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Original Article

The use of the three-dimensional printed segmented collapsible model of the pelvicalyceal system to improve residents' learning curve

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ABSTRACT

Objective: The aim of the present study was to determine the effectiveness of the use of the three-dimensional (3D) printed segmented collapsible model of the pelvicalyceal system (PCS) to improve the learning curve of the residents.

Material and methods: 3D printed models based on computed tomography (CT) images of 10 patients with a staghorn stone were developed. Used images of patients were obtained from CT scans in Digital Imaging and Communications in Medicine format. The area of interest was extracted and saved in stereolithography format. Further, the bioengineer performed virtual segmentation corresponding to the level of each calyces group that was defined by an experienced urologist. The final stage was the printing of each separated detail. Special questionnaire for evaluating the effectiveness of 3D models during both the examination of PCS anatomy and planning percutaneous nephrolithotomy was invented.

Results: The determination of the anterior and posterior calyces of the upper group was improved by 61% and 69%, the difference in the determination of the calyces of the middle group was 60% and 51%, and the answers regarding the number of the anterior and posterior calyces of the lower group became better by 67% and 74%, respectively ($p<0.001$). The ability to select the optimal calyx for the primary and the second access became better by 60% and 55%, respectively ($p<0.001$).

Conclusion: 3D printed segmented collapsible model of the PCS is promising for the improvement of the learning curve of residents and enables to optimize their clinical education, as well as compensate for their lack of experience.

Keywords: 3D printing; nephrolithiasis; PCNL.

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Introduction

In recent years, three-dimensional (3D) printing has become popular in various fields of medicine, such as maxillofacial, orthopedic, and neurosurgical interventions.[1-4] Non-biological 3D printed models are used in urology for planning for upcoming surgery, as well as for improving young specialists' learning curve.[5-9] Percutaneous nephrolithotomy (PCNL) is a safe and effective method of treatment for patients with large and staghorn kidney stones.[10,11] Both the understanding of the pelvicalyceal system (PCS) anatomy and correct access through the appropriate calyx allow performing PCNL safely and efficiently. Computed tomography (CT) scan with and without intravenous contrast is the current method for visualizing kidney stones.[12] Advances in CT technology make it possible to reconstruct 3D images of the PCS, which can be used to increase the efficiency of PCNL with minor complications.[13-15] Moreover, it is possible to create the exact model of the PCS using 3D printing technology. 3D printing based on patient data allows physicians to create an individual model for adequate visualization of kidney structures. The ability to generate 3D models from patient data is allowing to visualize complicated pathologies better, which improves the resident's learning process.[6-9,14,15] The purpose of the present study was to define the effectiveness of the use of collapsible 3D printed PCS models to improve the residents' learning curve.

Material and methods

Patient selection and CT images processing

The study was approved by the Mariinsky Hospital ethics committee (Date:14.04.2019, No:75-2019). A total of 10 patients with staghorn stones were included in the study. All patients provided informed consent for the use of their clinical information in research studies, and the confidentiality of the data was guaranteed. Data acquisition was performed using a 64-row CT unit with the 0.5 mm step intervals “Somatom Definition AS” (Siemens, Germany) with the patient in supine position. Then, CT images were opened in the 3D Slicer 4.8.1 software to check the images and to confirm their appropriateness. After that, the area of interest was extracted and saved in stereolithography (STL) format by the attending urologist. This process took approximately 15 min for one PCS of the kidney.

Then, STL files were sent to the bioengineer (Top3DShop Co., Saint Petersburg, Russia) who performed virtual segmentation of the PCS corresponding to the levels of each calyces group defined by an attending urologist. In addition, each group was divided into two parts to make the disassembly process and intraluminal examination easier. After that, colored processing of the segmented virtual models with red, blue, and green colors corresponding to the upper, medium, and lower calyces, respectively, was performed.

Creation of the 3D printed segmented collapsible PCS models

The next step was the printing of each separated detail using the Picaso designer X 3D printer. Acrylonitrile butadiene styrene was selected as the printing material. Its most important properties are high density, impact resistance, and low price. The fixation of the whole model was ensured through the use of magnets, enabling isolating a separately selected detail without losing the configuration of the remaining PCS model (Figure 1). In each subunit of the model, 4 mm×1 mm round-shaped magnets with a gap’s effort of 320 g were embedded. It provides a more durable fixation with the weight of the whole model equal to 150 g (Figure 2). The average price for the production of one printed model was at approximately $150, and the print time was approximately 12 h.

Main Points:

- Creating 3D models that are anatomically identical to the patient’s PCS allows surgeons to analyze each specific case and select the optimal access better than using 2D images.
* 3D segmented collapsible models of the PCS, allowing partial and complete examination, are promising for the improvement of the learning curve of residents.
* The developed non-biological collapsible 3D model allows to optimize the clinical education of residents and reimburse their lack of experience.

Approbation of models and questionnaire

To evaluate the effectiveness of 3D models as a reference tool during the examination of the PCS, as well as planning PCNL, a special questionnaire was invented (Figure 3).

For participation in the study, 25 residents were included. They evaluated 10 patients using traditional CT scans. After that, each resident was asked to fill out the questionnaire to reveal their ability to determine the amount of the posterior and anterior calyces in each calyceal group and to select the optimal calyx for the primary and probable second access into the collecting system. In 10 min, all residents were asked to complete the questionnaire again using traditional CT scans, coupled with 3D printed models. Results of the two questionnaires were compared.

Statistical analysis

The total number of the right answer for each question gained by all residents together before and after applying 3D printed models was compared with the corresponded result. Since we included 25 residents and 10 patients, all residents together answered 250 times to each question following each PCS examination. The correct answers were determined by the urologist who performed >350 PCNL.

The critical value p=0.05 was obtained to evaluate the differences between the groups. The paired nominal data were compared using McNemar’s test. Statistical analyses were performed using StatXact® 11 software.

Results

The results of the study are shown in Figure 4. Statistical difference was identified for each question. The determination of the

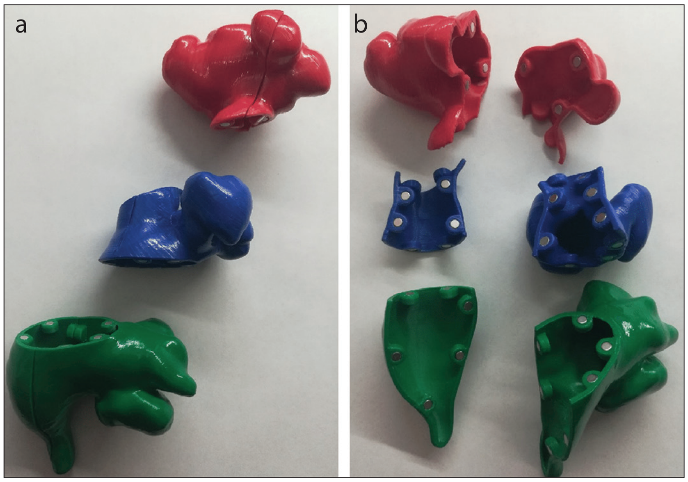

Figure 1. a-b. 3D printed model in disassembled view (1-according to each calyceal groups and 2-fully disassembled)

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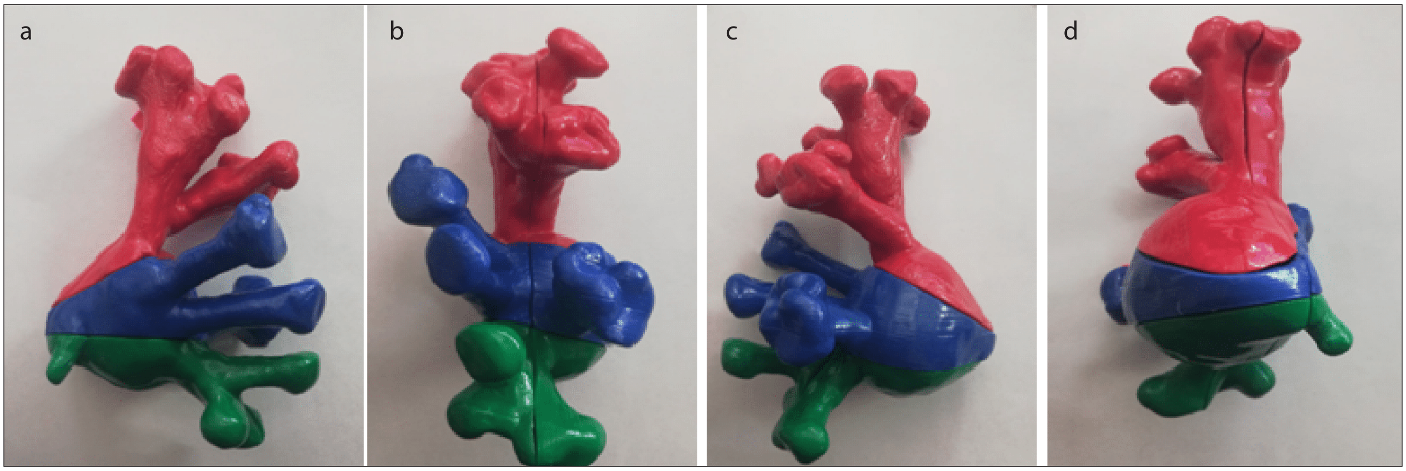

Figure 2. a-d. Printed pelvicalyceal system of the left kidney (1-anterior, 2-lateral, 3-posterior, and 4-medial views, respectively)

Question	Answer
The number of anterior calyces of the upper group	
The number of posterior calyces of the upper group	
The number of anterior calyces of the middle group	
The number of posterior calyces of the middle group	
The number of anterior calyces of the lower group	
The number of posterior calyces of the lower group	
The optimal calyx for the main access	
The optimal calyx for the second access	

Figure 3. The questionnaire consisted of two columns: questions and answers, respectively

anterior and posterior calyces of the upper group was improved by 61% ($p<0.001$) and 69% ($p<0.001$), the difference in the determination of the calyces of the middle group was improved by 60% ($p<0.001$) and 51% ($p<0.001$), and the answers regarding the number of the anterior and posterior calyces of the lower group became better by 67% ($p<0.001$) and 74% ($p<0.001$), respectively. Similarly, the ability to select the optimal calyx became better by 60% ($p<0.001$) for the primary access and 55% ($p<0.001$) for the second access.

Discussion

The use of standard 2D images restricts the ability of surgeons to predict intraoperative scenarios. For this reason, 3D printed visualization methods are increasingly introduced into various surgical specialities.[1-4,7-9,14,15] PCNL is the gold standard approach for managing multiple, large, or inferior calyx renal stones, but some factors limit its effectiveness and increase the risk of possible complications. Several studies have shown that the more size of the stone and the number of accesses, the less chance to remove all stone fragments.[16-18] Staghorn stones often require several approaches to remove it as much as possible and reduce the frequency of residual fragments. The ultimate purpose of PCNL is to clean the PCS of stones with minimal complications thoroughly.

Currently, 3D printing technology is widely used for preoperative planning for complex orthopedic, maxillofacial, and neurosurgical interventions.[1-4] This tendency is also seen in urology. There are several publications in the literature about PCS modelling for planning endourological interventions.[7,9,14,19] Preoperative application of 3D PCS printed models makes it possible to achieve a better understanding of the structure of the patient's PCS, as well as to improve the results of upcoming intervention.

To achieve better image quality, the cut-off thickness of the CT scan should be approximately 3–5 mm as low-resolution images can cause mismatching between the created model and the natural anatomy of the PCS.[20] Thinner slices are performed during CT scan as a more significant dose of radiation is delivered to the patients. It may increase by 75% compared with that when using low-dose CT, which is more actively used in clinical practice.[21]

Creating 3D models that are anatomically identical to the patient's PCS allows surgeons to analyze each specific case and select the optimal access better than using 2D images.

In the present study, we showed that the possibility of a partial or complete examination of PCS printed models, coupled with standard CT images, resulted in the better determination of the anatomic features of an individual patient's PCS by residents, as well as improved their ability to plan PCNL. It should be pointed out the usefulness of color coding of each calyceal group. As mentioned above, an experienced urologist controlled this moment

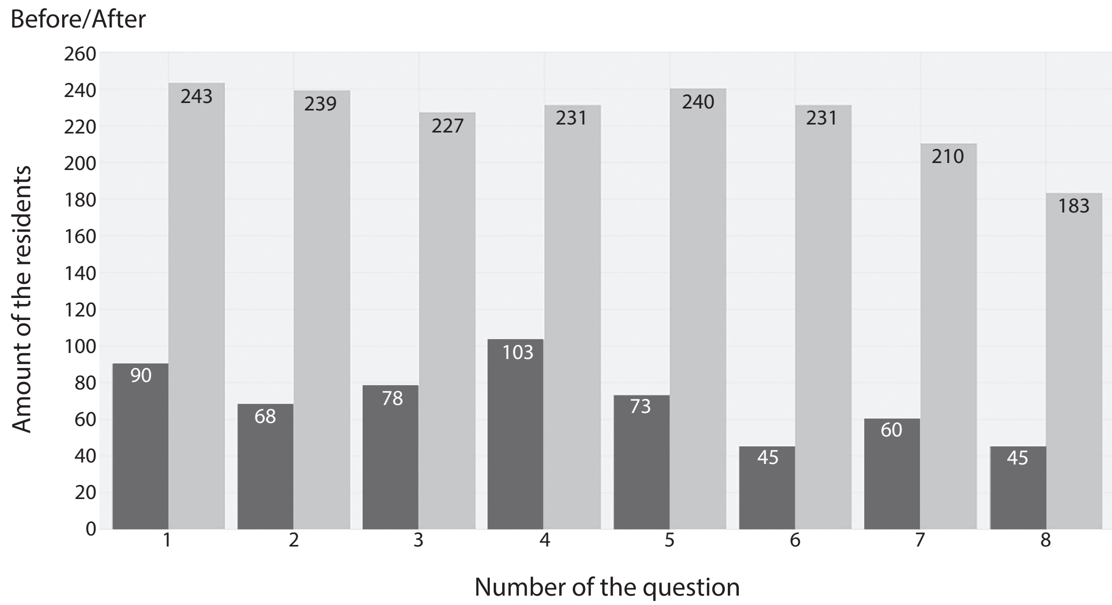

Figure 4. Comparison of the points of the residents before and after examination of the 3D printed model. The questions were as follows: (1) the number of anterior calyces of the upper group, (2) the number of posterior calyces of the upper group, (3) the number of anterior calyces of the middle group, (4) the number of posterior calyces of the middle group, (5) the number of anterior calyces of the lower group, (6) the number of posterior calyces of the lower groups, (7) the optimal calyx for the first access, and (8) the optimal calyx for the second access

and determined the borders of the segmentation. This way makes it easier for non-experienced residents to develop the capacity to determine both the precise level of each calyceal group and orientation of calyces. Using this method of creating a 3D model, all residents better understood the anatomy of the PCS of the kidney and more effectively determined the optimal calyx for both the first and second accesses. Moreover, these models potentially can be used intraoperatively in the context of intraluminal navigation. We are on the way to investigate this method of use.

Our study has several limitations. First, residents from other hospitals were not included. Second, we did not place the printed stone inside the created model that potentially could improve the results of the participant's learning. Third, the usefulness of 3D printed models can be estimated only, coupled with some visual modality, such as CT images, as used by the urologist when performing puncture. As a result, the evaluation of the model without CT images may not be appropriate.

In conclusion, 3D segmented collapsible models of the PCS, allowing partial and complete examination, are promising for the improvement of the learning curve of residents. Studying the anatomy of the PCS in this way makes it easier to select the optimal calyx for the percutaneous puncture in PCNL. The developed non-biological collapsible 3D model allows to optimize the clinical education of residents and reimburse their lack of experience.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Mariinsky Hospital (Date:14.04.2019, No:75-2019).

Informed Consent: Written informed consent was obtained from all patients who participated in this study.

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