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POTENTIALS OF THREE DIMENSIONAL PRINTING IN RADIOLOGY – A CASE OF A KNEE INJURY

MOGUĆNOSTI PRIMENE TRODIMENZIONALNIH ŠTAMPAČA U RADIOLOGIJI – SLUČAJ POVREDE KOLENA

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Summary

Introduction. Images of computed tomography, computed tomography angiography, ultrasonography, magnetic resonance imaging, positron emission tomography are usually stored in Digital Imaging and Communication in Medicine standard formats, which can be used later for processing and making three dimensional models and objects. The three dimensional printing has become increasingly popular in various fields of medicine. The purpose of this article was to present the workflow for three dimensional printing of medical models and to point out potential significance of three dimensional model printing in clinical practice and in training of medical students and residents. This type of approach may open new perspectives in communication and interaction between clinicians, radiologists and patients, in order to achieve better treatment results.

Material and Methods. Images of an injured knee in digital imaging and communication in medicine format were used for creation of a three dimensional printed model. Digital imaging and communication in medicine files were without sensitive information on the patient using three dimensional Slicer software, then processed with embodi three dimensional cloud service, further prepared with MeshLab and printed on a Ultimaker 2 printer.

Results and Discussion. A three dimensional model of an injured knee was printed and presented. The model was used for the evaluation of tibial fractures. It may be shown to the patient and also to the surgeon in order to be more specific about the treatment procedure. Application of three dimensional printing in medicine was discussed.

Conclusion. Medical three dimensional printing is likely to play a more important role in the clinical practice, not only for surgical planning, but also in the education of students and residents in different medical branches. This three dimensional plastic model of an injured knee may serve as a good example of the potentials of the three dimensional printing technology in medicine.

Key words: Printing, Three-Dimensional; Radiology; Knee Joint; Models, Educational; Education, Medical

Sažetak

Uvod. Slike dobijene pomoću kompjuterizovane tomografije, kompjuterizovane tomografije angiografije, ultrasonografije, magnetne rezonancije, pozitron-emisije tomografije obično se nalaze u formi koja prati Digital Imaging and Communication in Medicine standard i koje se mogu upotrebiti za kreiranje trodimenzionalnih modela i objekata. U različitim oblastima medicinske trodimenzionalne štampa postaje sve popularnija. Svrsu ovog rada bila je da se prikaže tok izrade štampanog modela i potencijalni značaj štampašnog trodimenzionalnih modela u kliničkoj praksi i edukaciji studenata i specijalizanata. Ovakav pristup može otvoriti nove kanale u komunikaciji i interakciji između kliničara, radiologa i pacijentaa, sa ciljem ostvarenja boljih rezultata lečenja.

Materijal i metode. Slike fraktura zgloba kolena skladištene u formatu Digital Imaging and Communication in Medicine su korištene za kreiranje trodimenzionalnih modela za štampu. Iz fajlova Digital Imaging and Communication in Medicine su uklonjeni osetljivi podaci o pacijentu pomoću programira embodi3d, programa MeshLab i odštampane pomoću ultimaker 2 štampača. Rezultati i diskusija. Prikazan je trodimenzionalni model povredenog kolena. Model je korišćen za evaluaciju frakturbe tibije. On se može prikazati pacijentu, kao i hiurgu da bi se procenio dalji tok lečenja. Diskutovana je primena trodimenzionalne štampa u medicini. Zaključak. Očekuje se da primena trodimenzionalne štampa u medicini postane značajnija u kliničkoj praksi, ne samo u vezi sa planiranjem hirurških zahvata, već i u obražnovnom procesu studenata i specijalizanata u različitim medicinskim granama. Ovaj trodimenzionalni plastični model povredenog kolena može poslužiti kao dobar primer potencijala tehnologije trodimenzionalne štampa u medicini.

Ključne reči: 3D printing; radiologija; zglog kolena; edukativni model; medicinska edukacija

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Introduction

Three dimensional printing

Three dimensional (3D) printing, also known as rapid prototyping, allows creation of three dimensional objects using computer aided design information [1]. It refers to manufacturing technologies that produce physical models from information stored in a digital format [2]. It is an emerging discipline with potential application in various fields of medicine and biomedicine. Radiology is a discipline of images where information on patients, their pathologies, imaging data, and often interventional procedures encounter, so implementation of 3D printing and its technologies may be reasonable. Possibilities for applications of 3D models in healthcare are diverse, from preoperative planning, medical implant manufacturing, intraoperative guidance to education of students, physicians and patients education. This process was created in 1986, for use in architecture and manufacturing, called additive manufacturing or rapid prototyping. Medical 3D printing is a new, innovative method that converts two-dimensional (2D) scans from Computed Tomography (CT) or Magnetic Resonance Imaging (MRI) into 3D objects, physically tangible, made of specific materials [3].

Three dimensional model creation

The process of 3D model creation is divided into three stages: image acquisition, image post-processing and 3D printing. The 3D printing of organs or some part of the organ starts from images stored in Digital Imaging and Communication in Medicine (DICOM) format. The acquisition of images can be performed by CT, CT angiography (CTA), MRI, Ultrasonography or Positron Emission Tomography (PET). The DICOM images are then transferred to Standard Tessellation Language, Standard Triangle Language or stereolithography (STL) format (or 3D file format) which is suitable and appropriate for 3D printers. Image post-processing allows segmentation of tissues using region of interest. Segmentation tools could be volume rendering technique, minimal intensity projection, and multiplanar reconstruction. Technically, DICOM stored 2D images are transformed into 3D models written in standard STL format. Those models are subjected to further manual editing and arranging which leads to the final shape of structure. Determination of the layers, temperature, color, tool path and printing speed are important for printing. The code that the slicer makes is sent to the 3D printer for the final model [2, 3].

Material and Methods

The 3D printing uses computer models to create 3D objects made of specific material layers that join together using computer aided design (CAD) and form the final shape and figure. This type of object is supposed to be printed. Then the model is exported as a STL format file, imported into slicing software and finally printed on a 3D printer.
Images of an injured knee stored in DICOM format (Figure 1) were used for creation of a 3D printing model. The DICOM files were converted into nearly raw raster data format for the purpose of removing sensitive patient information (so-called anonymization process) using a 3D Slicer software, then processed with cloud service embodi3D to get a STL format (Figure 2) and finally the region of interest was segmented with MeshLab (Figure 3).

The model was printed on a Ultimaker 2 (https://ultimaker.com/) using polylactic acid (PLA) a thermoplastic polymer derived from renewable resources, such as corn starch or sugar cane. The printing process lasted 18 hours, and the injured knee model outsourcing the printing presented in this study cost around $ 35.

**Results and Discussion**

**Potentials of 3D printing in the Radiology Center (Clinical Center of Vojvodina)**

The 3D model of an injured knee was printed (Figure 4). The model (size: 98.2 x 76.6 x 86.6 mm) was used for assessment of fractures among the clinicians. It was possible to show it to the patient for consent and decision making about treatment and also to the surgeon in order to be more specific about the possibilities of treatment in the future.

In our Radiology Center, routine practice has included making numerous 3D reconstructions as digital files using computer softwares, as images on films or prints on paper. It offers possibilities for presentation of different anatomical variations of the organs or pathology. This type of 3D reconstruction does not demonstrate the deep sensory feeling of anatomy and relationships with other structures in comparison with the real 3D model. It appears that 3D model may be a useful tool that gives a new dimension of touch and offers better understanding of complex relations between structures [4]. Application of currently available software at the Clinical Centre of Vojvodina (Carestream and Syngo. via) and 3D printing platforms may allow instant utilization of created 3D reconstructions and production of printed 3D models.

**3D printing history**

The 3D printer was invented in the beginning of the 1980s by Charles Hull, an engineer who worked on producing plastic devices from photopolymers. Just a few years later, in 1986, he established STL and developed the first commercial 3D printer - SLA-125. Eyewear frames were the first to be printed using 3D technology. For many years, it was used in manufacturing industry in producing product samples, such as airplane and car prototypes, in architecture for making structural reproductions, in government defense etc [5, 6]. Today, 3D printing is of great importance in clinical practice and experimental research [7].

**3D printing in medicine**

The 3D printing has been applied in medicine since the early 2000s and according to the available scientific reports it accelerated in the 2010s [2]. Today, 3D printing is widespread in maxillofacial surgery, orthopedics, plastic and vascular surgery, neurosurgery, cardiovascular interventions, in radiation oncology and could also be implemented in the interventional radiology using CTA data [8]. Most often, it is used in maxillofacial surgery for head and neck pathology (making prostheses, custom-made implants, etc.) [9]. A 3D printing model can be used in thoracic surgery as well, in planning of thorascoscopic procedures in patients with rare
anomalies or to show relations between a tumor and nearby structures. It was even used for a newborn baby with tracheomalacia to make a customized airway splint [10]. It can also be used in spine surgery for vertebral stabilization by creating 3D printing guides for optimal and precise hole drilling [11]. This process may be technically very challenging and the model helps surgery residents improve their skills and the outcome. Previous studies of 3D printed endoprostheses for palliative care of 16 patients with metastases of the humerus and ulna showed good outcomes in almost 70% of patients [12]. In the field of cardiac surgery, 3D models, based on cardiac CT, MRI and CTA, for visualization of different congenital heart problems, were applied, which played a significant role in the preoperative treatment, providing better understanding of the health condition of patients and education of students [13]. Also, a 3D printed model was used for rehearsal of planned myectomy in patients with hypertrophic cardiomyopathy [14]. The 3D printing has an important role in neurosurgery, in preoperative preparation and visualization of tissue variations and anomalies, as well as in many other surgical specialties. Patient-specific custom cutting guides are up to date as well as creation of patient-specific implants and bioprinting. Bioprinting is definitely the most impressive step in the 3D printing [15]. Its main aim is engineering functional healthy organs, but making an organ for transplantation, like liver for example, has not yet been done.

Costs, benefits and opportunities

Three dimensional printers are being used more and more, as their price is decreasing every day. For example, some basic 3D printer models cost around US $300, but sophisticated ones may cost up to US $ 1,000,000 [3]. Models made for medical purposes cost from US $50 to 2,500 [16]. The main benefit of 3D printing is a relatively low cost and a great number of possible applications in medicine [17]. Apart from using them for better comprehension of medical problems, additional tools for MRI diagnostic can be printed as well [18]. By using this process, better surgical outcomes and less time for surgical procedures can be expected. The radiologists may play an important role in reading the scans and converting them into 3D models [2]. This all requires a great involvement and collaboration between radiologists and physicians. The 3D printed models may also be used in training medical students and residents [19].

Conclusion

It is expected that three dimensional printing in medicine will play an important role in clinical practice, not only in surgery planning and therapy, but also in education of medical students and residents, as well as in simulation-based training in different medical branches. The three dimensional plastic model of an injured knee produced for the purpose of this study may serve as a good example on the potentials of this technology. Making three dimensional objects is not very demanding, and in the future, radiologists should be trained for implementation of three dimensional printing in complicated cases in the best interest of treatment and optimal recovery of patients.

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