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Abstract

Graspable human embryonic development with 3D-printed educational models

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During pregnancy the human body plan develops. Knowledge of normal human development is of great clinical interest, particularly for paediatricians and clinical geneticists. Unfortunately, (bio)medical students have to struggle with textbooks that use static, 2D schematics to grasp the intricate three-dimensional morphogenesis of the developing human body. Current physical 3D models of embryos are available, but these are expensive, inaccurate, and lacking in detail. A unique digital dataset encompassing 3D models of 34 human embryos of the Carnegie collection between Carnegie stages 7 (15-17 days) and 23 (56-60 days) was created at Amsterdam UMC by manual annotation of >150 organs and structures on 15 000 historical histological sections. After publication in *Science* in 2016 this *3D Human Embryo Atlas* became available online as educational and scientific tool. With this dataset as starting point and in close cooperation between industry and university, 3D-printed educational models were developed to address the needs of researchers in university clinics worldwide, each set with a selected set of relevant morphological features. To make those datasets 3D-printable, extensive preparation work had to be performed e.g. repairing surfaces, separating parts, performing sagittal cuts and setting the right transparency. The first series of models is intended for professionals in midwifery and obstetrics to educate expecting parents and lay people about the actual size of a human embryo or fetus early in pregnancy. Therefore, a 1:1 scale block encompassing five embryos from 6 to 10 weeks of pregnancy was prepared using PolyJet® technology, complemented with single fetuses of 11, 12 and 13 weeks pregnancy executed in soft dyed thermoplastic polyurethane. A second series of 3D-printed models, which has been designed for general embryology education at (bio)medical faculties, consists of six different Carnegie stages: CS8, CS10, CS13, CS16, CS20, CS23 and a 1:1 scale block as reference to their actual embryonic size. Furthermore, three dedicated series of educational 3D-prints have been designed to serve the specific educational needs concerning the intricate development of the nervous system, the cardiovascular system and the alimentary tract. All educational 3D-prints were equipped with a sagittal cut for better appreciation of the internal structures. To display the complex multicolor details of these educational models PolyJet ® technology was used. To deal with the massive amount of 3D surface data, several strategies had to be developed e.g. to create digital sagittal cuts and to correct for artefacts in the biological material. Further specialist models elucidating embryonic brain, lung, urogenital, skeleton and coelom development, aimed for the education of medical specialists, are under planning forming a comprehensive toolbox for embryonic education.

AUTHOR'S STATEMENT

Conflict of interest: Hans Nopper, Thomas Lück, Ubiratan S. Freitas, Peter Malauschek, and Andreas Lingner are employees of cirp GmbH, Department Research and Development, Heimsheim, Germany. Informed consent: N/A, as the speicmen are part of a historical museum collection. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee. Research funding: The 2019 Amsterdam Science & Innovation award category Life Sciences (AUMC). Funded by the Federal Ministry of Education and research (BMBF); project SOW funding code 02K20Z002 (cirp).

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