Visualizing Human Embryonic Development of the Heart's Outflow Tract

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Abstract

Data from the Virtual Human Embryo Project, a digital image database of serially sectioned human embryos from the Carnegie collection, was used to visualize and create 3D reconstructions of multiple embryonic stages. Using these reconstructions as references, 3D morphing animations were created and compiled into a 3D interactive learning tool. This learning tool allowed the user to visualize and interact with the developing heart's outflow tract in 3-dimensions as the embryo undergoes complex morphological changes during Carnegie Stages 13-23. A learning and teaching tool for medical students studying embryology and anatomy to quickly and easily grasp how the heart's outflow tract develops, thereby clarifying their relationships to structures seen in adult anatomy.

Introduction, Purpose or Hypothesis

Human embryology is difficult for students to visualize in 3-dimensions, especially the development of the heart's outflow tract and its' associated structures, the semilunar valves.[1] This 3D interactive tool visualized additional important structures involved in the heart's outflow tract development, such as the semilunar valves, to improve students' understanding of the relationships between the various anatomical structures during heart development. Animations were created to visually and dynamically depict the growth the aorticopulmonary septum that forms in the Truncus arteriosus and Conus Cordis in the heart's outflow tract.[2] These animations were compiled into an interactive program, giving the user the ability to rotate around the models as the animation plays. This interactive tool aims to help users to develop an improved spatial understanding of the heart's development.[3]

Materials & Methods

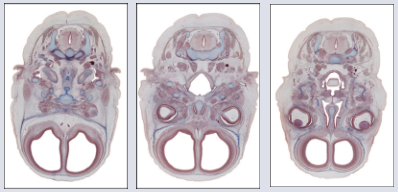

Fig. 1 Carnegie Collection Data, Stage 23 Embryo

Digital images of serially sectioned embryos from the Carnegie collection were brought into Materialise Mimics, a program used to extract 3D reconstructions from imaging data (*Fig. 1*).

Models extracted from Materialise Mimics (*Fig. 3 & 4*) were imported into Pixologic ZBrush, a 3D sculpting and texturing program, and used as a reference to sculpt the heart and its structures. Content experts, textbooks, and online resources were referenced and utilized to ensure accuracy in the models.

Fig. 2 List of programs and the procedure to develop this 3d interactive learning tool

Materials & Methods cont.

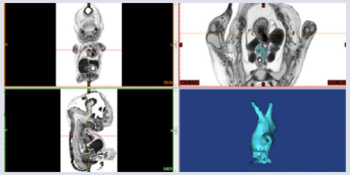

Fig. 3 Stage 21 Outflow Tract in Materialise Mimics

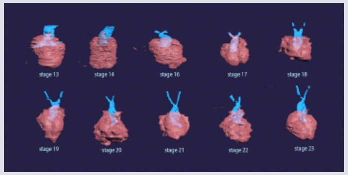

Fig. 4 Stages 13-23, Extracted Hearts and Outflow Tracts

The surfaces of the heart from each stage were sculpted in ZBrush. Starting with a box modeled heart, the Stage 23 heart was sculpted first. Once this model was completed, it was saved as Stage 22 and adjusted accordingly. This process was continued stage by stage, until Stage 13 was reached. By working backwards, ensured that each model contained the same numbers of vertices and polygons, which is requisite for morphing between the models in Autodesk 3ds Max.

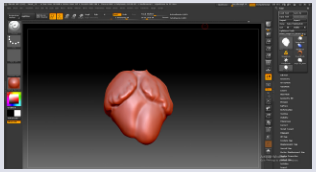

Fig. 5 Stage 23 Heart sculpted in ZBrush

The inner surface of the heart, outflow tract, aorticopulmonary septum, and semilunar valves were created as low polygon objects in 3ds Max (*Fig. 6*). Once all the models were created for each stage (*Fig. 7*), and all the components were compiled, a morph modifier was applied to the outer surface of the heart, inner surface of the heart, outflow tract, aorticopulmonary septum, and semilunar valves (*Fig. 8*). All the models were loaded in as morph targets and animated.

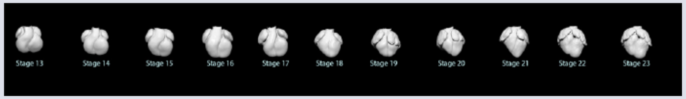

Fig. 7 Sculpted Hearts, Stages 12-23

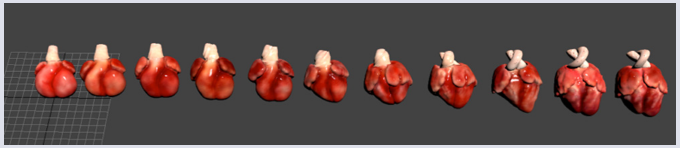

Fig. 8 Final painted Sculpted Hearts, Outflow Tracts, Aorticopulmonary Septums, and Semilunar Valves, Stages 12-23

Morphing animations were exported into Unity 3D. Once in Unity, C# scripts were created and assigned to the animations and models to allow for user interactivity and control (*Fig. 9*).

Fig. 9 Imported Heart Model and User Interface in Unity

This research also introduces the common embryological defect, tetralogy of Fallot. A motion graphic animation explaining tetralogy of Fallot was developed in Adobe After Effects. Illustrator files and audio were imported in Adobe After Effects, where multiple compositions, effects, and transitions were used to create the final animation (*Fig. 10*).

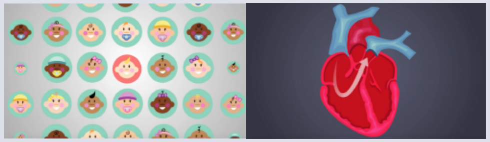

Fig. 10 Final motion graphic animation on tetralogy of Fallot

Materials & Methods cont.

The final interactive and tetralogy of Fallot animation were placed in Articulate Storyline, an e-learning authoring tool (*Fig. 11*). Articulate Storyline was used to house the outflow tract interactive, tetralogy of Fallot animation, and quiz while also easily creating a user interface.

The final interactive program allows the user to rotate around the heart as it morphs and develops. In addition, the user has the ability to hide different components of the heart in order to focus the aorticopulmonary septum develops.

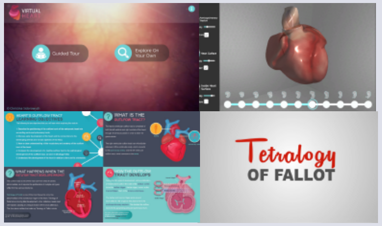

Fig. 11 Final Interactive pages in Articulate Storyline

Results

The completed interactive was tested on a pool of first year medical students enrolled in the BMS 645 Anatomy and Embryology II class at UIC College of Medicine, and medical students at the University of Chicago, College of Medicine. The students were asked to interact with the program and then complete an online assessment survey, which allowed the students to rate and comment on the overall effectiveness of the program as a study tool. Data from the assessment survey was analyzed using Qualtric's analysis tools.

A total of 21 students participated in the pre-test, 9 students from the University of Illinois at Chicago and 12 students from the University of Chicago. Based on the pre-test results, most first year medical students did not have a clear understanding on how the outflow tract develops.

Fig. 12 Pre-test results

A total of 3 students participated in the post-test, 2 students from the University of Illinois at Chicago and 1 student from the University of Chicago.

Fig. 13 Post-test results

All 3 students who participated in the research study reported they would recommend or use this animation in the future. Most students found the interactive very easy to use and navigate. However, one student found the rotation of the heart was slightly challenging to navigate on a laptop, but was easier on an iPad. When asked if the interactive was useful in helping them better understand the material, the answers ranged from extremely useful to slightly useful. One student wrote that they were not sure how to play with all the features. Another student wanted a clearer explanation of the heart development before playing with the interactive for context.

Discussion & Conclusions

Continued work is planned to improve the quality and value of the interactive program. The addition of internal structures of the heart will aid in the story of how the outflow tract develops in relation to internal structures, such as the interventricular septum and endocardial cushion. In addition, adding labels and an information page on how to navigate the interactive will provide more contexts for users. Improved models of the heart will also help improve the aesthetic of the interactive program.

Based on the results of the administered surveys and post exam scores, this research has demonstrated that a 3D interactive that visually and dynamically illustrates concepts that students have a difficult time visualizing can improve overall understanding and increase retention. The results show that this tool is useful. In comparison to current pedagogy, such as embryology text books and plastic models, this interactive benefits students on visualizing the spatial relationships in the development of the heart and advances the teaching of embryology in the future. The interactive can be made available to professors to use as a teaching tool in their classrooms and labs.

Bibliography

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