direct loading onto the graphics card for the application to run at an interactive frame rate. The usual software technique of occlusion culling, whereby data relating to structures obscured by others in the image are not processed (and therefore do not slow down performance) was not possible because of the need to be able to display a large proportion of the data all of the time.

This challenge was finally resolved by the timely introduction of a new graphics card by the Nvidia Corporation, along with innovative use of software techniques to buffer the rendering of light effects

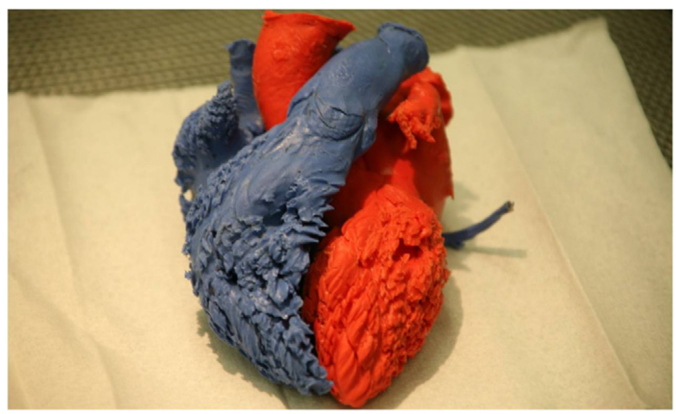

Figure. 1 Latex cast of a human heart.

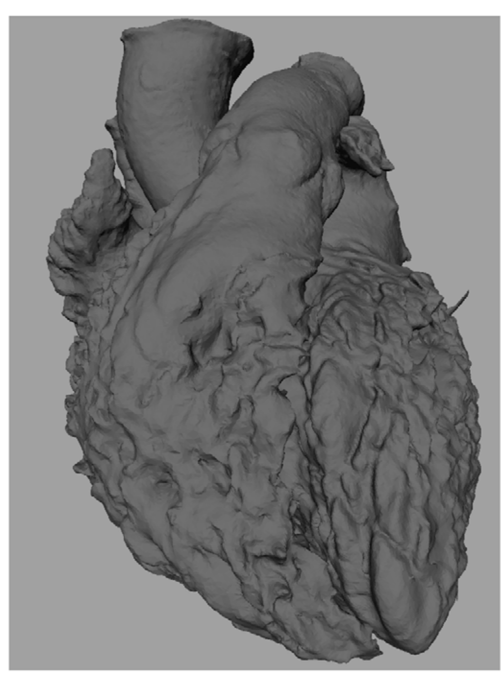

Figure. 2 3D scan of latex cast.

of portions of the heart not visible on screen. These solutions allowed a frame rate of 25 frames per second and the ability to display smooth cardiac motion with the timing of intracardiac events, accurate to within 20msec.

The simulated ultrasound image was developed to be displayed in real time next to the virtual heart, according to how the operator has positioned the ultrasound probe and plane (Fig. 5). The echocardiographic image was enhanced by the addition of image artefact and a degree of blurring of edges to more closely replicate real ultrasound images, an effect which adds significant processing demands to the programme.

The ability to display labels for intracardiac structures was considered an integral part of the teaching tool but also presented specific challenges to the software specialists, because of the need to define the volume enclosed by any intracardiac structure (rather than solely its surfaces) so that it could be selected on screen even when not represented in the cut surface of the heart. Definition of the individual volumes corresponding to the 160 separately labelled structures within the virtual heart was a laborious process, but has allowed any portion of the 3D model or the corresponding ultrasound image to be identified along with detailed anatomical text which has been integrated into the labelling structure. This facility also allows the student to isolate and display separately any intracardiac substructure, either alone or in combination with others, to support understanding of intracardiac anatomical relationships (Fig. 6). The system software permits the selection and simultaneous display of any combination of the 160 separately labelled intracardiac structures; in this view the four valves and cardiac vasculature.

Substantial flexibility in the graphical user interface (GUI) has allowed the system to be used for teaching in a variety of ways. The ability to display any combination of the three windows within the system (heart model, simulated ultrasound image and explanatory text) in any arrangement on screen (Fig. 7) permits self-directed learning as easily as it facilitates tutored instruction in the practice of TOE.

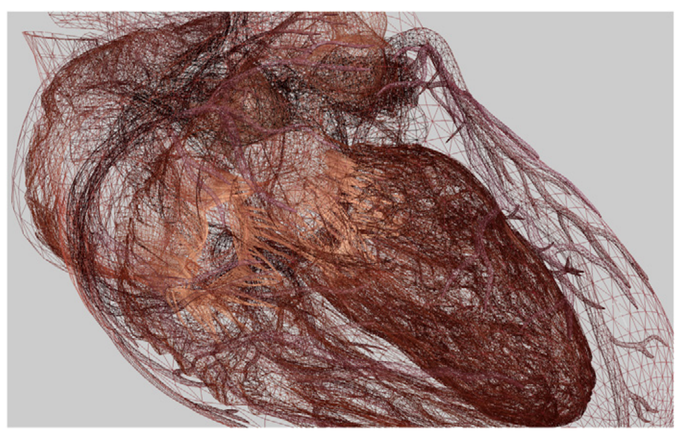

Figure. 3 Polygonal mesh model of the heart.

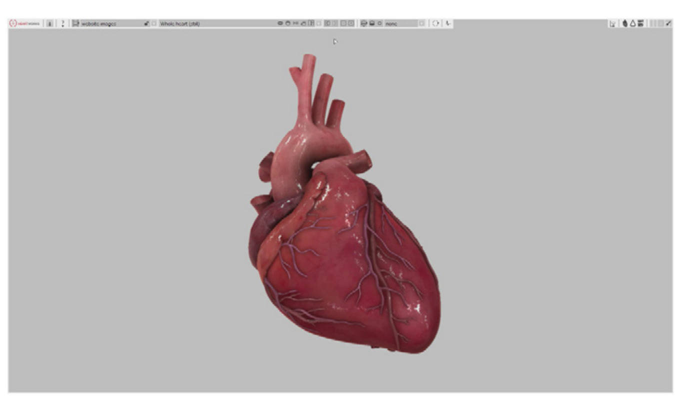

Figure. 4 Heart model with surface textures applied.

The first stage of development resulted in a desktop computer based TOE simulator, whereby the TOE probe and ultrasound plane could be manipulated in real time using keyboard and mouse controls. The system's power as a teaching tool was strengthened greatly by the development of a torso mannequin with a realistic TOE probe which controls the software, to reproduce the practical experience of performing a TOE examination (Fig. 8 & Fig. 9). The simulator probe is capable of the real-life range of movement of a TOE probe along the path of a virtual oesophagus into the stomach, with free anteflexion and retroflexion of the probe tip and rotation of the 'ultrasound plane' through 180°, using controls which resemble those on any commonly used TOE probe in clinical practice. The user has the option of displaying the 3D heart model on the screen alongside the simulated TOE image to reinforce the correlation between the 2D echocardiographic slice and the underlying 3D cardiac anatomy.

Considerable attention was paid to the choice of materials used in the creation of the mannequin and probe in order to recreate a realistic 'feel' in probe manipulation and the use of the controls. Registration of the probe position and alignment of the ultrasound plane by the operator was facilitated by the haptic interface designed in collaboration with Asylum Ltd., a models and effects company whose primary work lies in advertising and the film industry.

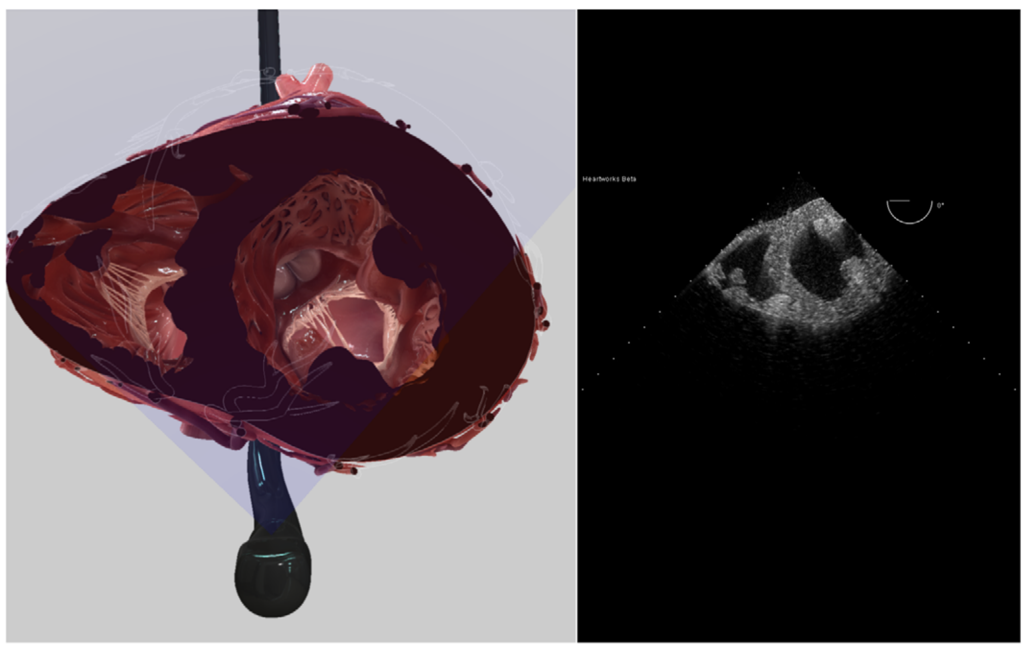

Figure. 5 Simultaneous display of ultrasound image and 3D model.

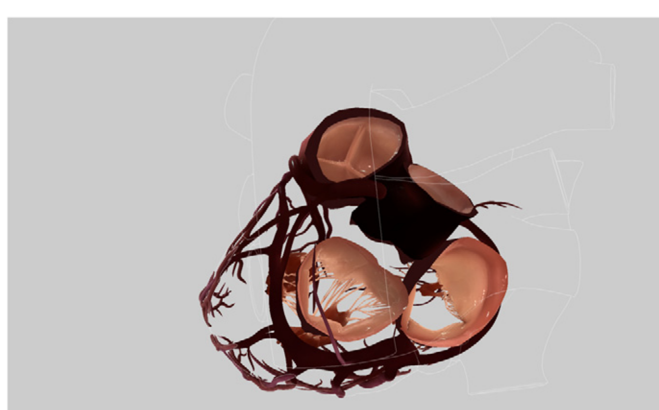

Figure. 6 Selection of intracardiac substructures.

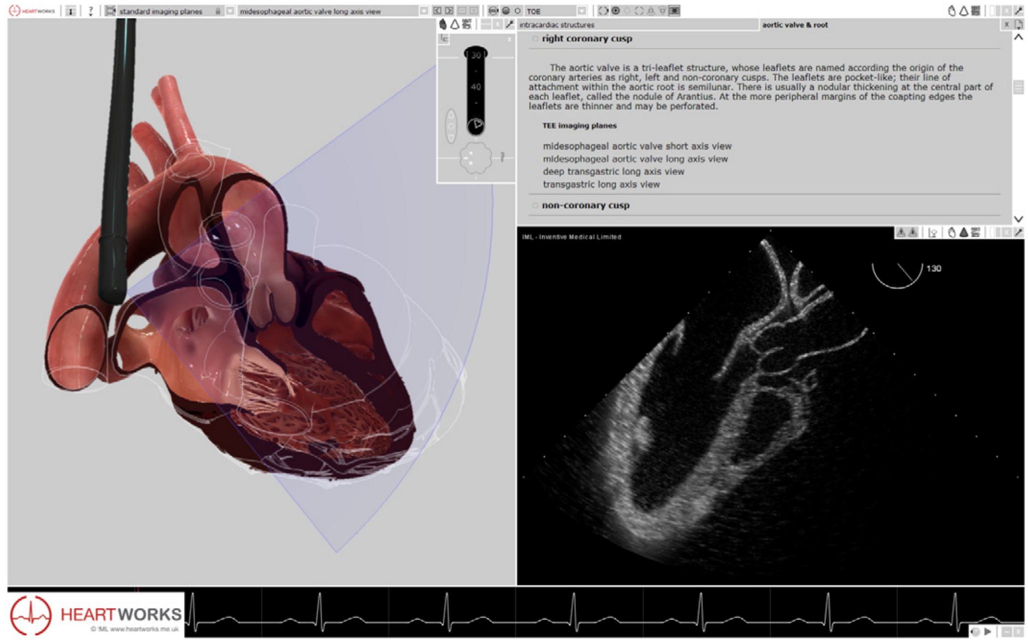

Figure. 7 Graphical user interface. The 3D model of the heart, ultrasound image and explanatory text may be displayed in any configuration and any combination on the screen.

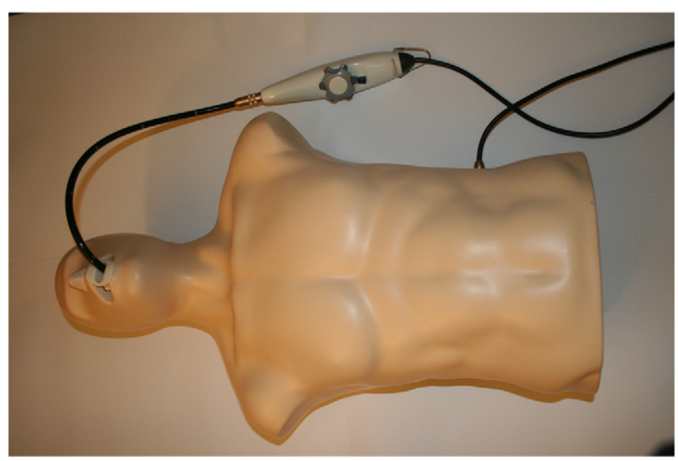

Figure. 8 Simulator mannequin and probe.

RESULTS

The development group's anecdotal experience of the HeartWorks system as an aid to training in TOE has been extremely positive [4], and it has been used to teach schoolchildren and medical students as well as anaesthetists, cardiologists, intensivists and cardiac surgeons. However, formal validation studies are important to the verification of the system's role in clinical training and are currently in progress [5] in three teaching centres (King's College Hospital, London, Duke University, North Carolina, and Vanderbilt University, Tennessee). Evaluation and incorporation of feedback into future modification and development of the system is central to the philosophy of the group.

CONCLUSIONS

Simulators are increasingly used in medicine to prepare clinicians for practical procedures performed on patients [6]. This TOE simulator permits the skills required in acquiring and recognising conventional echocardiographic imaging planes to be achieved without potential risk to patients. The development of the system has entailed collaboration of teams from widely different professional fields, a breadth of input that has resulted in an invaluable teaching tool.

Figure. 9 TOE simulator in use. The software has been configured to display the student's positioning of the TOE transducer and ultrasound plane relative to the heart, alongside the simulated ultrasound image. The 3D heart model has been sliced in the plane of the ultrasound.

COMPETING INTERESTS

Dr. Susan Wright is a paid consultant to Inventive Medical Ltd., manufacturer of the HeartWorks TOE simulator.

ACKNOWLEDGEMENTS

No other persons have made substantial contributions to this manuscript.

FUNDING SOURCES

The HeartWorks TOE simulator project was funded by the University College London Hospitals Charity.

References

[1] Eltzschig HK et al. Impact of Transesophageal Echocardiography on Surgical Decisions in 12,566 Patients Undergoing Cardiac Surgery. Ann Thorac Surg. 2008;85:845–852.
[2] Shanewise JS et al. ASE/SCA guidelines for performing a comprehensive intraoperative multiplane transesophageal echocardiography examination: recommendations of the American Society of Echocardiography Council for Intraoperative Echocardiography and the Society of Cardiovascular Anesthesiologists Task Force for Certification in Perioperative Transesophageal Echocardiography. Anesth Analg. 1999;89(4):870–884.
[3] Cahalan MK et al. American Society of Echocardiography and Society of Cardiovascular Anesthesiologists Task Force Guidelines for Training in Perioperative Echocardiography. Anesth Analg. 2002;94(6):1384–138.
[4] Bose R et al. Transesophageal Echocardiography Simulator: A New Learning Tool. Journal of Cardiothoracic and Vascular Anesthesia. 2009;23 No 4 (August):544–548.
[5] Smith, LA, et al. Expert evaluation of a novel transoesophageal echocardiography simulator. Poster presentation, EuroEcho, Copenhagen, December 2010.
[6] Scalese RJ et al. Simulation Technology for Skills Training and Competency Assessment in Medical Education. J Gen Intern Med. 2008;23(Suppl 1):46–49.