CONFERENCE PAPER

COST-EFFECTIVENESS OF 3D PRINTING OF ANATOMICAL MODELS

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ABSTRACT

3D printing or additive manufacturing is one of the newest technologies that has begun to be used for production of anatomical models in veterinary medicine. The main aim of this research was to evaluate the total cost required for 3D printing of different anatomical models and the cost-effectiveness of use of these technologies in practice. For purpose of this study, we evaluated a cost of 3D printed model of the human heart, inner ear, cross-section of the animal cell and spinal cord, sheep, cow and cat brain and complete dog model with internal organs. The costs were calculated separately for raw material consumption and personnel operative work. The results show that 3D printing technologies are cost-effective for the production of anatomical models, and the total cost depends mostly on working time of the personnel.

Keywords: alternatives, costs, veterinary anatomy, 3D additive manufacturing

INTRODUCTION

3D printing or additive manufacturing is a rapidly expanding technology, today often promoted as one of the most significant technological advances in our modern era (McMenamin et al., 2014; Attaran, 2016). In the last two decades, these technologies have been successfully applied in different medical fields, especially in surgery, orthopedics, stomatology, anatomy including education (Abou Hashem et al., 2015; Aimar et al.,2019). However, since this is a relatively new technology in medicine, there is very little data about the costs of 3D printing (Tack et al., 2016). Research conducted so far indicates that the use of these techniques has potential for low-cost production of

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3D models (Choonara et al., 2016; Lau et al. 2019; Gómez-Cirizet el., 2021; Chen et al., 2021). In maxillofacial surgery and orthopedics, it has been found that 3D printing reduce the operating room costs and shortens the procedure times (Ballard et al., 2019; Choonara et al., 2016).The review research reported that the cost-effectiveness of the 3D printing was described only in 7% of selected publications, while some research conclude that the use of 3D printing is not cost effective (Tack et al., 2016). Considering all mentioned above, the main aim of this study was to evaluate the total cost required for 3D printing of different anatomical models and the cost-effectiveness of use of these technologies in practice.

MATERIAL AND METHODS

The research was conducted at the Department of Anatomy and Histology with Embryology, Veterinary Faculty, University of Sarajevo and FabLab, digital fabrication laboratory, during the period of one year (2020-2021). For purpose of this study, we printed 3D model of the human heart, inner ear, cross-section of the animal cell and spinal cord, sheep, cow and cat brain and complete dog model with internal organs. Two models (spinal cord and cow brain) were scanned by XYZ hand low-cost scanner and prepared for print. The cross section of animal cell and dog with all internal organs were designed in Blender software, while all other models were obtained as 3D obj. and stl. files directly from the internet. The G-Code for all 3D models was generated in Cura software 4.8.0. All models were printed on CreatBot DX printer, whose work is based on fused deposition modeling (FDM). The printing speed was between 80 and 100. The models were printed with ABS and TPU flexible filaments. The infill was 20% for all models. For model support we used the same as print material. In order to minimize consumption of supporting material, the models were oriented in optimal direction and leveled with the printing bed. Later, the support material was removed by scissors and scalpel. The costs of 3D printing were divided in two sets of data, the raw material cost and personnel working costs. The row material cost was calculated from the purchase price of the filaments and weight of the final 3D printed model, including the support material. The ABS filament was purchased for the price of 23,4 €/kg and TPU flex filaments for price of 52,65 €/kg (Henan Suwei Electronic Tech. Ltd). The personnel working time costs were calculated by recording a total time needed for production of each 3D model, individually. The operative cost of the personnel involved in this study was estimated to be 23 €/h. Time spent for preprint preparation (3D scanning, CAD-computer-aided design, 3D software image processing and slicing), 3D printing and postprint processing (removing support material) were recorded and based on it, we calculated total personnel working costs.

RESULTS

All 3D models were successfully printed, and the costs of raw materials consumption for their production were displayed in Table 1. From this data set, it is evident that the price of the 3D printed model mostly depends on the price of the filaments, size and complexity of the model (Figure 1). More complex anatomical models require a higher consumption of the supporting material.

Table 1 Dimensions of 3D anatomical models and material costs of their 3D printing

3D MODEL	DIMENSIONS OF 3D MODEL (mm)	TYPE OF PRINTING MATERIAL (FILAMENT)	PRICE BASED ON CONSUMED RAW MATERIAL (FILAMENT)
HUMAN HEART	97.3x100x89.3	ABS 86g	2.0€
INNER EAR	100.9x59.8x60.4	TPU 37g	1.94€
ANIMAL CELL	93.6x79.1x31.4	ABS 37g	0.86€
SPINAL CORD	99.7x69.9x22	TPU 24g	1.2€
SHEEP BRAIN	60.9x100.9x48.5	TPU 54g	2.8€
COW BRAIN	78.1x60.4x120	TPU 78g	4.1€
CAT BRAIN	57.2x39.8x34.6	TPU 19g	1.0€
DOG MODEL WITH INTERNAL ORGANS	160.3x70.4x187.2	ABS 93g	2.1€

The personnel working time needed for production of 3D printed anatomical model is presented in Table 2. If we exclude the size of the model, from this set of data is visible that the fastest production was when 3D models were already available in stl. and obj. format.

Production time and costs increase if models need to be constructed by scanning or modelling. These preprint preparations represent the most demanding and extensive part of the work. A particularly large expenditure of working time is present when the model is created from the start in CAD-computer aided design (Table 2). The

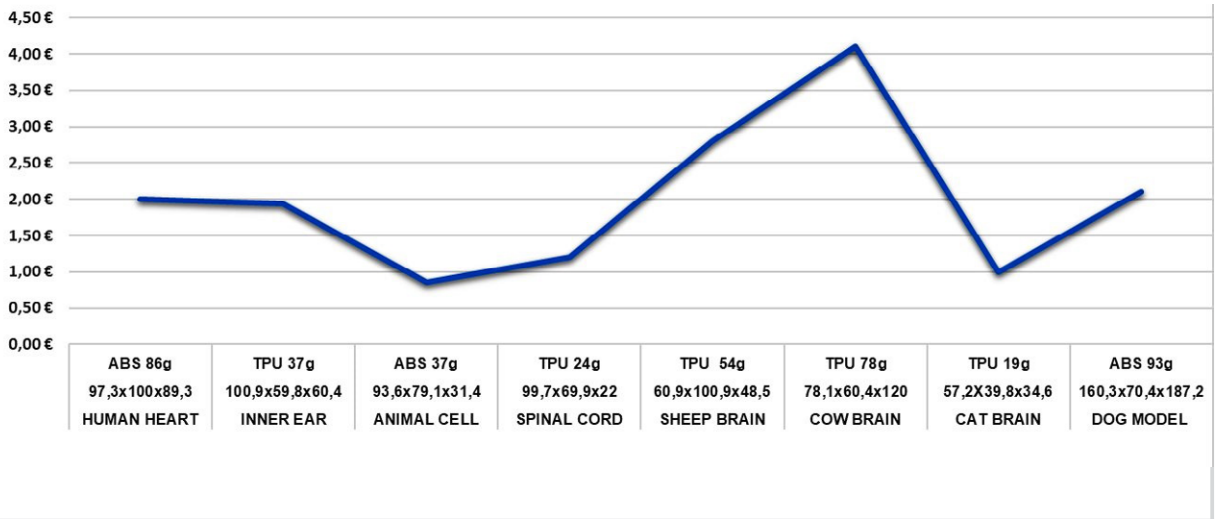

Figure 1. Price of 3D printed model related with dimension and material consumption

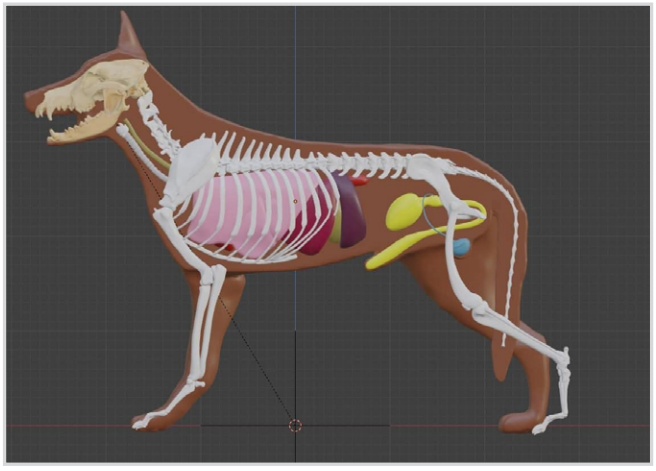

Figure 2. Dog model with internal organs designed and modelled in Blender software

results show that it takes about7 hours to create one simple 3D model such as animal cell, while more complex anatomical models such as 3D dog model with internal organs (Figure 2) require much more time for fabrication (Table 2). The time of 3D printing was not calculated as costs since the machine does not require human surveillance. The post-printing costs depend on the amount of support material; therefore, the optimal model orientation should be taken into account during the acquisition of 3D printing settings.

Table 2 Personnel working costs on preprint, print and postprint processing

	PREPRINT			**PRINT**	**POSTPRINT**	
3D MODEL	3D scanning time	CAD (Computer-aided design)	3D Software image processing and slicing	3D printing	Removing the support material	**TOTAL COSTS**
HUMAN HEART	0	0	1	1 day 7h 53min	1	46€
INNER EAR	0	0	1	10h 54 min	1	46€
ANIMAL CELL	0	7	1	11h 32 min	0	184€
SPINAL CORD	1	0	1	5h 16 min	0	23€
SHEEP BRAIN	0	0	1	11h 54 min	2	69€
COW BRAIN	1	0	1	17h 44 min	2	69€
CAT BRAIN	0	0	1	6h 2 min	2	69€
DOG MODEL WITH INTERNAL ORGANS	0	207	1	1 day 8h 42 min	3	4916,3€

DISCUSSION AND CONCLUSION

3D printing is a relatively new technology that has begun to be used in veterinary medicine (Garcia et al., 2018). The world trends show that as 3D printers evolve, they become more affordable. Many medical schools today try to procure the equipment for 3D printing, however, there are very few official reports about the cost and cost-effectiveness of use of these technologies (Gómez-Ciriz at el., 2021; Chen et al., 2021, Lau et al., 2019). In most of the studies is stated that these technologies are cost-effective, but the same do not provide data on material or operative costs for model production (Mc Menamin et al., 2014; Choonara et al., 2016; Attaran, 2016; Ballard et al., 2020), while other studies claim the opposite (Tack et al., 2016). The results of this research show that 3D printing technologies are cost-effective for the production of anatomical models, but several factors should be considered during the final evaluation of the costs. As we described, the costs are the lowest when digital models are available from public source in stl. or obj. format, while those models which require modelling in CAD become much expensive due the personnel operative costs. These finding agrees with the reports of Gómez-Ciriza et al., (2021) who also calculated that the personnel working costs were the highest in fabrication of human heart models. The costs of printing material are low and these depend on model size, complexity and price of the filament. However, in this research we did not include amortization and machinery maintenance costs, but in the report of Gómez-Ciriza et al., (2021) these costs were also quite low, almost negligible. The results confirm previous findings that 3D printing of anatomical models with FDM technology is cost-effective (Chen at al., 2021). This research provides basic guidance for calculating the cost of 3D printing and the cost-effectiveness of future research.

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CONFLICT OF INTEREST

The authors declared that there is no conflict of interest.

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ISPLATIVOST 3D ŠTAMPANJA ANATOMSKIH MODELA

SAŽETAK

3D štampanje ili aditivna proizvodnja predstavlja jednu od najnovijih tehnologija koja se počela koristiti u proizvodnji anatomskih modela u veterini. Glavni cilj našeg istraživanja jeste procijeniti ukupne troškove 3D štampanja različitih anatomskih modela i isplativost ovih tehnologija u praksi. U svrhu istraživanja smo procijenili troškove štampanja 3D modela ljudskog srca, unutarnjeg uha, presjeke životinjske stanice i kičmene moždine, mozak ovce, krave i mačke, kao i model cijelog psa s unutarnjim organima. Troškovi su izračunati odvojeno za potrošnju sirovina i operativni rad osoblja. Rezultati pokazuju da su tehnologije 3D štampanja isplative za proizvodnju anatomskih modela, a da ukupni troškovi uglavnom ovise o radnim satima osoblja.

Ključne riječi: alternative, troškovi, veterinarska anatomija, 3D aditivna proizvodnja