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Avoiding Intraoperative Ultrasonography during Partial Nephrectomy by Combined use of Three-Dimensional Reconstructed Images and Three-Dimensional Laparoscopy

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Abstract

To evaluate the efficacy of preoperative planning and intraoperative image navigation in combination with three-dimensional (3D) visualization for a laparoscopic partial nephrectomy (PN) procedure, we examined the results of our cases and compared those with previously reported studies. From September 2009 to June 2015, 6 patients with cT1 renal tumors underwent 3D laparoscopic PN in combination with preoperative planning and intraoperative image navigation at our hospital. The tumor cutting line and clamping portions of the renal artery were preoperatively determined based on reconstructed 3D images. Real-time navigation was performed during the operation. Average operative and ischemia times were 442 and 28.5 minutes, respectively, while blood loss was 129 ml. Renal function shown by creatinine level after surgery was comparable to the preoperative measurements. The pathological diagnosis in each case was renal clear cell carcinoma with a negative margin. There were no complications related to the procedures. All patients survived without recurrence after a mean follow-up period of 38 months. Our results suggest that preoperative planning and intraoperative image navigation in combination with use of a 3D laparoscopic system is feasible and useful for laparoscopic PN.

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Introduction

A laparoscopic partial nephrotomy (PN) is a challenging surgical procedure, because of the need to resect the tumor within a limited warm ischemic time, followed by hemostasis and renorrhaphy. To successfully achieve that, a thorough understanding of the renovascular tumor anatomy is helpful. A three-dimensional (3D) image reconstruction technique is useful for selective devascularization of the tumor and preservation of normal perfusion of the remaining kidney as much as possible. Recently, a zero-ischemia partial nephrectomy method was reported that employs the aid of new devices for vascular coagulation of the renal parenchyma [1]. Alternatively, zero-ischemia partial nephrectomy for a hilar mass in combination with preoperative planning and intra-operative 3D image navigation was reported, in which the incision line of the renal mass was determined preoperatively on the basis of reconstructed 3D images [2]. On the other hand, with recent technological developments, 3D laparoscopes are now used in clinical settings. The aim of the present study was to show the feasibility and usefulness of 3D image navigation and 3D endoscopic viewing for laparoscopic PN procedures.

Materials and Methods

Between September 2009 and June 2015, 6 patients with cT1 renal tumors underwent 3D laparoscopic PN procedures at our hospital. Following a complete description of the various surgical procedures, including the laparoscopic method that utilizes a dome-shaped screen system for stereo viewing, informed consent was obtained from all patients. This study received approval from the ethics committee of our hospital.

Using a retroperitoneal approach, the patient was positioned in a lateral decubitus position on a surgical table, which was inclined dorsally to 30˚ for a transperitoneal approach. A 3D rigid endoscope with 0- and 30-degree fields of vision was used (Shinko Optical Co., Ltd., Tokyo, Japan), with the dome-shaped display system and a 3D liquid crystal display (Panasonic Healthcare Co. Ltd., Tokyo, Japan) placed side by side for surgeons and nurses to see a stereoview of the operative

Figure 1: The dome-shaped screen was placed in a central position, which provided a sense of immersion for the surgical team in a wide observation area. A liquid crystal 3D display and a conventional 2D monitor were arranged closely to each side to present stereoscopic and navigation images, respectively.

field (Figure 1).

Prior to the operation, all patients were examined with a multi-row detector computed tomography (CT) device, and 3D images of the kidney including the arterial and venous anatomy were reconstructed. Preoperative conferences attended by the surgeons and radiological technicians were held, during which the portions of the vessels to be clamped and the marginal line of the renal tumor to be cut were determined. Determination of the incision line began by establishing 4 points; the uppermost, lowermost, innermost, and outermost points of the tumor on the renal surface when located on the anterior or posterior surface of the kidney. In cases with a tumor on the lateral border of the kidney, the innermost 2 points on the anterior and posterior surface of the kidney, as well as the uppermost and lowermost points were determined. Those 4 points were relocated in respective directions to secure a safety margin to avoid incising the tumor with reference to multi-planer reconstructed images obtained in various directions. The distances between the final 4 points determined on the incision line and 4 points highlighting the tumor contour on the renal surface were measured and recorded on multi-planer reconstruction images (Figure 2). These 4 preoperatively recorded distances were measured during the actual operation with a measuring tape, while the 4 points on the cutting line were marked using an electrocautery device. Accordingly, there was no need to use

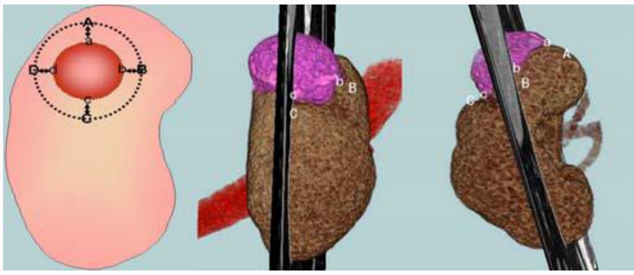

Figure 2: First, the tumor border on the renal surface was outlined. Next, 4 points; the uppermost (a), innermost (b), lowermost (c) and outermost (d), were determined on that line. Those 4 points were relocated in each direction to secure a safe margin while referring to reconstructed multi-planar images in various directions. Finally, the 4 points (A, B, C, D) were determined, and the distances for a-A, b-B, c-C, and d-D were measured and recorded on reconstructed multi-planar images. The ideal curved incision line including points A, B, C, and D are shown on the dotted line in the figure image.

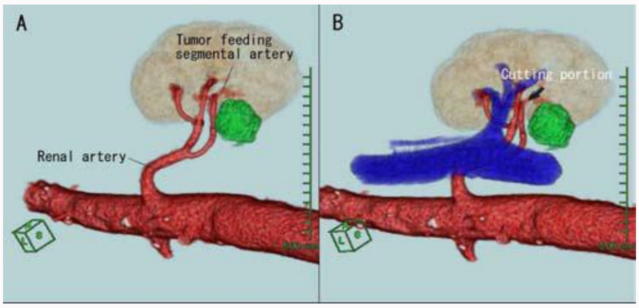

Figure 3: Case 1. (A) Depicted are a right-side 2-cm medial hilar mass on the central upper midpole and the associated arterial anatomy. The mass was fed from a branch of the upper pole segmental artery. (B) Shown is the renal vein anatomy overlaid on the image shown in (A), with the site for cutting the tumor feeding artery shown by an arrowhead.

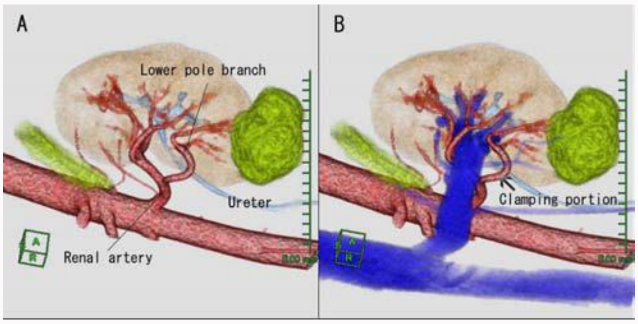

Figure 4: Case 2. (A) A left-side 4-cm renal mass on the central lower pole, along with the urinary tract and arterial anatomy are demonstrated. (B) The renal vein anatomy is overlaid onto the image shown in (A) and the clamping portion of the lower pole branch of renal artery is shown by an arrow.

intraoperative ultrasound in these cases.

The operations were essentially performed by 2 different surgeons. A novice urologist who had experience with 5 laparoscopic nephrectomy cases as an operating surgeon prior to installation of the 3D system performed all of the steps, except for the partial nephrectomy of the renal tumor. An expert urologist with experience with 120 laparoscopic nephrectomy cases performed the cutting line marking, renal artery clamping, tumor resection, caliceal suturing, and renorrhaphy procedures.

Specific details about preoperative planning for Cases 1 and 2 are described following. Case 1 was a 61-year-old male with a right-side 2-cm medial hilar mass on the central upper midpole. Our plan was to super-selectively cut the segmental artery feeding the tumor (Figure 3), followed by zero-ischemia PN. The Case 2 patient was a 40-year-old man male with a left-side 4-cm renal mass on the central lower pole. We planned to clamp the lower pole branch of the left renal artery (Figure 4).

For all cases, a sub-monitor was placed next to the dome-shaped display and reconstructed 3D images were presented as needed for navigation by the surgeon (Figure 1). Tumor resection was commenced with cold scissors immediately after arterial occlusion with a bulldog clamp. In Cases 1 and 2, resection was performed with the scissors and an I/O electrical rod connected to a monopolar SOFT COAG system (VIO 300D; ERBE Elektromedizin GmbH, Tübingen, Germany), with settings of 80 W and Effect 7. A SURGICEL (Ethicon) bolster was placed on the resection bed and renorrhaphy was performed with an interrupted 1-0 polyglycolic suture (VICRYL).

Table 1: Demographics, and perioperative and renal function data for the present 6 patients.

Case no.	1	2	3	4	5	6
Age (years)	61	40	53	71	62	63
Gender (M/F)	M	M	M	F	M	F
BMI (kg/m^2)	22	25	24	24	23	23
Tumor size (mm)	21	38	28	24	20	18
RENAL score	5	6	7	5	6	7
Approach (intra/retro)	I	I	R	I	I	I
Pure/HALS	HALS	Pure	Pure	Pure	HALS	HALS
OR time (min)	486	405	403	424	311	626
Clamping portion of artery		Seg	Main	Seg	Main	Seg
WIT (min)	0	35	36	26	33	41
Tumor resection (min)	2	8	7	5	3	3
Caliceal suturing (min)	0	0	11	0	0	11
Hemostasis (min)	8	10	9	8	12	13
Renorrhaphy (min)	13	17	12	13	18	14
Blood loss (ml)	200	100	110	50	215	100
Pathology	RCC	RCC	RCC	RCC	RCC	RCC
Margin	Neg	Neg	Neg	Neg	Neg	Neg
Normal parenchyma length at base of specimen (mm)	3	2	3	3	3	1
Pre/postoperative Cr	1.6/1.5	1.0/1.0	0.8/0.8	0.6/0.6	0.7/0.7	0.7/0.8
Complications	none	none	none	none	none	None

Abbreviations: M: Male; F: Female; BMI: Body Mass Index; Pure: Pure Laparoscopic Surgery; HALS: Hand-Assisted Laparoscopic Surgery; OR: Operating Room; Seg: Segmental Renal Artery; Main: Main Renal Artery; WIT: Warm Ischemic Time; Cr: Creatine

For all cases except 1 (Case 6), knotless renorrhaphy using a sliding-clip technique was performed by securing the suture with Hem-o-lok clips slid under tension against the renal capsule [3].

RENAL nephrometry scoring [4] was used to grade the complexity of the kidney tumor and define its hilar location. The Clavien Classification of Surgical Complications was used for surgically related complications [5]. Detailed demographic data for the present patients were compared with those previously published.

Results and Discussion

Laparoscopic PN using a combination of reconstructed 3D images for preoperative planning followed by intraoperative navigation and 3D endoscopy was successfully completed without conversion to laparoscopic nephrectomy or open surgery in all cases. Detailed patient demographic data are listed in Table 1. The mean RENAL score was 6, operative and warm ischemic times were 442 and 28.5 minutes, respectively, and blood loss was 129 ml. Main and segmental renal artery clamping was applied in 2 and 3 cases, respectively. The positive surgical margin rate was 0%.

No intraoperative complications occurred and there was no significant renal functional deterioration noted after surgery. Surgical pathology findings revealed a clear cell renal cell carcinoma with a negative margin in all cases. In terms of cancer control, no recurrence has been seen and 100% disease-free survival was obtained at a mean 38 (10-79) months after surgery.

The main difficulty associated with a PN procedure under ischemia is that accurate resection and suturing must be performed within a limited time period. An accurate incision can be achieved by excising the renal cortex adjacent to the tumor while holding the long axis of surgical scissors at an appropriate angle in order to avoid cutting into the tumor tissue. In our experience, 3D laparoscopy enables excision of a renal mass surrounded by normal renal parenchyma tissue of appropriate thickness. In addition, elucidation of the 3D configuration of the renal mass using reconstructed 3D images was very helpful. Moreover, shortening the warm ischemia time and avoiding renal parenchyma volume loss with a PN procedure are also important for conserving renal function.

Preoperative planning to establish marginal line cutting based on reconstructed high resolution 3D images is very useful and considered to minimize damage to normal renal parenchyma tissue adjacent to the tumor. Knowledge of the precise renal vascular anatomy enabled us to selectively clamp the segmental artery feeding the tumor and maintain perfusion of the normal parenchyma. When ultrasound findings are used to determine the incision line, the slice thickness of the ultrasound probe can have an effect to make a wider cutting line due to the effect of slice thickness and principle limitation of the device for lateral resolution. In general, the axial resolution obtained by ultrasonography is superior to that by CT and a spatial resolution of 0.2 mm is possible with use of a 7.5 MHz probe. On the other hand, lateral resolution is a problem encountered with ultrasonography and its principal determinant is the width of the ultrasound beam, namely, the thickness of the ultrasound probe. Thus, lateral resolution is inferior to axial resolution. Moreover, slice thickness, which is equivalent to the width of the beam, has what can be described as a superimposition effect and is one of the causes of the characteristic fuzzy edges seen in images of spherical structures. Since most body surfaces are curved, ultrasound imaging superimposes echoes from those surfaces, resulting in less well-defined margins for the structures. Determination of the margin cutting line without need for intraoperative ultrasonography is worthy of special mention as a virtue of preoperative planning.

A warm ischemic time of up to 25–30 minutes is the primary goal of a minimally invasive nephron-sparing surgical procedure [6,7]. The mean ischemia time in the present patients (34 minutes, excluding zero-ischemia Case 1) during laparoscopic PN seemed to be longer than previously reported, likely because our institute is a small volume hospital in regard to laparoscopic PN and the early learning curve is difficult. Nonetheless, we obtained positive results in regard to renal function and cancer control, though segmental renal artery clamping might contribute to full recovery of renal function in cases with an ischemic time greater than 30 minutes. In 2011, Gill et al. [2] described zero-ischemia PN, after which Ukimura et al. [8] reported the usefulness of 3D reconstruction of renovascular anatomy images to facilitate that procedure. In the present case 1, zero-ischemia partial nephrectomy was successful with the aid of reconstructed 3D renovascular images. Recently, off-clamp partial nephrectomy has come to be accepted for comparatively smaller renal tumors, aided by the development of coagulation devices [1].

Recently, positive results of 3D visualization have been reported, though a definitive conclusion regarding the efficacy of 3D endoscopy in laparoscopic surgery remains to be elucidated. Velayutham et al. [9] noted that 3D visualization might reduce operating time as compared with conventional two-dimensional imaging for laparoscopic liver resection. Furthermore, Tang et al. [10] suggested the clinical

Table 2: Oncological and prognostic outcomes of laparoscopic partial nephrectomy.

Author	Porpiglia	Gill	Permpongkosol	Bollens	Present series
No. of patients	34	430	85	39	6
Mean tumor size (mm)	3.2	3.6	2.4	3.2	2.5
Cancer-specific survival (%)	100	100	91.4	100	100
Positive surgical margin (%)	2.9	0.0	2.4	2.6	0.0
Local recurrence (%)	0.0	0.0	2.4	0.0	0.0
Mean follow-up (mo.)	16	30	40	15	38

effectiveness of a 3D imaging system for a laparoscopic cystectomy procedure with pelvic lymph node dissection. Inoue et al. [11] also found that use of a 3D endoscope improved depth perception and task performance in neuroendoscopic surgery. Indeed, 1 of our patients with normal renal parenchyma tissue that measured only 4 mm between the tumor base and renal sinus underwent a successful operation without cutting into the renal mass or renal sinus because of the depth perception provided by 3D laparoscopy. Ruan et al. [12] concluded that their 3D laparoscopic PN group of patients who underwent selective segmental artery clamping had superior results as compared to the conventional endoscopic PN control group in terms of suturing time, warm ischemic time, and postoperative ipsilateral renal function. In addition, Wang et al. [13] found that preoperative planning along with intraoperative image navigation with a 3D laparoscopic system resulted in shorter operation time and less blood loss. We compared the oncological and prognostic outcomes of the laparoscopic partial nephrectomy procedures in the present series with previously published findings, and noted that our results were favorable [14-17] (Table 2). However, to achieve a shorter warm ischemic time, an early unclamping method and use of a surgical robot system should be considered in the future [18,19].

Conclusion

Use of a 3D endoscope in combination with navigation with reconstructed 3D renovascular images is considered to be feasible and useful for an effective laparoscopic PN procedure.

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