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Virtual simulation, preoperative planning and intraoperative navigation during laparoscopic partial nephrectomy

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Introduction The use of computer navigation systems is a new and actively explored method used for surgical procedures concerning the abdominal and retroperitoneal organs. In this paper, we propose an original hardware – software complex, which forms a virtual body model, based on preoperative computer tomography data, transmitted to the operating screen monitor using a surgical navigation system, involving a mechanical digitizer.

Material and methods During a laparoscopic procedure, a three-dimensional (3D) model of a kidney with a tumor was used to obtain additional information on the primary or secondary monitor or for combining the virtual model and video images on the main or additional monitor in the operating room. This method was used for laparoscopic partial nephrectomy, where twelve patients were operated with an average age of 45.4 (38–54) years, with clear cell renal cell carcinoma size 27.08 (15–40) mm.

Results All patients successfully underwent laparoscopic partial nephrectomy with intraoperative navigation. The mean operative time was 97.2 (80–155) minutes, warm ischemia time – 18.0 (12–25) minutes. Selective clamping of segmental renal arteries was performed in 7 (58.3%) cases, in the remaining 5 (41.6%) cases the renal artery was clamped. There were no serious complications. The average duration of hospital stay was 7.0 (5–10) days.

Conclusions Preliminary results of our clinical study have shown the success of 3D modeling for qualitative visualization of kidney tumors in the course of surgical intervention, both for the surgeon and for the patient to understand the nature of the pathological process.

Key Words: 3D modeling ‹› computer navigation system ‹› laparoscopic partial nephrectomy

INTRODUCTION

Intraoperative three-dimensional (3D) navigation based on preoperative computed tomography (CT) data is actual for laparoscopic surgery on retroperitoneal space. The 3D model forms the best image of the organ and then complex images of a virtual model with the real images on the screen are obtained during the operation. This technique of augmented reality is actively being explored [1, 2]. The undoubtable advantage of this methodology is the better orientation of the surgeon in the operative field, which is especially important throughout the educational process of surgeons [3]. The possibility of applying the models/images in real time, reliability and precision applications of virtual and real objects are important for the usual requirement applicable to such systems. In this article, we present the original hardware – software complex 'Volga-M' [4] that allows the creation of a 3D model rendered from CT scan data, in order to perform preoperative planning of surgery using virtual models on the screen, and initial clinical trials of intraoperative navigation during laparoscopic partial nephrectomy.

MATERIAL AND METHODS

In the Volga State Technical University and Republican Clinical Hospital of Yoshkar-Ola of the Republic of Mari El, a hardware – software complex called 'Volga-M', consisting of a computer and a mechanical digitizer combined with a laparoscope and a video camera was developed. The program 'Volga-M' allows for the formation of a 3D model of a surgical zone of interest obtained from CT data. In order to form a 3D model, a contour of a segmented image should be selected. The contour tracking includes a series of sequential image processing, resulting in the formation of a 3D model of the kidney and tumor at different angles [5]. Finally, the 3D model of the kidney formed with the translucent parenchyma in order to demonstrate the internal structure of the organ. Patients with kidney tumors were selected as a test group (Figure 1). The obtained models of the organs were looked at and discussed with patients and their relatives in order to explain the nature of the disease and planned surgical procedure.

We used a mechanical digitizer, combined with a laparoscope and video camera head during endoscopic surgery for combining the images of the 3D model with video images on the screen in the operating room [4]. The image of the virtual organ in the corresponding projections according to the location of the real camera was transferred to the main or to the additional monitor.

The trial obtained the approval of the local Ethics Committee of the Republican Clinical Hospital and voluntary informed consent was obtained from the patients. Nine patients, among whom 6 (50%) were men and 6 (50%) were women, with a mean age of 45.4 (38–54) years underwent standard clinical examination, including spiral CT scan, the results of which were recorded in the DICOM system. CT was performed using the Siemens 'Sonotom 3000' or Philips 'Brilliance 64' scanners using 'Ultravist-370' contrast in the standard doses, with the kidney as the target retroperitoneal organ. All patients presented with renal cancer T1N0M0. Using the original product 'Volga-M' we formed 3D models of the surgical zone of interest - the kidney with the tumor and blood vessels. The 3D models of the kidneys with the tumors were shown to patients for the better understanding of the nature of their lesions, including their localization and size and planned surgical procedure.

During the preoperative planning, the selection of vessels supplying the segment containing the tumor were performed and marked most convenient for their temporary clamping. Virtual removal of the kidney tumor was performed, the results of which could later be compared with video of the real operation.

All patients underwent standard transabdominal laparoscopic partial nephrectomy, with mobilization of the relevant surrounding intestines. Selecting of kidney blood vessels, if possible to the segmental level, and clamping of a segmental or renal artery with respect to warm ischemia time, was performed. The kidney tumor was resected and hemostatic sutures were administered.

The trial studied demographic, intraoperative and postoperative data of patients in addition to the duration of operation, including the time of warm ischemia, and postoperative data including histopathology results, surgical margins and postoperative complications.

RESULTS AND DISCUSSION

All patients successfully underwent laparoscopic partial nephrectomy. Selective clamping of segmental renal arteries was performed in 7 (58.3%) cases, in the remaining 5 (41.6%) cases the renal artery was clamped. The renal pelvis was not opened in all cases. For hemostatic purposes, the parenchyma was sutured using a blanket stitch on plastic clips. The warm ischemia time was 18.0 (12–25) minutes. Average duration of the procedures was 97.2 (80–155) minutes. Average blood loss amounted to 207.5 (100–400) ml. In the postoperative period, early mobilization of the patient was conducted. Serious complications according to the Clavien classification [6] in the postoperative period were not observed. Patient no. 6 presented with a transient elevation of serum creatinine, however, this did not require any special treatment (G1). Patient no. 3 presented

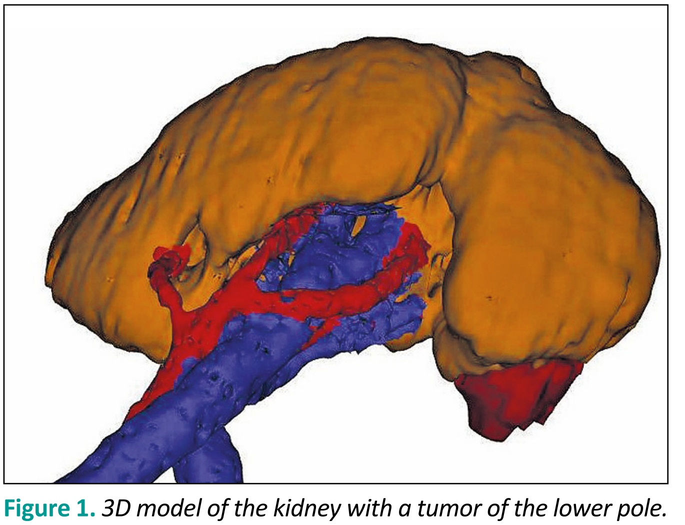

Figure 1. *3D model of the kidney with a tumor of the lower pole.*

Table 1. *Patients' demographic, intraoperative and postoperative data*

Patient N/Demographics	1	2	3	4	5	6	7	8	9	10	11	12	Mean	Standard deviation
Age	45	49	39	51	46	38	54	47	44	41	48	43	45.42	4.78
Sex	f	m	f	f	m	f	m	f	m	m	m	f	f-6	m-6
BMI	26	29	34	25	38	33	45	27	42	40	48	32	34.92	7.67
Baseline renal function (EGCF)	98	79	70	99	92	87	68	92	80	88	91	93	86.42	10.12
Tumor size (mm)	22	30	21	15	32	20	31	25	40	33	31	25	27.08	6.96
Operative data														
Warm is chemic time (min)	12	18	16	25	24	15	18	14	14	17	25	18	18.0	4.43
Operative time (min)	80	155	100	90	95	90	105	90	110	85	95	80	97.92	20.16
Blood loss (ml)	200	300	150	100	400	250	100	300	200	110	250	130	207.5	95.26
Perioperative data														
Hospital stay (d)	5	6	7	6	10	7	8	6	7	6	9	7	7.0	1.41
Clavien complications	–	–	G2UTI	–	–	G1tES	–	–	–	–	–	–		
Pathologic data	T1a	T1b	T1b	T1a	T1b	T1b	T1b	T1a	T1b	T1a	T1b	T1a		
Tumor histology	All–ccRCC4													
Margin status	All–negative													

BMI – body mass index; UTI – urinary tract infection; tESC – transient elevation of serum creatinine; ccRCC – clear cell renal cell carcinoma

with a urinary tract infection and the appropriate antibiotic therapy was administered (G2). All patients were diagnosed with clear cell carcinoma and there were no cases of positive surgical margins histologically. The average duration of treatment was 7.0 (5–10) days. Preoperative patient demographics, tumor characteristics, operative data, perioperative data, and pathologic outcomes for each patient are described in Table 1.

The volumetric model of the organ obtained using the program ‘Volga-M’ before surgery allowed for the preoperative planning of the upcoming partial nephrectomy by determining the localization of the tumor, its relation with kidney vessels and the renal pelvis, and identifying sections of the renal artery most convenient for vascular clamping. During the virtual removal of the tumor it was possible to observe the probable damage of the internal structures of the kidney, determine their location, and predict methods for eliminating future complications. In all cases of preoperative planning and discussion of its results, patients and their relatives understood the essence of the disease and the features of the forthcoming surgical intervention.

The video image of the virtual model of the kidney was visualized on the main or additional monitor screen together with the image obtained with a laparoscopic camera (Figure 2).

When using augmented reality technology, we combined the video image of the kidney tumor and a 3D model, with the demonstration the location of the renal vessels, segmental arteries, selected at preoperative planning a section of an artery to overlay vascular clamps, precise localization of the tumor (Figure 3).

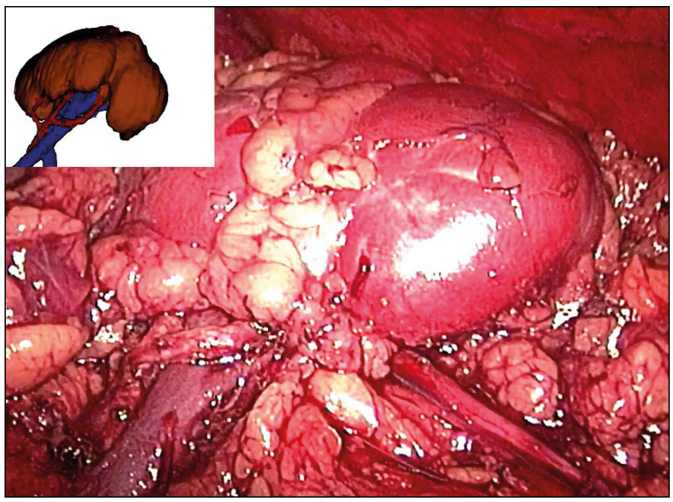

Figure 2. *Demonstration of the 3D model on the surgical monitor.*

The technique of combining the 3D model obtained from CT data with the intraoperative video image, allowed the surgeon to accurately represent not only the vessel architecture of the operated organ and its anatomy but also the location and spread of the kidney tumor, and its relationship with the surrounding blood vessels. Thanks to this, radical nephrectomy with maximum preservation of the undamaged renal parenchyma was possible.

The locating and subsequent isolated clamping of the segmental artery gives significant advantage in terms of preserving renal function after surgery by excluding ischemia of renal parenchyma [7]. The blood circulation is disturbed only in the segment affected by the tumor process, thus maintaining the total renal function in the postoperative period. In the present study, the average time of warm ischemia was 18.0 (12–25) minutes, blood loss averaged 207.5 (100–400) ml.

Virtual simulation is increasingly used in medical practice as a combination of the achievements of modern computer technology and medical imaging [8–11]. Creation a 3D model of the organ or area of the surgical intervention based on CT study images allows the combination of different contrast-phase studies, including vascular, parenchymal and excretory which gives the surgeon additional information and is helpful for the patient to understand the essence of the disease [12, 13].

The modern development of endoscopic technology has significant advantages for the patient, associated with minimally invasive surgery. However, the application of endoscopic technology creates additional difficulties such as the unusual nature of the visualization as the surgeon is watching his actions on the screen as a 2D image, the lack of tactile sensitivity, and limited field of view. In such a situation, additional information about the individual anatomy of the area of intervention becomes extremely useful.

The use of virtual 3D models and augmented reality allows the surgeon to estimate the boundaries of the pathological process and to see the internal structure in the 'translucency' that is particularly valuable in partial nephrectomy [14]. However, the use of augmented reality technology during surgery is complicated by the combination of the 3D model and the real image on the monitor screen in real time.

In terms of laparoscopic operations when the main source of information is the monitor, its use for visualization of 3D models is used by many authors [2]. The 3D model superimposed on the video image can be transmitted to the main or to additional monitor screen [12, 15].

Computer platforms that allow the creation of virtual models of organs or areas of surgical interest based on CT data and not tied directly with CT scanner, such as TilePro, OsiriX, have started to be used in laparoscopic and robotic surgery also during partial nephrectomy [2, 15, 16]. In 2009 Su et al. successfully applied the technology of augmented reality during robotic partial nephrectomy using an overlay of a reconstructed 3D tomography video of the image in real time [17].

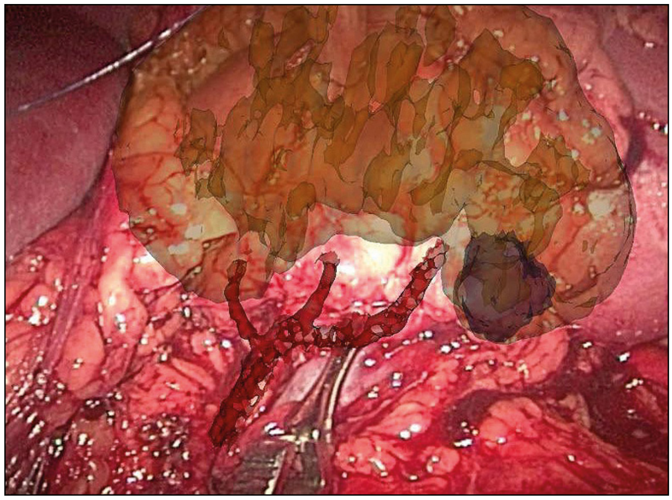

Figure 3. *Installation a vascular clamp on the segmental artery of the kidney using translucent virtual model.*

In our study, we developed our own method of forming virtual models based on preoperative CT studies and integration of the images of the virtual model and the real organ – the kidney with the tumor. Further experimental work is planned in order to improve the quality of the image and automatic segmentation of organ images, adapt the virtual model to print on a 3D printer, and improve the integration of the 3D model to video image. Currently, research is aimed at pairing real and virtual video when performing endoscopic operations on the retroperitoneal organs in real time.

CONCLUSIONS

The software product 'Volga-M' allows the creation of a virtual three-dimensional model of the surgical zone or chosen organ based on data received from any CT scan. A 3D model of the marked organ can be successfully used for planning a surgical procedure or as a tool for explaining the procedure to the patient. Preliminary results of this study demonstrate the possibility of successful use of our hardware – software complex and 3D models for visualization of the affected organ during surgery, which is especially important in organ-preserving urologic procedures, such as laparoscopic partial nephrectomy.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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