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Short Communication
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Personalized 3D Model Printing and Better Surgical and Oncological Outcomes: The Kidney Tumor Paradigm

Kostis Gyftopoulos[1] and Spyridoula Zagkou[2]*

[1]*Department of Anatomy, University of Patras, Greece*

[2]*Department of Electrical and Computer Engineering, University of Patras, Greece*

Abstract

Renal cancer is a common malignancy in both sexes, with Renal Cell Carcinoma (RCC) representing the majority of renal tumors. The increasing use of imaging modalities has resulted in earlier detection of smaller lesions that are candidates for nephron sparing surgical removal. Although many advances in imaging and image reconstruction technology have improved preoperational planning, personalized 3D model printing appears to be an innovative, tailor-made approach towards improved pre- and intra-surgical planning and enhanced surgical and oncological outcomes. Recent advances in 3D model designing are increasingly refining the qualitative results of 3D printed models as a surgical aid.

Keywords: Renal cancer; Partial nephrectomy; 3D printing; Model

Short Communication

Renal cancer is a common malignancy in both sexes: Recent data estimate that it accounts for 5% and 3% of all types of tumors in men and women respectively [1]. Renal Cell Carcinoma (RCC) represents the majority of renal tumors [2]. During the last decades, incidence rates have been increasing; a fact attributed to the heterogeneity of the disease and an extensive palette of known- and yet unknown-risk factors. However, it is also probable that increasing rates have been affected by the extensive use of diagnostic modalities such as ultrasound and, more importantly, computed tomography, as approximately 50% of cases are incidental findings [2]. This simply means that smaller, down-staged tumors are more frequently discovered, offering the patient an opportunity for earlier and less radical intervention.

The surgical management of small (<7 cm) renal masses is generally oriented towards nephron sparing surgery, usually Partial Nephrectomy (PN) through a minimally invasive approach [3]. Although no extensive robust data are available, the merits of a reduction in blood loss, hospital stay, postoperative pain and a comparable oncological outcome have established PN (laparoscopic or robot-assisted) as a "gold standard" of surgical treatment in T1 RCC [1,4]. However, partial nephrectomy is technically more demanding than radical nephrectomy and requires careful preoperative planning and anatomical visualization to achieve an optimal surgical and oncological outcome, along with renal function preservation.

Traditionally, careful surgical planning was based on careful examination of Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) sets of slices [5]. Advances in imaging and reconstruction technology over the last decade have offered several useful tools, including interactive software for volume rendered images, virtual 3D models and "mixed reality" holograms as an aid to Virtual Surgical Planning (VSP) [6-8]. A major breakthrough however was the use of 3D printers in producing reliable models with accurate anatomical detailing. In several surgical disciplines, including neurosurgery, orthopedics, cardiac and general surgery, these models have been successfully used in preoperative and intraoperative planning [9]. Nevertheless, RCC surgery has been the field where 3D model printing was met with enthusiasm by urologic surgeons.

Since 2015, several studies have assessed the ability of 3D model printing of renal masses to guide preoperative planning and to enhance the surgical technique used. In a systematic review by Lupulescu et al. [10], a total of 27 studies were identified. Although a great diversity was present between the 3D printers, the materials and software used, the number of cases and the origin of image datasets (CT or MRI), the overall appraisal of the use of 3D models was a positive impact on presurgical planning, surgical outcome and surgeon's perception of their value on decision-making

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Correspondence:
Kostis Gyftopoulos, Department of Anatomy, School of Medicine, University of Patras, Greece, E-mail: kogyftop@upatras.gr

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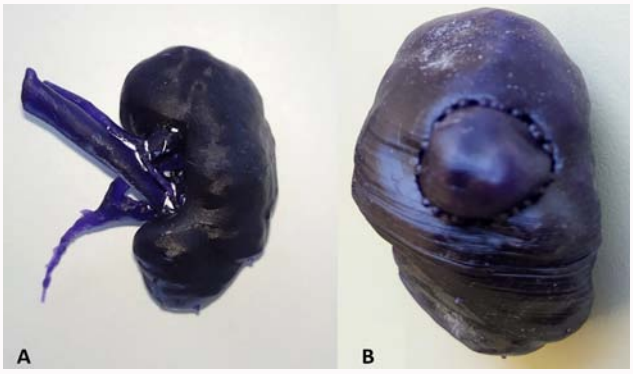

Figure 1: A) 3D printed model of normal kidney. B) 3D model of RCC; note the spheres delineating the tumor-normal parenchyma interface.

and intraoperative navigation. In a systematic review by the ESUT-YAUWP Group in 2019, investigating the impact of 3D printing in general Urology, the studies pertained to renal cancer suggested that 3D printed models may have a positive impact on both surgeons' efficiency and patient outcomes [11].

More recent studies have focused on the quantitative assessment of the use of personalized 3D models of renal cancer patients. In a feasibility study, using 3D kidney models during partial nephrectomy (both open and robot-assisted techniques), Kyung et al. [12] found that estimated blood loss during the resection was lower in the 3D model group. In a larger retrospective study of 127 patients with renal tumors, Fan et al. [13] compared the surgical outcomes of laparoscopic partial nephrectomy with/without the use of 3D models (3D LPN *vs.* LPN). They concluded that the use of a 3D model significantly reduces warm ischemia time, with possible impact on renal function. Although the complication rate was similar in both groups, it is interesting that in more complex cases (patients with a RENAL nephrometry score ≥ 8) not only ischemia time but also estimated intraoperative blood loss was significantly lower in the 3D model group. Similar results were found in a prospective, case-matched study on the efficacy of personalized 3D models in complex renal tumors (RENAL nephrometry score ≥ 7): In all cases, the operative time was significantly reduced, compared to the control group [14]. Apparently, in more complex cases, the development of a personalized 3D physical model may prove valuable in surgical planning and navigation.

Along these lines, complex RCC cases that pose a higher degree of technical difficulty are currently under investigation as possible candidates for personalized 3D printed modeling. In a current multicenter trial, the efficacy and efficiency of preoperative planning using 3D models of RCC with Venous Tumor Thrombus Extension (VTE) is investigated [15]. The initial results of Phase 1 yielded various 3D models with anatomical accuracy and suitability for surgical simulation. Similarly, the role of a 3D model for a complex case of RCC in a horseshoe kidney has been positively evaluated [16]. Moreover, both older and recent data suggest that 3D modeling may prove useful especially in tumors that are not entirely exophytic or are completely intraparenchymal [12]. After all, the main goal of the oncological outcome in PN is the complete excision of the tumor with a safety margin. Recently, a method was developed to delineate the interface between the tumor and healthy renal parenchyma [17]. By using a cutting algorithm that roughly compares the scalar values of two meshes that correspond to the kidney and tumor respectively, it is possible to integrate small, icosahedron-shaped objects at the interface line, as an aid to distinguish between normal and tumorous tissue in a 3D printed resin model (Figure 1). The integration of similar approaches in personalized 3D models may prove useful in facilitating the optimal resection planes during PN.

It appears that a paradigm shift is occurring in pre-and intraoperative planning of nephron sparing surgery, as 3D printed models prove to be a game changer. Both operative data, regarding intra- and post-operative complications and surgeons' perceptions of the clinical usefulness of 3D models are supporting their value. If we further consider their documented efficacy in surgical training and patients' education, 3D models are here to stay. Newer, standardized techniques and improved 3D printers may also overcome the major drawbacks of increased cost and time needed to produce a reliable and accurate personalized 3D model, with a clear impact on surgical and oncological outcomes.

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