# Personalized 3D printed model of kidney and tumor anatomy: a useful tool for patient education

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## Abstract

**Purpose**—To assess the impact of 3D printed models of renal tumor on patient's understanding of their conditions. Patient understanding of their medical condition and treatment satisfaction has gained increasing attention in medicine. Novel technologies such as additive manufacturing [also termed three-dimensional (3D) printing] may play a role in patient education.

**Methods**—A prospective pilot study was conducted, and seven patients with a primary diagnosis of kidney tumor who were being considered for partial nephrectomy were included after informed consent. All patients underwent four-phase multi-detector computerized tomography (MDCT) scanning from which renal volume data were extracted to create life-size patient-specific 3D printed models. Patient knowledge and understanding were evaluated before and after 3D model presentation. Patients' satisfaction with their specific 3D printed model was also assessed through a visual scale.

**Results**—After viewing their personal 3D kidney model, patients demonstrated an improvement in understanding of basic kidney physiology by 16.7 % ($p = 0.018$), kidney anatomy by 50 % ($p = 0.026$), tumor characteristics by 39.3 % ($p = 0.068$) and the planned surgical procedure by 44.6 % ($p = 0.026$).

**Conclusion—**Presented herein is the initial clinical experience with 3D printing to facilitate patient's pre-surgical understanding of their kidney tumor and surgery.

### Keywords

3D printing; Renal cancer; Kidney tumors; Partial nephrectomy; Education

## Introduction

Tumors affecting the kidney commonly develop asymptomatically [1]. When the diagnosis is made, imaging is the only graphic representation to share with patients so that they can visualize and understand the otherwise non-palpable kidney tumor they are faced with. Ideally speaking, an important aspect of obtaining informed consent from the patient prior to partial nephrectomy surgery is for them to have a basic understanding of kidney physiology and anatomy, tumor location and characteristics and the proposed surgical procedure with its related risks of complications. Patient understanding may be further complicated by the plethora of available contemporary treatment strategies (surveillance, ablation, excision), with their specific risks of complications.

Reported herein is, to our knowledge, the initial experience with 3D printed models in order to improve patients' education.

## Materials and methods

### Study methodology

Following kidney tumor diagnosis, seven English-speaking patients who were being considered for partial nephrectomy were enrolled in an IRB-approved single-center prospective pilot study. All patients were referred to a single surgeon (ISG), underwent four-phase MDCT scanning and received similar preoperative information on their disease, tumor characteristics, the planned surgery and its related risk of complications. This information was delivered during a face-to-face consultation with the surgeon using CT scan images.

Two questionnaires were created to prospectively evaluate the level of patient's preoperative knowledge and understanding. This was at first evaluated based on the previously delivered information and CT scan images and secondly using the 3D printed model in order to assess the improvement following the model presentation. Questionnaire #1 consisted of 22 questions to evaluate four components of patient knowledge: (a) basic kidney physiology, (b) basic kidney anatomy, (c) tumor characteristics and (d) planned surgical procedure ("Appendix 1"). Questionnaire #2, in addition to the 22 questions presented in form #1, investigated patient satisfaction using visual analog scales ("Appendix 2").

The day before surgery, each patient was seen again by an investigator (JCB) and the CT scan images were used again as a teaching aid to deliver information on the organ itself, the disease and the surgery. During this face-to-face visit, patients were free to raise all outstanding issues and then asked to complete questionnaire #1 as baseline reference. Then, that patient's personal 3D printed model was presented, and after a basic description of the

3D printing process, the patients were again free to ask any question and then completed questionnaire #2.

### Statistics

Number of correct responses to the first 22 questions was used as endpoint. Median number of correct responses for each category, before and after 3D printed model presentation, was compared (Wilcoxon test). Statistical analyses were performed using SPSS Statistics version 21.0 (IBM Corporation, Armonk, NY, USA).

### 3D printed model fabrication

From the DICOM data of patient's MDCT, kidney structures of interest (tumor, healthy parenchyma, arterial tree, renal vein, collecting system) were extracted using an image recognition algorithm (Synapse 3D, Fujifilm, Tokyo, Japan) and transferred into STL format. Using this STL file, a 3D printed model was created on the OBJET 500 Connex 3 (Stratasys, Eden Prairie, MN, USA) with the assistance of a 3D printing manufacturing company (Fasotec, Makuhari, Chiba, Japan).

The color-segmented 3D model was manufactured by the combination of three different types of photopolymer materials (opaque magenta, opaque yellow and transparent clear material) with 16 µ thickness of each layer under solidification by UV.

As displayed in Figs. 1, 2 and 3, the arterial tree was represented in opaque magenta, the collecting system in opaque yellow and mixing magenta and yellow resulted in opaque orange for tumor display. The renal parenchyma and the renal vein were kept translucent to achieve the best visualization of the relationships between the tumor, the collecting system and the arterial branches.

## Results

Table 1 shows patient and tumor demographics.

The fabrication cost was $560 per kidney model. For each cognitive component investigated, Fig. 4 reports the level of improvement of patient's understanding based on an individual analysis.

Table 2 reports a group analysis of the median and percent of correct responses, reflecting the patients' level of understanding for each component, before and after 3D printed model presentation. Patient's understanding was significantly improved on basic kidney physiology ($p = 0.018$), basic kidney anatomy ($p = 0.026$) and planned surgical procedure ($p = 0.026$).

Figure 5 shows the mean improvement rate in patient understanding after viewing their personal 3D kidney model. Patients demonstrated an improvement in their understanding of basic kidney physiology by 16.7 %, kidney anatomy by 50 %, tumor characteristics by 39.3 % and the planned surgical procedure by 44.6 %. Overall improvement was 37.6 %.

Table 3 reports patients' satisfaction level in terms of usefulness of the 3D printed model to improve their understanding and knowledge of the kidney organ itself, their disease, the

planned surgery and potential complications. The overall mean satisfaction score among the group was 9.4/10, and five patients over 7 rated their experience with their own model at the maximum level.

## Discussion

Use of 3D printing in science started more than 20 years ago [2]. Successive improvements in 3D imaging and 3D printing have progressively led various surgical specialties to embrace these innovative technologies, especially in the field of reconstructive surgery [3, 4]. High concordance with patient anatomy, a decrease in production costs of prosthetic materials, expediency of the fabrication process and its potential use for pre-surgical planning or teaching have made 3D printing increasingly popular.

In addition, patients can benefit from the introduction of personalized physical 3D models with the intent of facilitating mutual understanding between patient and physician. Silberstein at al. recently reported 3D printed models of five renal units with malignancy [5]. The authors stated that patients and families verbally expressed improved understanding of their condition and treatment options. However, no objective assessment of the level of improvement was reported. To our knowledge, our study is the first of its kind, specifically designed to evaluate the concept of 3D printing to assist patient education in the field of urology.

We have shown that use of such patient-specific 3D physical models is valuable for patient understanding, with an overall 37.6 % increase in correct responses. It is noteworthy that although every single patient was provided with extensive verbal and written preoperative information as well as a detailed explanation of their CT scan images, their initial reference level of understanding was low. This was especially true regarding basic kidney anatomy but more surprisingly also regarding the planned surgical procedure and its associated risk of complications. This reflects how difficult it can be for patients to understand CT images and also how difficult it can be for the physician to adjust his/her message to an individual patient's understanding ability [6]. Since in our study, the 3D printed models were used as an aid for mutual exchange, we witnessed how they helped patients raise and ask their own questions, enhancing their understanding. Three-dimensional printed model appeared to be most appropriate in helping the patient understand basic kidney anatomy. As a consequence, it is a helpful tool to deliver comprehensible and personalized messages about partial nephrectomy and its specific risks of complications.

In addition to objective performance, we assessed overall patient satisfaction through four specific questions. The overall feedback was highly favorable with a mean rating of 9.4/10. Patient satisfaction with healthcare experience has now become a priority. Indeed, it is more and more taken into account not only by patient associations, but it has also recently been linked to Medicare reimbursement in the USA. Moreover, Kennedy et al. [7] recently demonstrated that patient perceptions of their care were influenced by factors over and above surgical outcome. Improving patient education by the use of personalized 3D printed models appears to be a promising way to efficiently enhance the quality of personal exchange between a patient and his surgeon and influence overall patient satisfaction.

However, financial costs of patient-specific 3D printed models represent a limitation that merits discussion. Indeed, our models had a unit cost of $560 that was related to their multi-material and multi-color characteristics. This resulted in high quality and detailed models whose fabrication was only made possible by a professional 3D printer. Nevertheless, a balance between quality, user-friendliness and cost efficiency could easily be defined resulting in the production of monocolor, monomaterial more simple models as reported by Watson [8]. In short order and with further development, additive manufacturing will achieve lower production and equipment costs. Consider that, in 2009, The Economist announced the future launch of a less than $5000 3D printer; four years later, the same source was reporting on how competition and expiry of early patents brought the price of 3D printers below $1000 [9, 10].

Moreover, using this kind of models not only for patient counseling but also for students, residents and fellows surgical teaching could help achieve better cost-effectiveness. Indeed, such models, in making easier 3D anatomical understanding, may certainly be useful tools to enhance surgical strategy discussion and improve preoperative planning.

## Conclusion

As our results suggest, additive manufacturing is certainly of major interest for patient education in surgery. Increasing spread of the technology and multi-purpose use of the models for treatment planning, trainee teaching and patient education may help achieve cost efficiency. Larger sample size and assessment in other pathologies are needed to confirm these preliminary findings.

## Acknowledgments

## Appendix 1

"3D PLANNING" study

Patient # ....          **Patient questionnaire number 1**

We thank you for completing this questionnaire.

| 1/ What I know about the kidney, generally speaking: | True | False | Don't know |
|---|---|---|---|
| 1.1- The kidney is a paired organ | | | |
| 1.2- The kidney function is to "clean" my blood | | | |
| 1.3- The kidney produces urines | | | |
| 1.4- The urine is collected in cavities inside of the kidney, called the collecting system | | | |
| 1.5- The kidney is a highly vascularized organ; a lot of blood flows through the renal vessels | | | |
| 1.6- The renal vessels can be described as an artery and a vein | | | |
| 1.7- To work properly the kidney needs blood coming through the renal artery | | | |
| 1.8- When the kidneys are not working properly this leads to renal insufficiency | | | |

| 2/ What I know about my disease: | True | False | Don't know |
|---|---|---|---|
| 2.1- My kidney is bearing a tumor | | | |
| 2.2- The tumor is located in the mid part of my kidney | | | |
| 2.3- The tumor is in close contact with the kidney vessels | | | |
| 2.4- The tumor is in close contact with the collecting system | | | |

| 3/ What I understand about my planned surgery: | True | False | Don't know |
|---|---|---|---|
| 3.1- My surgeon will try to remove the tumor only | | | |
| 3.2- My surgeon will remove the entire kidney | | | |
| In case of tumor only removal my surgeon will have to cut the kidney itself to separate the tumor from surrounding healthy tissue. This may lead to: 3.3- bleeding with a risk of hemorrhage | | | |
| 3.4- opening the collecting system with a risk of urine leakage | | | |
| 3.5- To reduce the risk of hemorrhage at the time of tumor removal my surgeon may need to clamp (=interrupt blood flow) the renal artery | | | |
| 3.6- Prolonged renal artery clamping is known to alter renal function so my surgeon will have to speed up the procedure to limit the length of clamping | | | |
| 3.7- In case of tumor only removal, the benefit is preservation of healthy kidney tissue | | | |
| 3.8- Preserving healthy tissue from my tumor bearing kidney decreases the risk of renal insufficiency | | | |

## Appendix 2

"3D PLANNING" study

Patient # ....          **Patient questionnaire number 2**

We thank you for completing this questionnaire.

| 1/ What I know about the kidney, generally speaking: | True | False | Don't know |
|---|---|---|---|
| 1.1- The kidney is a paired organ | | | |
| 1.2- The kidney function is to "clean" my blood | | | |
| 1.3- The kidney produces urines | | | |
| 1.4- The urine is collected in cavities inside of the kidney, called the collecting system | | | |
| 1.5- The kidney is a highly vascularized organ; a lot of blood flows through the renal vessels | | | |
| 1.6- The renal vessels can be described as an artery and a vein | | | |
| 1.7- To work properly the kidney needs blood coming through the renal artery | | | |
| 1.8- When the kidneys are not working properly this leads to renal insufficiency | | | |

| 2/ What I know about my disease: | True | False | Don't know |
|---|---|---|---|
| 2.1- My kidney is bearing a tumor | | | |
| 2.2- The tumor is located in the mid part of my kidney | | | |
| 2.3- The tumor is in close contact with the kidney vessels | | | |
| 2.4- The tumor is in close contact with the collecting system | | | |

| 3/ What I understand about my planned surgery: | True | False | Don't know |
|---|---|---|---|
| 3.1- My surgeon will try to remove the tumor only | | | |
| 3.2- My surgeon will remove the entire kidney | | | |
| In case of tumor only removal my surgeon will have to cut the kidney itself to separate the tumor from surrounding healthy tissue. This may lead to: 3.3- bleeding with a risk of hemorrhage | | | |
| 3.4- opening the collecting system with a risk of urine leakage | | | |
| 3.5- To reduce the risk of hemorrhage at the time of tumor removal my surgeon may need to clamp (=interrupt blood flow) the renal artery | | | |
| 3.6- Prolonged renal artery clamping is known to alter renal function so my surgeon will have to speed up the procedure to limit the length of clamping | | | |
| 3.7- In case of tumor only removal, the benefit is preservation of healthy kidney tissue | | | |
| 3.8- Preserving healthy tissue from my tumor bearing kidney decreases the risk of renal insufficiency | | | |

4/ Please, rate from 1 to 10 (1 = no help at all -> 10 = of a great help) to what extent the presentation of your personalized 3D Kidney model helped you in :
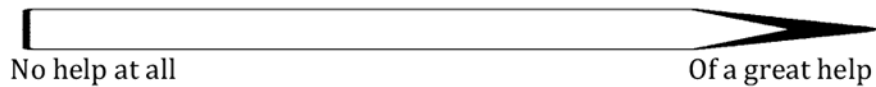
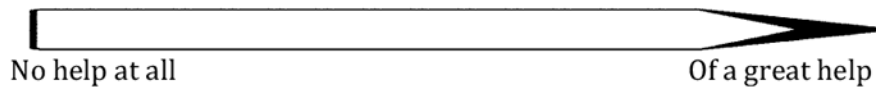- 4.1 - Learning about the kidney itself

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

No help at all → Of a great help
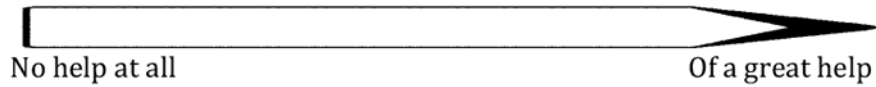
- 4.2 - Learning about your disease

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

No help at all → Of a great help

- 4.3 - Understanding the surgery you will undergo

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

No help at all → Of a great help

- 4.4 - Understanding the risk of complications related to the surgery you will undergo

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

No help at all → Of a great help
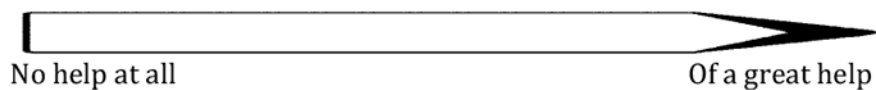
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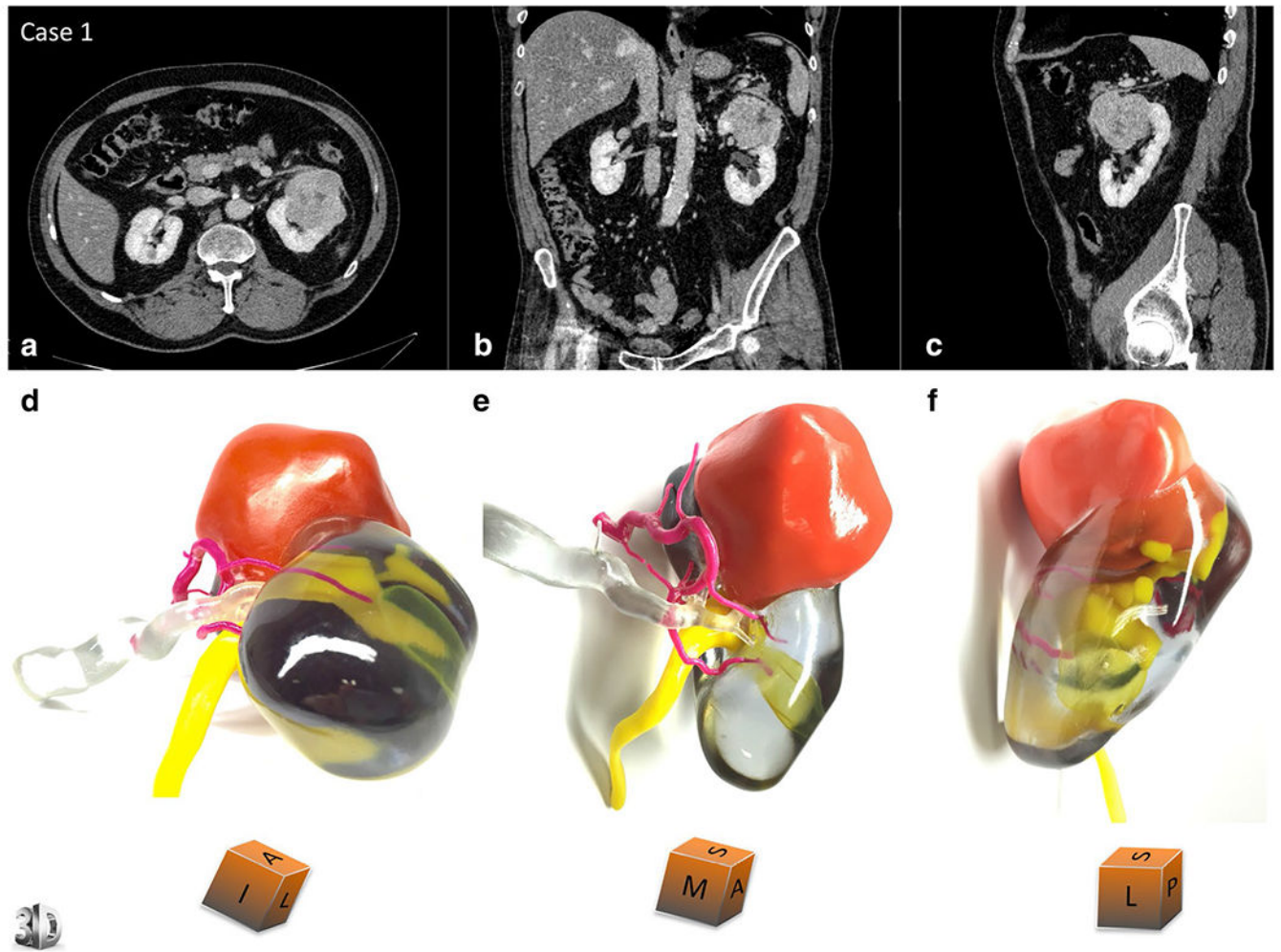
**Fig. 1.**
3D printed model for case 1. Comparative views of the CT scan at the nephrographic phase (**a** axial, **b** coronal and **c** sagittal planes) and corresponding views of the physical model (**d** superior and median view, **e** median and anterior view, **f** lateral view). An inferior polar cyst is also displayed on this model (translucent yellow). The cubes show the 3D printed model orientation in space (I = inferior face, A = anterior face, L = lateral side, S = superior face, P = posterior face, M = median side). Case 1 underwent a left radical nephrectomy for a $65 \times 56 \times 42$ mm clear cell renal cell carcinoma, pT1bN0Mx, Fuhrman grade 3
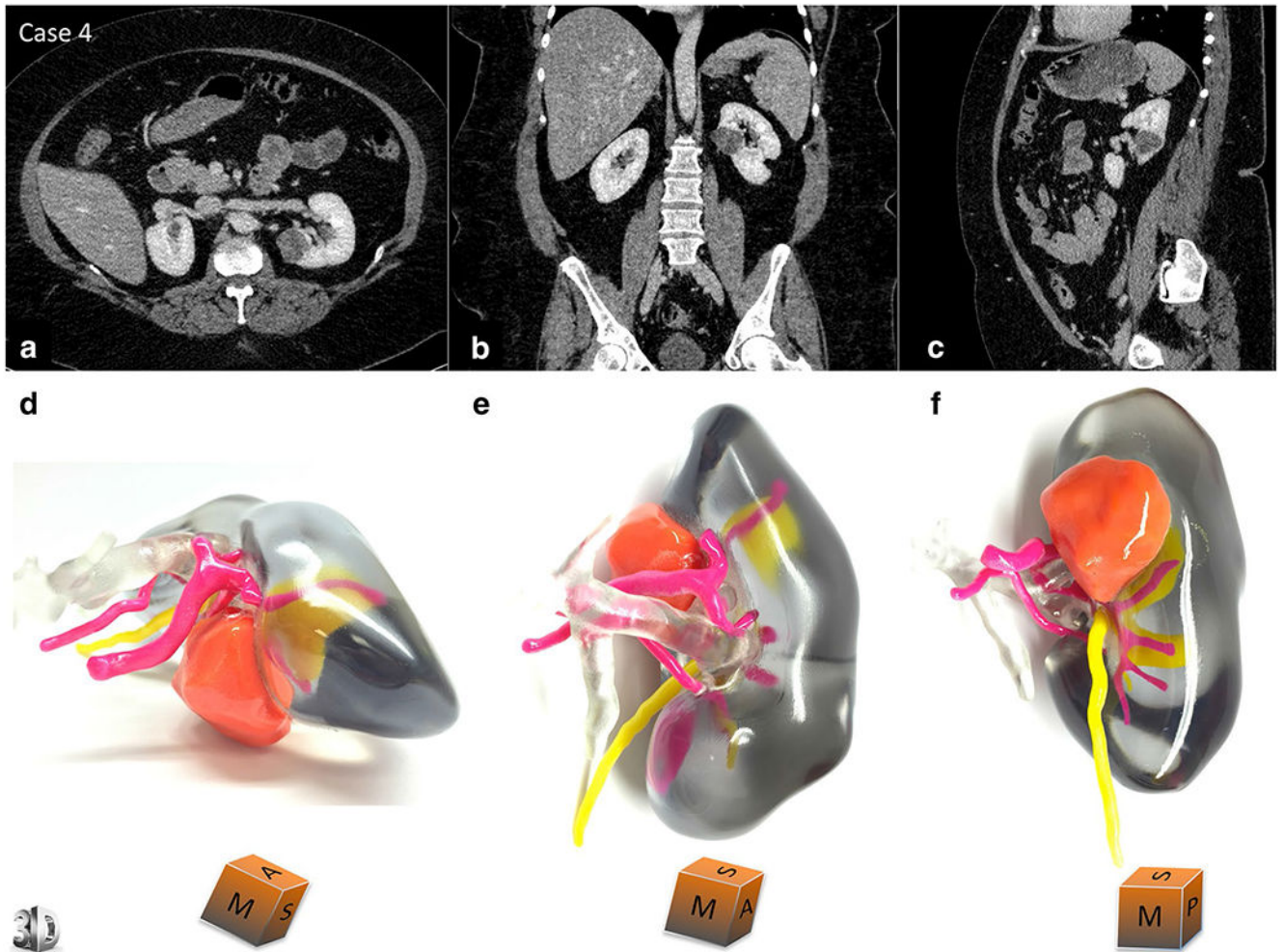
**Fig. 2.**
3D printed model for case 4. Comparative views of the CT scan at the nephrographic phase (**a** axial, **b** coronal and **c** sagittal planes) and corresponding views of the physical model (**d** superior and median view, **e** median and anterior view, **f** median and posterior view). The *cubes* show the 3D printed model orientation in space (I = inferior face, A = anterior face, L = lateral side, S = superior face, P = posterior face, M = median side). Case 7 underwent a left partial nephrectomy for a 36 × 22 × 16 mm clear cell renal cell carcinoma, pT1aNxMx, Fuhrman grade 3
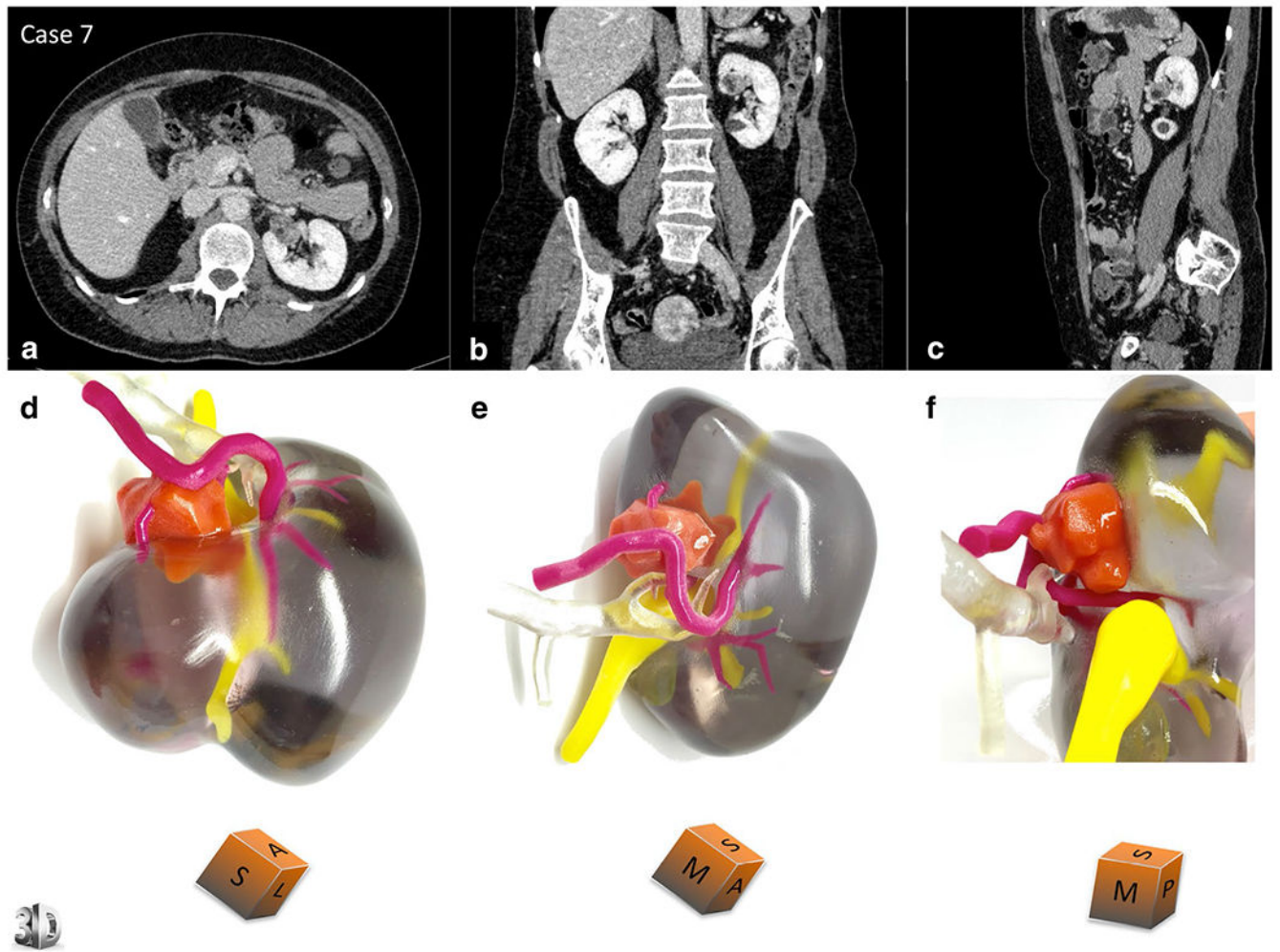
**Fig. 3.**
3D printed model for case 7. Comparative views of the CT scan at the nephrographic phase
(**a** axial, **b** coronal and **c** sagittal planes) and corresponding views of the physical model
(**d** superior view, **e** median view, **f** median view). The *cubes* show the 3D printed model
orientation in space (I = inferior face, A = anterior face, L = lateral side, S = superior face, P
= posterior face, M = median side). Case 7 underwent a left partial nephrectomy for a 21 ×
15 × 15 mm angiomyolipoma
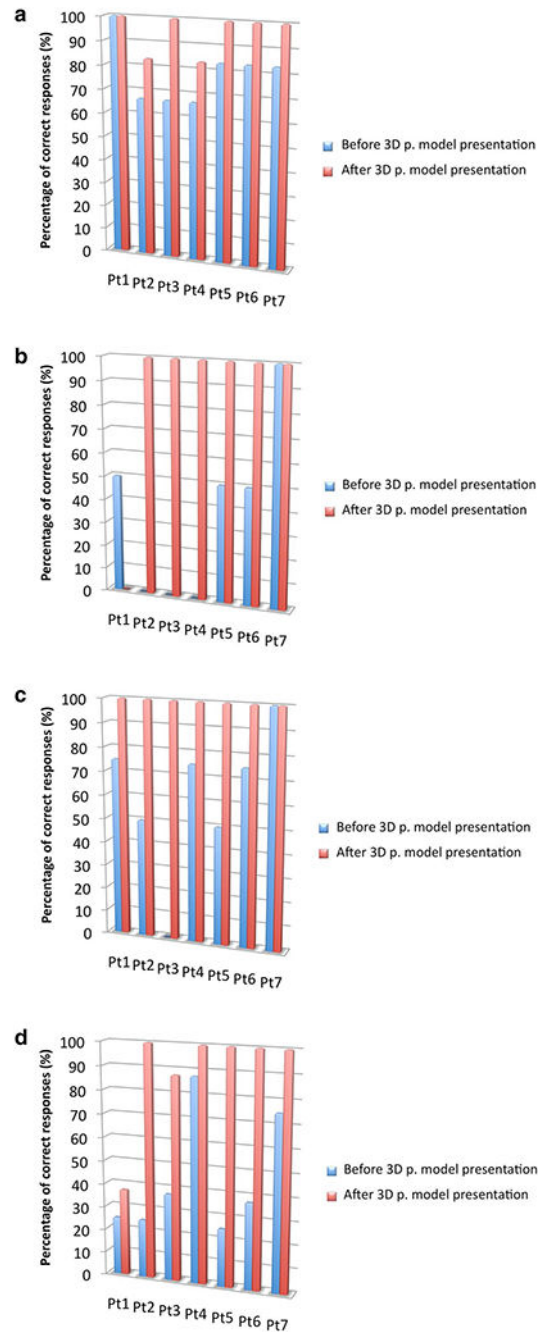
**Fig. 4.**
Percentage of correct responses per patient, before and after 3D printed model presentation.
Individual analysis of patient's understanding improvement (percentage of correct responses) on four areas: **a** basic kidney physiology; **b** kidney anatomy; **c** disease and tumor characteristics; **d** surgical procedure and risk of complications. 3D p. model = 3D printed model. Pt = patient
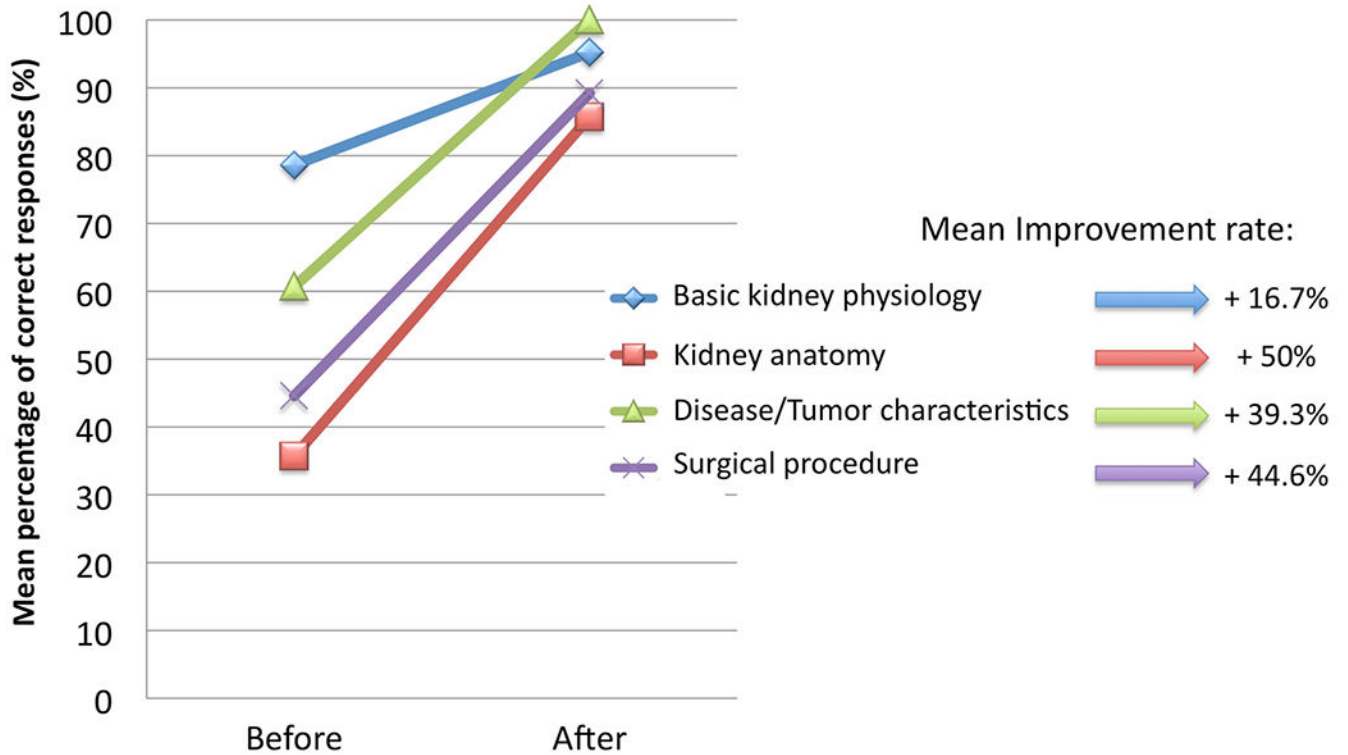
**Fig. 5.**
Mean percentage of correct responses per cognitive component, before and after 3D printed model presentation. Group analysis showing the mean improvement rate of patient's understanding on four cognitive components. After 3D printed model presentation, the mean improvement rate of understanding was 16.7, 50, 39.3 and 44.6 % for basic kidney physiology, kidney anatomy, disease and tumor characteristics and surgical procedure and risk of complications, respectively

**Table 1**

Patient and tumor characteristics

|  | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 | Case 6 | Case 7 |
|---|---|---|---|---|---|---|---|
| Age (years) | 67 | 46 | 54 | 49 | 69 | 33 | 53 |
| Gender | M | M | M | F | M | M | F |
| Education level | 12th g | 12th g | College 2 years | 12th g | 12th g | 12th g | College 2 years |
| Tumor side | Left | Right | Right | Left | Right | Right | Left |
| Tumor size (cm) | 7.2 | 5.6 | 3.8 | 3.5 | 4.1 | 6 | 2.5 |
| Tumor location | Upper pole | Upper pole | Interpolar | Interpolar | Upper pole | Interpolar | Interpolar |
| RENAL Score [a] | 9ah | 9ph | 10p | 9ph | 8p | 10ph | 8ph |
| PADUA Score [b] | 10a | 11p | 11p | 11p | 10p | 12p | 7p |

[a] Kutikov and Uzzo [11]

[b] Ficarra et al. [12]

## Table 2

Patient's understanding assessment before and after presentation of the personalized 3D printed model

| | Median [range] number and percent of correct responses | | $p$ * |
|---|---|---|---|
| | Before 3D printed model presentation | After 3D printed model presentation | |
| Basic kidney physiology | 5 [4–6] | 6 [5–6] | 0.018 |
| | 83.3 % [66.7–100] | 100 % [83.3–100] | |
| Kidney anatomy | 1 [0–2] | 2 [0–2] | 0.026 |
| | 50 % [0–100] | 100 % [0–100] | |
| Disease and tumor characteristics | 3 [0–4] | 4 | 0.068 |
| | 75 % [0–100] | 100 % | |
| Surgical procedure | 3 [2–7] | 8 [3–8] | 0.026 |
| | 37.5 % [25–87.5] | 100 % [37.5–100] | |

For each cognitive component, the number of correct responses among the group of patients reflects the level of understanding

*
Wilcoxon test

**Table 3**

Patient satisfaction

| | The presentation of my personalized 3D kidney model helped me in | | | | Mean ± SD |
|---|---|---|---|---|---|
| | Learning about the kidney itself | Learning about my disease | Understanding the surgery I will undergo | Understanding the risk of complications related to the surgery | |
| Case 1 | 8 | 6 | 8 | 8 | 7.5 ± 1 |
| Case 2 | 10 | 10 | 10 | 10 | 10 ± 0 |
| Case 3 | 10 | 10 | 10 | 10 | 10 ± 0 |
| Case 4 | 10 | 10 | 10 | 10 | 10 ± 0 |
| Case 5 | 10 | 10 | 10 | 10 | 10 ± 0 |
| Case 6 | 10 | 10 | 10 | 3 | 8.25 ± 3.5 |
| Case 7 | 10 | 10 | 10 | 10 | 10 ± 0 |
| Mean ± SD | 9.7 ± 0.76 | 9.4 ± 1.51 | 9.7 ± 0.76 | 8.7 ± 2.63 | |

The score was given using a visual scale from 1 to 10 with 1 = "no help at all" and 10 = "of a great help" ("Appendix 1")

Among the entire group, the overall mean satisfaction score was 9.4/10