

Comparison of three dimensional reconstruction and conventional computer tomography angiography in patients undergoing zero-ischemia laparoscopic partial nephrectomy

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Abstract

Background: Advances in the three dimensional (3D) reconstruction and printing technology have fueled a rapidly growing interest in its applications in the field of urology. To our knowledge, the experience on the use of 3D reconstruction to facilitate zero-ischemia partial nephrectomy (PN) remains sparse and the role of 3D reconstruction is still needed to be defined. This study aimed to assess the role of three-dimensional (3D) reconstruction and conventional computer tomography angiography (CTA) in zero-ischemia laparoscopic partial nephrectomy (LPN).

Methods: A total of 60 consecutive patients undergoing zero-ischemia LPN between October 2017 and March 2018 underwent CTA (CTA group including 30 patients) and 3D reconstruction (3D group including the remaining 30 patients) were included. 3D reconstruction and CTA images were prepared which were used to demonstrate the number and spatial interrelationships of the location of renal tumors and tumor feeding arteries. These radiology findings were directly correlated with intraoperative surgical findings at laparoscopy. Demographics, perioperative characteristics and renal function were compared between groups.

Results: CTA and 3D reconstruction were successfully performed without any related complications. All the procedures were performed successfully without conversion to main renal artery clamping. Preoperative 3D reconstruction identified that 15 patients had only one tumor feeding artery, 12 had two, and another 3 had three, while the conventional CTA revealed that 22 patients had one tumor feeding artery, 8 had two ($P>0.05$). The mean operation time was shorter and estimated blood loss was less in the 3D group ($P<0.05$). 3D reconstruction group resulted in more accurate dissection of tumor artery (91.7%) as compared to conventional CTA (84.2%). There were no statistical differences in the baseline characteristics and renal function outcomes between two groups.

Conclusions: 3D reconstruction can provide comprehensive information for the preoperative evaluation and intraoperative orientation that may facilitate tumor resection during zero-ischemia LPN for renal tumors.

Background

Laparoscopic partial nephrectomy (LPN) has gained popularity as a promising minimally invasive nephron sparing option for clinical T1 renal tumors [1]. Minimizing or even eliminating warm ischemic injury was the aim for improving the functional outcomes of nephron sparing surgery. Recent advances in surgical technique now make it possible to eliminate global ischemia completely during partial nephrectomy (PN), such as zero ischemia PN, unclamped "minimal-margin" PN and clampless techniques [2–4]. However, zero ischemia LPN is a technically challenging operation. As such, a detailed and case-specific understanding of the particular renovascular anatomy is of great importance to surgical planning and even orientation.

At most centers, renal angiography has been the preferred imaging modality for preoperative evaluation of patients with renal tumors. Although helical computerized tomography (CT) allow high quality images of the renal vasculature and soft tissue anatomy to be obtained in any plane, advances in the three dimensional (3D) reconstruction and printing technology have fueled a rapidly growing interest in its applications in the field of urology [5]. This image modality has been successfully used for preoperative evaluation of patients undergoing PN [6, 7]. Currently, the experience on the use of 3D reconstruction to facilitate zero-ischemia PN remains sparse, and the role of 3D reconstruction is still needed to be defined. We determined whether 3D reconstruction could be the preferred preoperative radiological examination, providing all information necessary for surgical planning and orientation for zero-ischemia LPN.

Methods

Patients

Between January 2018 and July 2018, 60 consecutive patients who underwent zero-ischemia LPN in our hospital were retrospectively analyzed. The patients with sporadic renal tumor at clinical T1N0M0 stage were included. Patients with multiple kidney tumors, bilateral kidney tumors, or a solitary kidney tumor were excluded from this study. The study was approved by the Institutional Review Board of Ren Ji Hospital affiliated to School of Medicine of Shanghai Jiao Tong University. Before surgery, all the patients received contrast-enhanced CT with angiography, and additional 3D reconstruction was conducted in 30 patients.

CTA and 3D reconstruction protocol

All CTA examinations were performed using a 64-multidetector computed tomography scanner (VCT Light Speed, GE Healthcare, Pittsburgh, USA). Patients drank 1000 ml of water before the examination. Four phase images were obtained in a craniocaudal orientation. The scanning covered the area from the diaphragm to the lower kidney poles (non-enhanced, arterial and portal phases) and from the diaphragm to the symphysis pubis (delayed nephrographic excretory phase). Contrast-enhanced images were obtained after intravenous administration of 150 ml of non-ionic contrast medium (Iopamiro, Bracco, Milan, Italy). The current was 110-380 mA, the slice thickness was 1.25-mm, and the pitch was 1.375. Non-enhanced nephrographic and excretory phase scans were reconstructed as 1.25-mm sections. The arterial phase images were reconstructed at an 0.725-mm interval.

Images in DICOM format were processed with a dedicated software by Mimics, 3-matic and Magics (Materialise, Belgium). Then, a 3D virtual model was rendered on the basis of CTA examination. The reconstruction focused on the semitransparent kidney, the tumor characteristics and the arterial vasculature. The segmentation of kidney surface was performed in the arterial phase images with automated threshold segmentation method using Hounsfield units. The renal pedicle and tumor feeding arteries were reconstructed in the arterial phase by using the dynamic region growing method. Then, the virtual renovascular-tumor models were reviewed by both urologists and bioengineers to evaluate the accuracy of models in comparison to the CTA images (Figure.1). The 3D model and the relative

interactive 3D images were then created. The number of renal tumor feeding arteries was compared between the 2 imaging modalities and matched with intraoperative findings on laparoscopy, which were considered the gold standard.

Surgical technique

Patients received general anesthesia and lied in a lateral decubitus position. All the procedures were performed using a retroperitoneal approach. Four ports in the lumbar region were applied. In the CTA group, off-clamp LPN was performed with the guidance of CTA images. In the 3D group, snapshots of 3D images from various angle views (e.g., lateral, anterior and posterior) were created and presented to the surgeon preoperatively and intraoperatively. After the tumor was completely exposed, the parenchyma was then incised, and the tumor was excised along its capsule with a margin of 1 to 2-mm normal parenchyma by blunt dissection, the dissection was kept at the relatively avascular intrarenal plane. On reaching the target vessels of the tumor, operation was done with Hem-o-lok clips (Figure.2). Homeostasis was achieved with point-specific suturing, and incised calyces were repaired. Then, the defected parenchyma was closed via continuous suturing with Hem-o-lok clips.

Outcome Measures

The general information, tumor characteristics including RENAL score [8] and the number of feeding arteries were collected and compared. All complications within 30 days after surgery were considered being related to surgery, and staged according to the 2004 Clavien-Dindo grading system [9]. The estimated glomerular filtration rate (eGFR) was calculated for all patients preoperatively and 12 months postoperatively according to the Modification of Diet in Renal Disease Equation [10]. Statistical analysis was performed using Student t-test for continuous variables or Chi-square for categorical variables, and a value of $P < 0.05$ was considered statistically significance.

Results

A total of 60 consecutive patients who underwent zero-ischemia LPN were included in this study. Patient demographics and surgical variables are reported in Table 1. The mean tumor size was 4.1 and 3.8 cm in 3D group and CTA group respectively without statistical significance. There were also no significant differences between two groups in the age, gender, body mass index and RENAL score.

Table 1
Patients' demographics and surgical variables

Variables	3D group (30 cases)	CTA group (30 cases)	p value
Gender, n (%)			0.774
Male	22 (73.3)	21 (70)	
Female	8 (26.7)	9 (30)	
Age (years, mean \pm SD)	57.6 \pm 11.7	56.4 \pm 9.8	0.669
BMI (kg/cm ² , mean \pm SD)	25.2 \pm 2.8	24.9 \pm 2.5	0.622
Tumor size (cm, mean \pm SD)	4.1 \pm 0.84	3.8 \pm 0.76	0.082
Renal Score, n (%)			0.339
4–6	11 (36.6)	12 (40)	
7–9	17 (56.7)	15 (50)	
10–12	2 (6.7)	3 (10)	
Operative time (min, mean \pm SD)	125.4 \pm 19.7	136.6 \pm 15.1	0.017
Estimated blood loss (ml, mean \pm SD)	130.3 \pm 39.9	179.0 \pm 77.2	0.003
Hospital stay (days, mean \pm SD)	5.0 \pm 1.1	5.4 \pm 1.0	0.114
Pathologic subtype, n (%)			0.543
Clear cell	26 (86.7)	25 (83.3)	
Chromophobe	1 (3.3)	3 (10)	
Papillary	3 (10)	2(6.7)	
Furhman grade, n (%)			0.740
I	10 (33.3)	12 (40)	
II	16 (53.4)	13 (43.3)	
III	4 (13.3)	5 (16.7)	
Complications, n (%)			0.365
Fever	1 (3.3%)	0	
Hematuria	1 (3.3)	3 (10%)	

Variables	3D group (30 cases)	CTA group (30 cases)	p value
eGFR change (ml/min/1.73 m ² , mean ± SD)	-8.67 ± 8.8	-10.6 ± 11.5	0.459

The number of tumor feeding arteries was identified preoperatively by 3D reconstruction and CTA, and then confirmed intraoperatively (Table 2). Preoperative 3D reconstruction identified that 15 patients had only one tumor feeding artery, 12 patients had two, and another 3 had three. While conventional CTA revealed that 22 patients had one tumor feeding artery and 8 patients had two, without significant statistical difference as compared to the 3D group. However, under the guidance of 3D reconstruction images, more tumor feeding arteries were correctly identified during the surgery as compared to surgery under the guidance of conventional CTA (P = 0.03). Although there was no significant difference between two groups, the rate of accurate tumor feeding artery orientation was higher in the 3D group than in the CTA group (91.7% vs 84.2%, p = 0.285).

Table 2

Tumor feeding arteries according to 3D reconstruction of renovascular-tumor, conventional CTA and surgically confirmed findings in 60 patients

Variables	3D group	CTA group	p value
Preoperative findings of tumor feeding arteries, n (%)			0.077
1	15 (50)	22(73.3)	
2	12 (40)	8(26.7)	
3	3 (10)	0 (0)	
No. surgically confirmed findings, n (%)			0.03
0	1 (3.3)	1 (3.3)	
1	16 (53.3)	26 (86.7)	
2	11 (36.7)	3 (10)	
3	2 (6.7)	0 (0)	
Rate of accurately tumor feeding arteries orientation	91.7% (44/48)	84.2% (32/38)	0.285

Zero-ischemia LPN was successfully performed in all the patients without conversion to main renal artery clamping, open surgery or radical nephrectomy. The mean operation time (OT) was 125.4 ± 19.7 min and 136.6 ± 15.1 min in the 3D group and CTA group, respectively (P = 0.017). And the average estimated blood loss (EBL) was significantly less in the 3D group as compared to the CTA group (P = 0.003).

However, no statistical differences were found between two groups in the hospital stay, major surgical complications and change in mean eGFRs (Table 1).

Histopathological results showed clear cell renal cell carcinoma (RCC) (3D group: n = 26; CTA group: n = 25), chromophobe RCC (3D group: n = 1; CTA group: n = 3), and papillary RCC (3D group: n = 3; CTA group: n = 2). There were no significant differences in the subtypes and Furhman grade between the two groups ($P > 0.05$). The surgical margins were all negative, and no renal capsule invasion was found. The median duration of follow-up was 18 months in the subgroups, and no local recurrence or metastasis was found.

Discussion

During conventional LPN, renal artery clamping could provide good intraoperative visualization and bleeding control, but inevitably causes warm ischemia injury [11]. Warm ischemia injury remains one of the most important factors influencing postoperative renal function during nephron sparing surgery. Several techniques have been developed to preserve better postoperative renal function, such as segmental artery clamping and thermal ablation techniques [12, 13].

The concept of zero-ischemia LPN was firstly introduced by Gill et al. [14]. They tried to eliminate global renal ischemia by meticulous microdissection of tertiary or quaternary renal arterial branches feeding the tumor, which is based on the concept of anatomical renovascular microdissection [3]. However, dissecting tumor feeding arteries from the renal hilum is technically difficult and time-consuming. Although off-clamp LPN has been developing and popularizing among the urologic communities [15, 16], the uncertainty of the intrarenal relationships of the tumor and feeding arteries makes off-clamp partial nephrectomy even more difficult. Therefore, preoperative understanding of the tumor and renal vascular anatomy is of great importance.

Preoperative CTA has been the preferred imaging modality for the evaluation of renal tumors in our hospital. With the development of CT and computer technology, it allows the generation of high quality images of the renal vasculature, tumor and collecting system at any plane [17]. It can also facilitate establishing conventional 3D models to visualize the arterial vasculature within the hilum, guiding in choosing the appropriate hilar approach and intraoperative target orientation during segmental artery clamping [18]. However, conventional CTA has a poor capacity to display the precise location and the precise anatomical interrelationship of various intrarenal tributaries, especially the tumor feeding arteries. Moreover, conventional 3D models based on CTA typically display kidney, renal vascular and tumor as opaque, which makes it impossible to visualize the intrarenal relationships between the tumor and its adjacent feeding arteries [6]. As a well performed preoperative evaluation of the relevant intrarenal anatomy and intraoperative orientation of tumor feeding arteries is needed for zero-ischemia LPN, it is imperative to develop new techniques for radiologic guidance.

Conventional 3D CT reconstruction techniques typically present kidney, tumor and renal vessels as opaque, which makes it impossible to visualize the intrarenal relationships of the tumor and adjacent feeding arteries [6]. In this study, the patients in the 3D group underwent 3D reconstruction. The

reconstruction images included 3D surface rendered semitransparent renal tumor, transparent kidney, and 3D course of extra- and intrarenal tumor feeding arteries (Figure.1C-D). Therefore, the location and number of tumor feeding arteries were clarified much more easily. In addition, the use of 3D reconstruction of renovascular tumor resulted in more accurate dissection of target tumor feeding artery than in the CTA group during the operation, thus decreasing intraoperative OT and EBL.

When compared to conventional CTA, 3D reconstruction techniques have several advantages. It could clearly display the intrarenal arterial tree and the detailed anatomical relationships between the tumor, collecting system and intrarenal arteries. The reconstructed images can also be rotated to clarify the number and location of tumor feeding arteries. It can not only provide reference for the preoperative evaluation and determination of appropriate dissection strategy, but also for the intraoperative orientation, therefore avoiding invisible injury to other interlobar arteries during zero-ischemia LPN.

There were also several limitations in this study. First, this was a single-center retrospective study with small sample size and patients received only short-term follow up, the evaluation of long-term outcomes is still awaited. Second, the mean tumor size was 4.1 and 3.8 cm in each subgroup, whether this approach is also applicable in the management of T1b renal tumors is still unclear. Robot assisted zero-ischemia partial nephrectomy may be helpful for better tumor resection, renorrhaphy and renal function preservation in the management of T1b or even complicated renal tumors [4, 19], but our experience is also lacking in this field. Third, the 3D reconstruction technique based on CT images is not applicable to magnetic resonance imaging. Thus, patients who cannot receive enhanced CT or CTA are excluded from the study. Although the tumor feeding arteries were confirmed more accurately under the guidance of 3D reconstruction technique, the rate of accurately tumor feeding arteries orientation was only 91.7%, without statistical significance as compared with conventional CTA technique.

Conclusions

Our study indicates 3D reconstruction technique might be a useful tool, which can provide comprehensive information of intrarenal interrelationships between renal tumor and its feeding arteries. The 3D model seems to facilitate tumor feeding artery orientation and dissection, therefore improving the surgical outcome after zero-ischemia LPN.

Declarations

List of abbreviations

3D: three dimensional; CT: computerized tomography; CTA: computer tomography angiography; EBL: estimated blood loss; eGFR: estimated glomerular filtration rate; LPN: laparoscopic partial nephrectomy; OT: operation time; PN: partial nephrectomy; RCC: renal cell carcinoma

Ethical approval and consent to participate

This study was approved by our Institutional review board (Shanghai Jiao Tong University School of Medicine affiliated Ren Ji Hospital, Shanghai, China) and patients' consent to participate was obtained.

Consent for publication

Not applicable.

Availability of data and materials

All data are fully available upon reasonable request. The corresponding author should be contacted if someone wants to request the data.

Competing interests

The authors declare no competing interests.

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Authors' contributions

Study concepts and design: XW, CJ, DL and WX; literature research and data collection: XW, CJ, GW, CS, QF and YC; Stastical analysis: CS, QF and YC; manuscript preparation: XW, CJ, GW and CS; manuscript editing: DL and WX. All authors have read and approved the manuscript.

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None.

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Figures

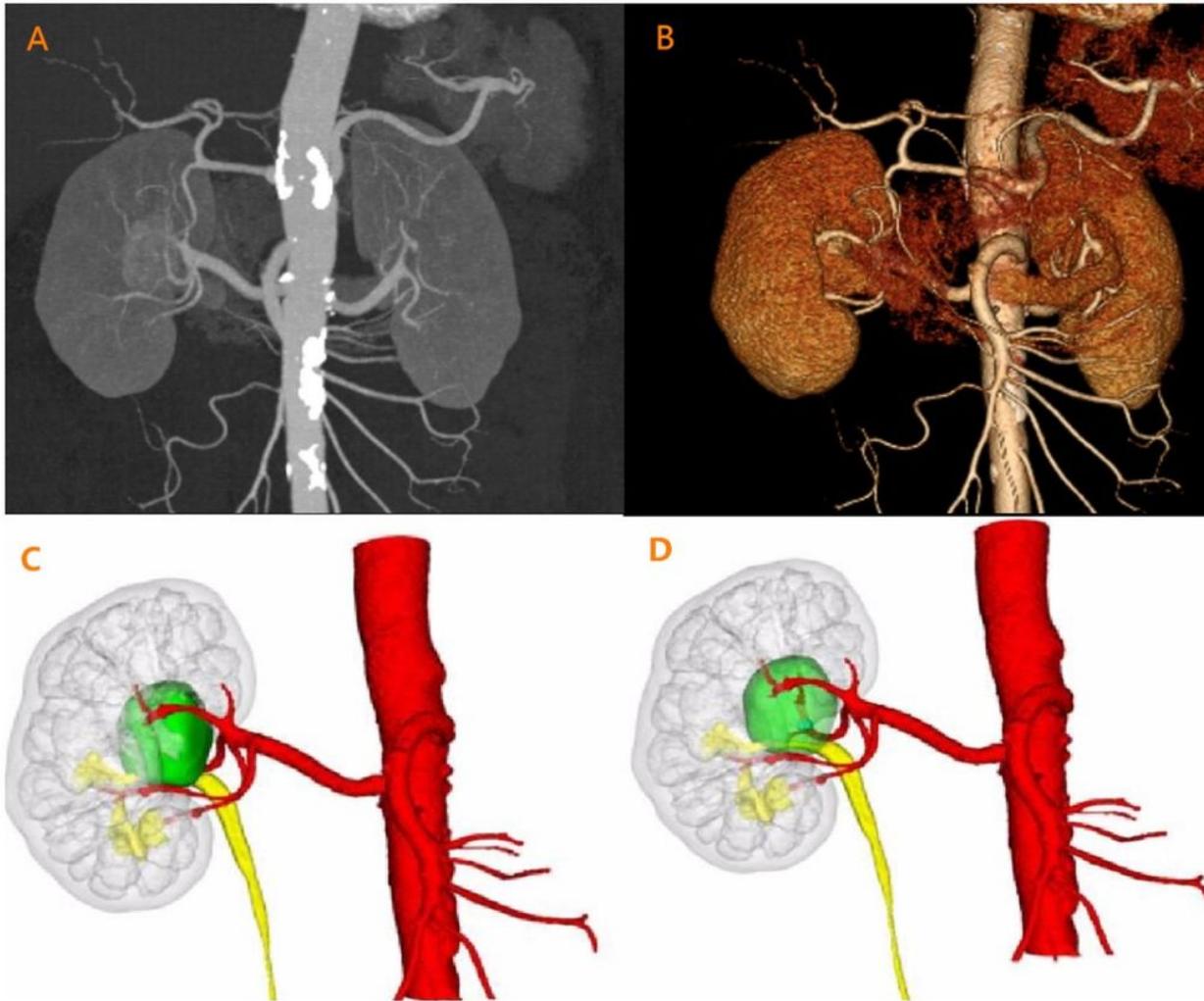


Figure 1

Conventional CTA and 3D reconstruction demonstrated a tumor located at the renal hilum. A: Conventional CTA image could identify extrarenal arteries and the tumor, and sometimes the intrarenal artery branches, but failed to illustrate the relationship between tumor and its feeding arteries. B: Conventional 3D reconstruction based on the CTA could reveal the relationship between kidney, tumor and extrarenal arteries, but it typically present kidney, tumor and renal vessels as opaque, which makes it impossible to visualize the intrarenal anatomy and tumor feeding arteries. C-D: The 3D reconstruction images in our study included transparent kidney and 3D course of extra- and intrarenal tumor feeding arteries (C) and 3D surface rendered semitransparent renal tumor, which make it possible to show the target feeding arteries all around the tumor (D).

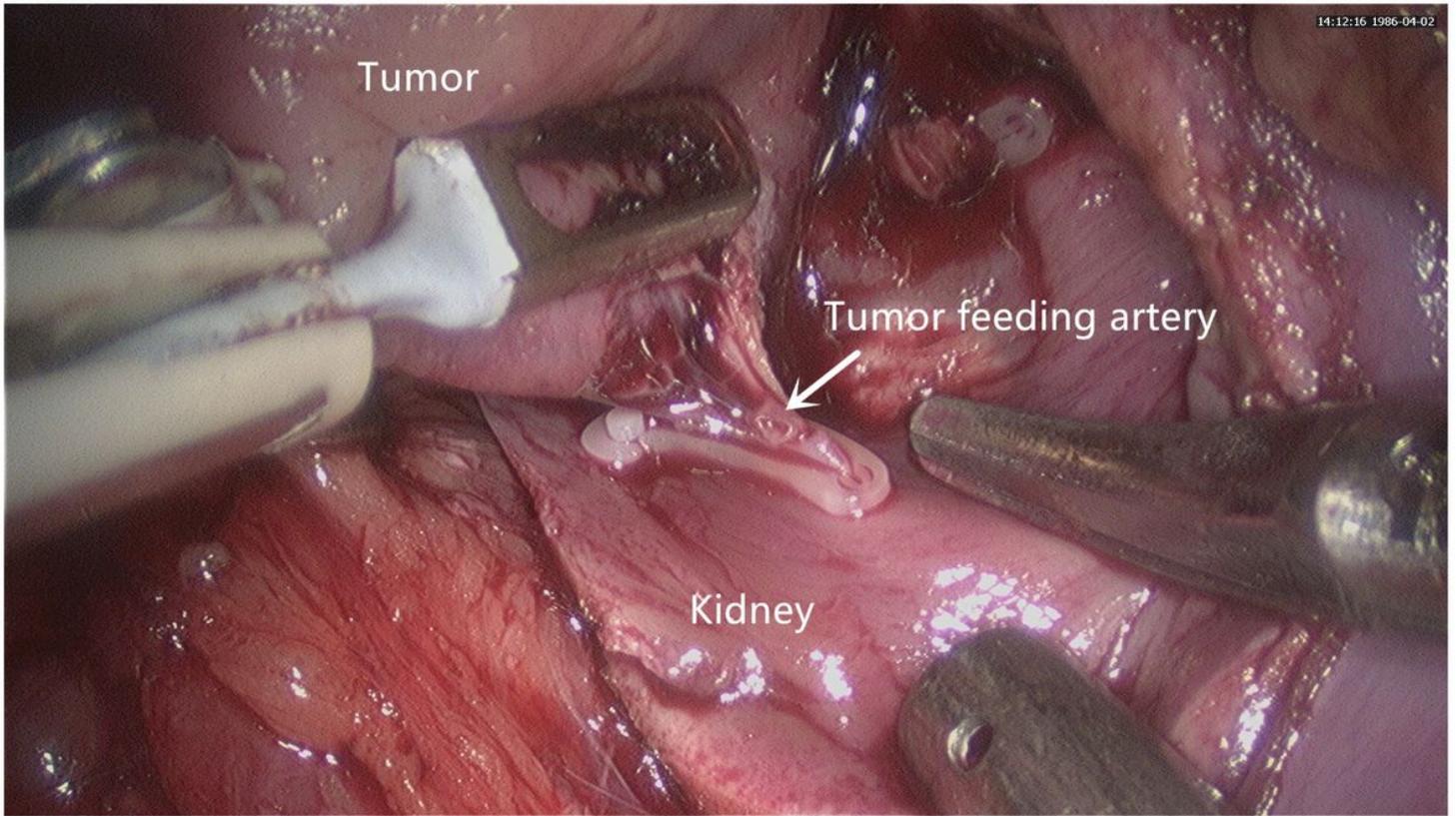


Figure 2

The tumor was excised with blunt dissection along its capsule. Under the guidance of 3D reconstructed images, the tumor specific feeding artery (white arrow) could be identified and then clamped with the Hem-o-lok clips during the operation.