Use of 3D models of congenital heart disease as an education tool for cardiac nurses

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Abstract

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Background: Nurse education and training are key to providing congenital heart disease (CHD) patients with consistent high standards of care as well as enabling career progression. One approach for improving educational experience is the use of 3D patient-specific models.

Objectives: To gather pilot data to assess the feasibility of using 3D models of CHD during a training course for cardiac nurses; to evaluate the potential of 3D models in this context, from the nurses' perspective; and to identify possible improvements to optimise their use for teaching.

Design: A cross-sectional survey.

Setting: A national training week for cardiac nurses.

Participants: One hundred cardiac nurses (of which 65 paediatric and 35 adult).

Methods: Nurses were shown 9 CHD models within the context of a specialised course, following a lecture on the process of making the models themselves, starting from medical imaging. Participants were asked about their general learning experience, if models were more/less informative than diagrams/drawings and lesion-specific/generic models, and their overall reaction to the models. Possible differences between adult and paediatric nurses were investigated. Written feedback was subjected to content analysis and quantitative data were analysed using non-parametric statistics

Results: Generally models were well liked and nurses considered them more informative than diagrams. Nurses found that 3D models helped in the appreciation of overall anatomy (86%), spatial orientation (70%), and anatomical complexity after treatment (66%). There was no statistically significant difference between adult and paediatric nurses' responses. Thematic analysis highlighted the need for further explanation, use of labels and use of colours to highlight the lesion of interest amongst improvements for optimising 3D models for teaching/training purposes.

Conclusion: 3D patient-specific models are useful tools for training adult and paediatric cardiac nurses and are particularly helpful for understanding CHD anatomy after repair.

Key words:

Cardiovascular nursing

Congenital heart defects

Training

3D printing

Introduction

Congenital heart disease (CHD) accounts for up to 9:1000 United Kingdom (UK) live births (1). Successes and advances in care, including medical and surgical interventions, have contributed to an ever-increasing population of adults now living with CHD, such that approximately 80% of children born with CHD now survive in to adulthood (1,2). It is thus important that both paediatric and adult nursing staff have the skills and knowledge to care for these patients lifelong.

Nurse education and training are key to providing CHD patients with consistently high standards of safe, quality care as well as enabling career progression (1,3,4). In the UK, attaining agreed national standards and competencies is crucial for meeting the needs of patients and nurses whilst enabling workforce and service planning for the National Health Service (1,3,4). It is recognised that an education and training programme can help nurses to attain competencies and meet standards (1,5).

Congenital cardiac care is increasingly being delivered using a network model in the UK, with the main surgical centre leading and coordinating care across the network with the aim of enabling patients to receive elements of care closer to home (1). There are a variety of standardised nursing roles across the cardiac network (1,3,4) and the education and training needs of nurses within these roles vary considerably. The role of the clinical nurse specialist (CNS) is recognised as "key […] in implementing disease management programmes" for patients with heart disease (6) and increasingly the role of the cardiac CNS is recognised as pivotal within the multidisciplinary team providing care to an increasingly complex and diverse patient group.

Furthermore, areas such as adult congenital cardiac nursing are still evolving as the patient population grows, evidenced by the fact that the British Adult Congenital Cardiac Nursing Association (BACCNA) was founded less than 10 years ago, with the recognition that education in this speciality is becoming increasingly important (7). The range and diversity of nurses' educational and training requirements, in addition to working across organisational and geographical boundaries, means that provision of education and training needs to be flexible and responsive to the dynamic nature of network working. Education and training remain essential in areas including anatomy of congenital malformations and basic pathophysiology (7,8).

A variety of training approaches can be used, including printed materials, e-learning (3,4,9), and simulation training (10), the latter including simulated scenarios, manikins with feedback mechanisms, expert instructors, video self-instruction and potentially in-hospital scenario-based videos (11). Indeed, different media can, and should, be employed to provide optimal training.

One technological innovation outside the field of cardiology that could be used as a teaching tool is 3D printing. The potential usefulness of 3D replicas has been explored in ophthalmology, particularly for optometry nurse training (12). This study focused on 3D prints of orbital dissections and discussed some of the potential advantages over plastinated specimens, such as their rapid reproduction, avoidance of ethical issues associated with viewing cadaver specimens and their suitability for different settings (e.g. office, home, laboratory or clinical setting). Quantification of the advocated usefulness of 3D models was, however, lacking. While such models could offer logistical and ethical advantages over specimens, even for other specialties such as cardiology, it is important to assess the trainees' response to such models and investigate further how 3D models could be incorporated in the context of formal training. In order to address these issues with respect to CHD, we conducted a study with the following aims:

- to gather pilot data to assess the feasibility of using 3D models of CHD for training cardiac nurses and incorporating them in the context of a training course;
- to evaluate the potential of 3D models in this context from the nurses' perspective, by means of a survey;
- to identify improvements, from the nurses' perspective, to optimise the use of 3D models for teaching and training.

Materials and methods

a) Participants

Participants were 100 nurses (65 paediatric cardiac nurses and 35 adult cardiac nurses; 90% female) attending a national introductory training course about congenital heart disease during 2015. Paediatric nurses had approximately three years of prior experience in this field, thus possessing some knowledge of CHD, while the adult nurses had none or minimal prior experience.

b) 3D models

A set of 9 models was generated for the purpose of this study. Models were manufactured from anonymised patients' cardiovascular magnetic resonance imaging data, according to a procedure described in detail elsewhere (13). The use of medical images for research purposes was approved by the Local Ethics Committee and R&D Office. The models depicted the following anatomies: a healthy heart; repaired transposition of the great arteries (arterial switch operation); aortic coarctation; tetralogy of Fallot; pulmonary atresia with intact ventricular septum; and the three stages of palliated hypoplastic left heart syndrome: Stage I (Norwood), two examples of Stage II (Glenn) and Stage III (total cavopulmonary connection, TCPC).

c) Format of the course and survey administration

The models were displayed on a table outside the lecture room (Figure 1) and nurses were encouraged to access them throughout the five-day course, e.g.

during breaks and in between lectures. Each model had a label including an image of the anatomy for reference, the name of the congenital defect, as well as the age and sex of the patient from whom the model was derived. Nurses could manipulate and discuss models without a specific time being allocated. On the first day of the course, the research team gave a 15 minute presentation to participants explaining how the 3D models were manufactured, as well as the rationale for including the models during the training course. The team then addressed any questions and invited participants to have a look at the models, which were accessible for the duration of the course without any time limit.

At the end of the course participants were asked to complete a short questionnaire specifically designed for this project to elicit participant views about the 3D models. The questionnaire consisted of five questions assessing the perceived usefulness of the course for learning, as well as providing the opportunity to give any additional feedback and recommendations. The first three questions focused on the learning experience and information elements of the models and were answered on a 5-point Likert scale (1-strongly agree to 5-strongly disagree). The fourth question addressed potential attributes of the model in terms of facilitating understanding, asking nurses to indicate, by ticking if applicable, whether they agreed with a series of statements (e.g. 3D patient-specific models helped me to appreciate anatomical complexity of repaired congenital heart disease) and the final question asked participants to rate all 9 models on a 7-point Likert- scale from 1 = “not useful at all” to 7 = “extremely useful”. Finally, an option was given to leave additional feedback.

d) Statistical analysis

Data for the total group were analysed using non-parametric descriptive statistics and responses of paediatric and adult nurses were compared using the Wilcoxon rank sum test and Chi squared test, for ordinal and dichotomous variables respectively. Qualitative comments in the optional feedback section were subjected to content analysis, whereby themes were identified and the frequency of occurrence of the themes determined.

Results

Results indicated that participants found the 3D models useful, with 60% agreeing or strongly agreeing that the models improved their learning experience and 74% agreeing or strongly agreeing that the models provided more information than diagrams. Conversely, a non-negligible 19% of participants reported that the patient-specific models did not provide more information than generic/idealised 3D models. These findings are summarised in Figure 2.

Rating models' usefulness on a scale from 1 (= "not useful at all") to 7 ("extremely useful"), nurses indicated that models were useful, with an average rating of 5.1 out of 7, and no significant difference between models of different defects (see Figure 3).

When asked to identify the most relevant uses for the models, participants indicated that the models helped them to appreciate and understand the overall anatomy (86%), spatial orientation (70%), and anatomical complexity after treatment (66%). Furthermore, 43% thought that models could provide information and insight, which would help them to understand the treatment of patients with CHD. Only 6% of participants felt that models were not helpful in the context of the course, and 17% thought they were somewhat confusing.

In comparing responses between adult and paediatric nurses, no statistically significant differences were observed. It is worth noting that although not reaching statistical significance, all participants who indicated that models were not helpful in the context of the course were paediatric nurses (0% adult vs. 9% paediatric, $chi^2 = 2.9$, $p = 0.09$), whilst a larger proportion of adult nurses felt models helped them to appreciate complexity in the anatomical arrangement after repair (79% adult vs. 60% paediatric, $chi^2 = 3.0$, $p = 0.08$) and to appreciate treatment for CHD patients (55% adult vs. 36% paediatric, $chi^2 = 2.9$, $p = 0.09$).

Thirty-six of the 100 participants, 20 (55%) of whom were paediatric nurses, provided additional qualitative feedback. Comments were grouped into 5 main themes:

1. *Information on models*: comments related to the need for further explanation for the models (n=7); the information presented being somewhat confusing (n=4); and a need for more labels (n=6). One adult nurse commented: “Some of the features were difficult to identify. If some were labelled in small writing it would have been more beneficial to understand”. A paediatric nurse reported that they “need the models explained”.
2. *Appearance of the models*: Several participants (n=6) suggested that colours would be helpful (“lack of colour made it difficult to make out structure”) and two nurses commented that transparent materials would make it easier to understand the anatomy. Of the 10 nurses who disagreed that the models improved their learning, half commented that use of colours or transparent materials would improve the models.
3. *Model shape:* three participants mentioned the size of the models, suggesting that a larger model would have been easier to understand, and two nurses commented that it would have been helpful to have a model of the whole heart as well as the particular lesion: “It would be

better to see the whole heart not just the anomalous part to put it into context"..

4. *Being able to see inside:* Eight of the nine nurses who commented on the value of being able to see inside the model heart explicitly suggested opening up the models to observe intra-cardiac structures: "I feel that it would be beneficial to open up the heart to look at the internal structures".
5. *Usefulness in teaching and explaining defects:* Eleven participants provided comments emphasising the usefulness of the models as training tools for better explaining CHD to different audiences, including: parents (n=5); patients (n=2); or clinical peers (n=2). As one participant commented: "Fantastic contribution to informing patient of their clinical condition. Valuable tool to enhance patient and family knowledge base". Nurses commented on their possible utility both in clinics and on the wards, "to teach staff and families about the specific conditions".

Overall paediatric and adult nurses made similar comments about the models, although adult nurses provided more feedback about the appearance of the models and the benefit of being able to see inside. The comments indicated that whilst for some nurses the models were not perceived as useful for learning about CHD, others viewed them very positively: "Looking forward to see what the 3D printing will bring in the future. The 3D models gave us a more precise image of different heart defects and this led to a better understanding of anatomical complexity of defects and surgical repairs. Amazing!!!"

Discussion

Three-dimensional (3D) models depicting patient-specific anatomical features constructed from medical imaging, in particular cardiovascular magnetic resonance imaging, is a potentially valuable training tool in the context of nursing paediatric and adult patients with CHD. Such 3D models can increase understanding of 3D orientation, which may in turn improve the study of cardiac morphology. This is particularly the case when the anatomical arrangement is unusually complex, as is often the case in CHD. 3D models have potential advantages compared with *ex vivo* specimens such as ease of manufacture, relatively low cost (varying on the volume of the part and the material with which it is printed), ease of preservation, and the possibility of providing each student with a whole set of CHD models (with multiple cases for each defect) . In the cardiovascular arena a recent study attempted a simulation-based educational approach for one simple CHD condition (ventricular septal defect) for 29 pre-medical and medical students, and all students reported improvements in knowledge acquisition, knowledge reporting and conceptualisation of the defect itself (14).

Our study demonstrated the feasibility of using 3D models during a nurses' cardiology course to address the need for more interactive and novel tools in nurse clinical training. Furthermore, in this study paediatric and adult nurses' responses to the 3D models' usefulness for teaching purposes were elicited, indicating a generally positive perception of the models, whilst at the same time highlighting areas for improvement. Specifically, some of the participants thought that additional explanations would have been beneficial and a number of suggestions were made, such as having more teaching about the models, providing the opportunity for participants to spend more time with the models, and for a professional with knowledge of 3D models to be available for further questions or explanations while the nurses were looking at and manipulating the models. Other suggested improvements included printing models in different colours as well as providing models that can be opened, in order to appreciate inner structures. The latter may by particularly helpful for conditions which require an understanding of intra-cardiac defects or valve defects.

We were interested in exploring whether there were any differences between paediatric and adult cardiac nurses, as they undergo different pre-registration training and have different post-registration clinical experience. There were no significant differences in the responses between the two groups of nurses but there was a trend for the adult nurses to be more positive about the benefits of the models and they offered more suggestions about how the appearance of the models could be improved.

There are some limitations that should be considered when interpreting the results. First, although all of the nurses attended the lecture about the models and all completed the questionnaire, we did not record how much time they spent looking at the models. It was clear from the feedback that some participants felt that they had had insufficient time to look at the models and the lecture slot itself was short, thus limiting the amount of information that could be given to the nurses about the models. Second, we did not assess nurses' prior knowledge or specifically ask them about other courses they had attended about CHD and any previous experience of 3D models. Third, we did not objectively assess the impact of the models on learning and knowledge acquisition. Finally, in order to increase the response rate of the survey we minimized the time required to complete it but in doing so we reduced our opportunity to understand in more detail how and why the models were helpful or not. Although all participants could provide feedback, only one third chose to do so. Whilst it is recognised that respondents are less likely to complete a general open question than a closed one (15), these responses were nevertheless very valuable in highlighting specific model features and suggestions for improvement.

In a recent systematic review of randomised controlled trials of e-learning compared with traditional methods of learning, no differences were found in terms of nurses' knowledge, skills or satisfaction (16) although the authors highlighted that e-learning "offers an alternative method of education". They also identified the lack of high quality research comparing different methods of providing education. Use of 3D models in health education is in its infancy and it will be important to assess the impact of the models on knowledge and skills acquisition as well as satisfaction. Whilst comparisons with other forms of learning might be the next step in the research process, we would argue that 3D models are already a valuable addition to the educational toolkit, with a number of potential advantages over other forms of learning whilst also recognising that they are not a replacement for other forms of learning.

A final caveat concerns ethical and financial considerations associated with 3D printing. Our results indicate that the models were valued as an educational resource by a large group of nurses, in particular with regard to understanding the anatomical arrangement of CHDs, which is known to be extremely complex in some cases. Whilst it was suggested that students would benefit from a model pre and post treatment, ideally for the same anatomy, it should be noted that the possibility of manufacturing 3D models depends on availability of suitable imaging data for a specific case (typically cardiovascular magnetic resonance imaging or computed tomography). For ethical and resource reasons, imaging is only undertaken where there is a clinical need and as such availability of a certain model depends on the clinical indication for imaging.

Conclusion

Patient-specific 3D models of CHD, manufactured by means of 3D printing technology, can be useful in training both adult and paediatric cardiac nurses in cardiac anatomy, particularly more complex lesions. A range of models for the same congenital heart defect can help to demonstrate patient-specific diversity for that individual lesion.

Conflict of interest statement

None to declare

Authors' contributions

GB: concept/design of the study, data analysis/interpretation, statistics and drafting the article; CC: data collection and critical revision of the article; DK data collection and data analysis/interpretation; DR: facilitating the study and data interpretation; LKL: critical revision of article; SS: critical revision of article; AMT: critical revision and approval of article; JW: concept/design of the study, Critical revision and approval of article.

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Table 1

Themes	Information on models	Usefulness in teaching and explaining defect	Being able to see inside	Suggestions for presentation improvements	Model shape
Feedback	Further explanation is needed (n=7)	Good for explaining to families (n=5)	Open up models (n=8)	Colours (n=6)	Include whole heart (n=2)
	Require labels (n=6)	Good for explaining to patients (n=2)		Transparent Material (n=2)	
	Information is confusing (n=4)	Good as a training tool (n=2)	Better visualise atresia (n=1)	Show flow (n=1)	Larger size (n=1)
		Should have them on the ward (n=2)		Presentation was too fast (n=1)	
Total	n=17	n=11	n=9	n=8	n=3

Figure legends

Figure 1: Models were displayed on a table outside the lecture theatre and nurses were invited to explore their features during the course. Labels included a 2D image of the model itself, the name of the defect being depicted, as well as the age and sex of the patient.

Figure 2: Responses (%) to Likert-type questions with regards to the usefulness of the 3D models.

Figure 3: Each model was rated on a scale from 1 (= “not useful at all”) to 7 (“extremely useful”). Overall models were rated as a useful tool, with an average rating of 5.1 out of 7 (dashed blue line). No significant difference was observed between models of different defects. Note: TGA = transposition of the great arteries, CoA = coarctation of the aorta, ToF = tetralogy of Fallot, PA = pulmonary atresia, HLHS = hypoplastic left heart syndrome, at different stages (“st I”, “st II”, “st III”) of palliation.