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3D PRINTING TECHNOLOGY IN HUMAN ANATOMY MODERN TEACHING AND LEARNING

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Abstract. *There are various combinations of 3D printing technology and medical study process. The aim of this study was to summarize our first experience on 3D printing and outline how 3D printed models can be successfully used in Human Anatomy modern teaching and learning. In 2018 autumn semester, together with traditional methods, a three-dimensional (3D) printing has been introduced into Human Anatomy curriculum at Department of Morphology. In practical classes 39 groups of students from Faculty of Medicine 1st year together with 3 tutors used 3 different open source softwares to create anatomical models and prepared them for printing process. All anatomical models were produced using an FDM 3D printer, a Prusa i3 MK2 (Prusa Research). As methods for data collection were used our observational notes during teaching and learning, analysis of discussions between tutors and students, comments on the preparing and usability of the created and printed models. 3D printing technology offered students a powerful tool for their teaching, learning and creativity, provided possibility to show human body structures or variations. Presented data offered valuable information about current situation and these results were suitable for the further development of the Human Anatomy study course.*
Keywords: *education, Human Anatomy, models, printing.*

Introduction

Human Anatomy studies for medical undergraduates have always been hard to memorize and understand (Yaminne, 2015; Yeom, Choi-Lunberg, Fluck, & Sale, 2017). Some available anatomical books, atlases or any other resources do not meet all their needs regarding all or details of anatomical structures (Trelease, 2016). In the modern medical education the traditional teaching and learning methods are improved with new and realistic three-dimensional (3D) modeling and printing (Michalski & Ross, 2014). The last mentioned tools are becoming widely available across many industrial, scientific and daily life fields (Violante & Vezzetti, 2017). As the technologies continue to develop, 3D printing has the potential to influence and revolutionize the future of medicine (Coles-Black, Chao, & Chuen, 2017).

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The anatomy teaching, learning and 3D printing play very important roles in the modern medical education. As described in several publications (Drake & Wojciech, 2014; Drake & Wojciech, 2017), the use of 3D printed reproductions in anatomy education had the potential to provide a readily available source of qualitative teaching materials. But very limited information has been published on the role of 3D printing technology in Human Anatomy education in Latvia.

In medical education teaching and learning are carried out through the utilisation of a variety of study resources and tools (Ruzycki, Desy, Lachman, & Wolanskyj-Spinner, 2018). To the existing materials, a new addition was made last year for medical students of the 1st study year at the Department of Morphology of Rīga Stradiņš University (RSU). There were offered lectures and practical classes in 3D modeling and printing.

The aim of this study was to summarize our first experience on 3D printing and outline how 3D printed models can be successfully used in Human Anatomy modern teaching and learning. As methods of data collection and analysis included our observational notes during teaching and learning, discussions between tutors and students, and comments on the preparing and usability of the created and printed models.

Material and Methods

This study was based upon the educational process and devices required in the teaching and learning environment and also the necessary using modern technologies in the Human Anatomy course. The study took place at Department of Morphology of the RSU. In 2018 autumn semester, together with traditional methods, a three-dimensional (3D) printing has been introduced into Human Anatomy curriculum. It didn`t replace any teaching and learning methods that were already being delivered, and was used to support the students in study process. Students from Faculty of Medicine have been involved in the study. In 4 practical classes 39 groups of the 1st year students, aged from 18 to 25 years, together with 3 tutors used 3 different open source softwares to create anatomical models and prepared them for printing process.

The basic procedures for anatomical 3D printing consisted of several steps: introduction in 3D printing technology, overview of materials, preparing for creation and downloading of 3D file of model, pre-processing, modeling, printing and post-processing.

We started use two printers and all anatomical models were produced using Fused Deposition Modeling (FDM) 3D printers, a Prusa i3 MK2 (Prusa Research).

In the first step students looked for 3D anatomical models in free online sources and after downloded them to personal computers. Before students moved

to next steps, they choosed models only with special format STL (standard tessellation language) or file extension. After that this file was loaded into Ultimaker Cura software and model was prepared for 3D printing.

In order to create a 3D print, there was provided special additional information (when required). In beginning of this step all students changed the anatomical model in size dimensions and optimal orientation, scaled, performed some other functions (spliting, mirroring, etc.) and positioned it in the center or corner of the build plate. After that there were generated support structures for models with overhanging parts and selected correct settings for printing process. At the end of these steps all anatomical models were sliced, annotated, saved to computer or SD memory card.

The special print code (g. code) for file of model was generated using Ultimaker Cura. Materials were the next parameters of the development process and there some models were printed using plastic materials, such as PLA (polylactic acid) or ABS (acrylonitrile butadiene styrene). The time necessary for production of 3D models varied and gererally it was determinated by the size of a model and the type of material.

After modeling and printing the final step was post-processing. This included removing the physical part from the printer platform and detaching the supports. In some cases the printed model required minor cleaning and surface treatment operations to improve its quality, appearance, stability and strength.

The quality of printed anatomical models was compared with original specimens. After these steps all printed models were ready for teaching use or learning.

Later as methods for collecting data were used our observational notes and discussions between groups of students groups. At the end of each practical class the tutors performed short sessions of questions with the students about role of the 3D modeling and printing in Human Anatomy studies.

Results

We describe our experience into the current use of 3D printing and the results of a survey aimed to answer to the question: „What is the role of 3D printing technology in Human Antomy teaching and learning?”

In the 1st printing practical class students were introduced to 3D technologies, their range, current and future applications, different equipment and development in medicine. After that tutors explained the composition of printers, rules and requirements, safety, learning tasks and formed students in 6-12 groups. Students downloaded existing designs from different free online sources. Obtained 3D models represented useful educational tools as they were easily downloaded from the different links, libraries of models and manipulated,

prepared by students and/or tutors. In this way students were made aware of the technical possibilities, materials using, the design restrictions and the variety of potential application areas.

In the 2nd, 3rd and 4th practical classes period students developed their independent designs of 3D anatomical models. Tutors demonstrated to students functions of different possibilities in preparing of models, made attention to the most frequent problems on and conducted preliminary design rules of the anatomical models. Students saved their models and/or submitted their final designs for a detail design rules check. Tutors provided technical feedback. In the last practical classes students received their 3D preliminary models, assessed the problems with the tutors and prepared new design or corrected previously prepared models. After that all models were printed in a relatively short time.

During all practical classes students were introduced to main steps to producing 3D models, digital files conversion, formatting, printed models problems, artefacts and variables. Students showed the ability to design and analyze 3D printed anatomical models. Analysis of these pre- and post-processed models showed significant increasing in student's teaching and learning process.

In several activities between teams and groups students communicated more effectively and used different techniques, skills and tools for modeling and printing practice. Modeling was very useful in designing small details and it allowed printing of several models and structures in different sizes. There were a lot of bones that were reproduced in different sizes. The largest models were more easily manipulated than smaller ones and some students started use them for self-directed learning. After that majority of students reported that they found 3D printed models of bones very helpful in their overall understanding of the structures, as well as improving their learning interest. Several students printed very simple structures of the bones and/or any organs to help visualize elementary concepts in anatomy. According to this, some 3D printed models were used to explain only general structures of the bones, body parts and organs.

Our practical classes` activities were very useful in helping students gain a better understanding of surfaces of anatomical structures. Students enjoyed holding the anatomical models, examining them and even took some photos of their prepared models. They showed great possibilities to rotate 3D models and during this procedure students understood and described some anatomical structures better than before. 3D models were several times less expensive than real specimens and students could examine models without damaging any originals. All the models have obtained good anatomical details, thus demonstrating the practicality of this technology. 3D printed models most included hard structures than flexible elements.

Tutors and students discussed the potential use of 3D technology, strong and weak directions of it in teaching and learning process of Human Anatomy. The

following types of views were discussed the relevant impacts of 3D printing on teaching and learning of Human Anatomy (Table 1).

Table 1 ***Students` views on 3D printing technology in Human Anatomy course***

Type of view	Groups of students (n=39)
	Effectiveness,%
Promotes students independent learning	93.0
Catches students attention by learning-by-making	100.0
Visualization of theory	75.5
Understanding the relationships between structures and surfaces	85.5
Teaching via visualization	99.0
Optimization of study process and/or troubleshooting	55.0
Creative teaching and learning	91.0
Models for more in-dept studies	100.0
Level of knowledge review	63.0

n - number

The most 3D printing helped catch students' attention via the learning-by-making approach (100%), easier concept teaching via visualization (99%) and promoting students' independent learning (93%).

For understanding, learning, demonstrating various useful 3D anatomical models were printed, including bones, organs or different parts with structures, shown in Figure 1.

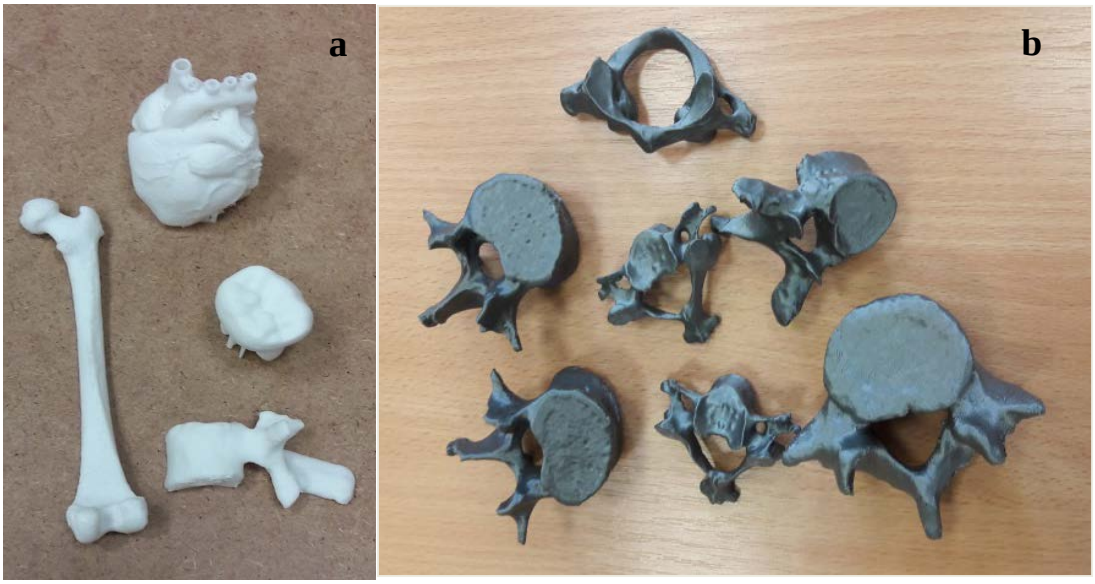

Figure 1 ***Various 3D-printed anatomical models by students (a) and tutors (b) for Human Anatomy applications***

Students were turned into active and creative users with the possibilities and limits of the 3D printing. They gained significant experience of 3D modeling and printing together with tutors, learned how to operate direct 3D software and upload, print anatomical models.

There were students that struggled with 3D models creating, pre- and post-processing of them. Problems showed that students needed tutors support in that cases. 10% of all students mentioned that anatomical structures in printed models were less realistic compared to the real specimens.

Discussion

The findings from the different authors indicate that 3D printing process allows to create and produce objects in many areas of our life, including fields of education (McMenamin, Quayle, McHenry, & Adams, 2014). It has numerous applications and has gained much interest in the medical world (Tack, Victor, Gemmel, & Annemans, 2016). The using of 3D printing innovations directly in medical education for a number of years have already been extensively described in different studies (Kim et al., 2016; Smith, Tollemache, Covill, & Johnston, 2017).

New innovations and speed of their development, very intensive using of 3D technologies may lead to institutions beginning to regularly create and produce their own models for teaching and training purposes.

For students who are preparing to undertake Human Anatomy course, educational 3D printed models on basic anatomy can serve as a summary and available review of the material. For other students, these models can serve as a basics or helpful tools in Human Anatomy study process. 3D printed anatomical models are being successfully applied in Human Anatomy teaching and learning at Department of Morphology of Rīga Stradiņš University.

It is known that Anatomical sciences are foundational to the health professions (Schaefer et al., 2018). One of the biggest challenges in Human Anatomy teaching is being able to successfully convey theoretical and practical concepts to students who have little understanding of the topics. The comprehension of anatomical terminology, structures of different systems of human body and their detailed composition and interconnections are complicated to understand (Khalil, Eiman, Meguid, & Elkhider, 2018). It is clear, that the understanding of Human Anatomy is very important for all students in basic study courses.

Evaluation of the effectiveness of anatomy teaching is multi-factorial (Li et al., 2017). The use of 3D modeling and printing can provide training and education in either normal or complex anatomy (AbouHashem, Dayal, Savanah, & Štrkalj, 2015). Different models and/or their prototyes can be made

of any area of interest to aid in process of teaching and learning (Negi, Dhiman, & Kumar Sharma, 2014). 3D models can be acquired from a large range of sources to produce an endless variety of models that can be printed by different printers and materials (Smith & Jones, 2017). Printed models also provide an ideal format for training (Eizenberg & Chapuis, 2014). All steps and processes of creating and/or printing of 3D anatomical models can be very important for combination of medical education and research.

3D printing technology offered our students a powerful tool for their ideas and creativity, provided possibility to show human body structures or variations. It was new experience for the 1st study year students about models creating process.

Several authors (Bartikian, Ferreira, Gonçalves-Ferreira, & Neto, 2018) mentioned that 3D printing was useful for the creating anatomical models that were not available for sale and reflected real-life variability. For example, some prepared models helped our students to identify places with different variations and/or the problems. It is very important to preserve any variations, because some of them can be experienced by future generations of students.

Different technologies will continue to develop and this will increase educational requests for the preparing and development of different clinical competencies. In the beginning of medical studies some students can observe diseases only in a non-stimulating setting such as textbooks, any presentations, computer tomography (CT) slices and specially preserved samples. Further research may support the regular usage of 3D models not only in normal Human Anatomy study process. Different clinical applications can be expanded through streamlining the 3D printing process.

Some authors (Mogali et al., 2018) underline that it can reduce costs, increase access and make 3D printing resources more readily available in smaller communities. We have demonstrated that accurate 3D printed anatomical models can be rapidly and economically reproduced.

In addition, we have shown that it is possible to use multiple types to create anatomical models. One of them was to manually create useful structure in available computer software. Some structures were usually being simplified and after that there were visible only their general shapes. For example, when a bone model was designed, some students decided to present the actual shape without any additional structures. Part of students prepared very detailed anatomical model together with blood vessels or nerves. Models and their production showed several anatomical structures on a wide scale.

In Human Anatomy course our future plans regarding 3D printing together with students include scanning and printing of other anatomical structures, particularly those that are complicated and aren`t easily or really visible.

Human Anatomy teaching and learning have been further improved with recent advancements in 3D printing, such as being able to print in multicolours and to prepare an even more realistic models.

Next way to create anatomical models will be combination of medical imaging with computer segmentation and visualization, using medical digital images, such as: CT, magnetic resonance imaging (MRI) and X-ray (Moore, Wilson, & Rice, 2017). This technology will offer new solutions for students to be able to study actual normal Human Anatomy with introduction in pathological Anatomy direction.

In addition, further steps are needed to develop a bioprinting direction at Department of Morphology.

Conclusions

The challenges of this running course included new strategies, problems, the need for continuous activities and the current lack of some anatomical tools and textbooks to support teaching.

The findings presented in this study suggested that the 3D printing technology was very interactive and effective tool in teaching and learning of Human Anatomy, creation of complex models (structures of bones, internal organs, nervous system, sense organs, etc.) that allowed a similar experience compared with natural speciments.

Despite potential benefits and positive things, there were some barriers to the integration of new technology into the teaching and learning of this course.

At Department of Morphology next our steps will soon involve development a bioprinting, other printers, scanner and 3D printed models with anatomical structures, particularly those that are difficult to observe and manipulate, including small structures, special, complicated and deep areas, cavities, different anatomical variations and/or pathologies.

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