Laparoscopic ultrasonography: The wave of the future in renal cell carcinoma?

Bitian Liu, Yunhong Zhan, Xiaonan Chen, Qingpeng Xie[1], Bin Wu
Department of Urology, Shengjing Hospital of China Medical University, [1]Department of Urology, Cancer Hospital of China Medial University, Liaoning Cancer Hospital, Shenyang, Liaoning Province, China

ABSTRACT

Laparoscopic or robotic surgery is the main method of treating renal cell carcinoma (RCC). Laparoscopic surgery can accurately target lesions and shorten patient recovery time. Renal endogenous tumors or inferior vena cava tumor thrombi are very difficult to remove using the laparoscopic approach. The emergence of laparoscopic ultrasonography (LUS) has solved this problem. LUS can assist in the detection of tumor boundaries and the extent of tumor thrombi. The lack of tactile feedback may hinder the development of laparoscopic surgery for the treatment of renal cancer. LUS has become an important tool that has improved the rates of successful surgery. LUS is applied in not only early and locally advanced RCC treatment but also in monitoring ablation therapy, testing renal blood perfusion, and exposing renal pedicles. Sonographic techniques used for LUS include initial B-mode, Doppler, and contrast-enhanced ultrasound (CEUS). Contrast agents applied for CEUS do not induce nephrotoxicity and can display renal perfusion more accurately than the regular color Doppler ultrasound. According to current literature, LUS is a promising technique for the treatment of RCC, especially for endogenous RCC or RCC with thrombosis, and for monitoring the effectiveness of radiofrequency ablation, although further well-designed studies are warranted.

Key words: Contrast-enhancement ultrasound, cryoablation, laparoscopic ultrasonography, partial nephrectomy, radiofrequency, renal cell carcinoma, tumor thrombectomy

INTRODUCTION

With technical advancement in urology, laparoscopic-assisted (LA) or robotic-assisted (RA) surgery, which is the basis for precise treatment with less surgical trauma, can replace most traditional surgeries. LA or RA urological surgery mainly focuses on tumor operations. In the laparoscopic treatment of malignant tumors in urology, prostate and urothelial carcinoma operations require organ resection to be performed radically. For the laparoscopic treatment of renal cell carcinoma (RCC), radical and partial resections are both reasonable treatment options. In the case of RCC with venous thrombosis or endogenetic RCC, it is difficult to locate and resect radically by laparoscopy or even open surgery. Moreover, the difficulty of the operation cannot be ameliorated by personal skill and experience.

Laparoscopic ultrasonography (LUS) is a multimodal medical technique and allows visualization of tissues

Access this article online

Quick Response Code:

Website: www.eusjournal.com

DOI: 10.4103/eus.eus_27_18

How to cite this article: Liu B, Zhan Y, Chen X, Xie Q, Wu B. Laparoscopic ultrasonography: The wave of the future in renal cell carcinoma? Endosc Ultrasound 2018;7:161-7.

Address for correspondence
Dr. Bin Wu, Shengjing Hospital of China Medical University, Shenyang 110011, Liaoning Province, China. E-mail: wubin8888@aliyun.com
Received: 2018-04-25; **Accepted:** 2018-06-07; **Published online:** 2018-06-25

beyond the two-dimensional laparoscopic image, enhancing the amount and quality of information available to the surgeon.[1] In general surgery, LUS is mainly used in hepatobiliary and pancreatic diseases such as cholelithiasis in the common bile duct,[2-4] hepatic carcinoma, and insulinoma exploration;[5,6] in gynecology, LUS reduces the residual and recurrence rates of hysteromyoma[7] and helps explore the lymph nodes around cervical cancer.[8] In urological surgery, LUS is mostly used in renal diseases such as renal cysts, endogenous renal tumors, RCC with thrombolysis, real-time monitoring of RCC radiofrequency ablation (RFA), and cryoablation therapy.[9-12] The greatest drawback of traditional laparoscopic surgery is the lack of tactile feedback compared with open surgery, but LUS can compensate for this weakness through precise positioning and imaging of the target tissue.

To preserve more kidney units, partial nephrectomy (PN) has been widely used in RCC operations. Laparoscopic PN has also become available for endogenous RCC but is accompanied by risk factors such as postoperative bleeding and urine leakage. Furthermore, because the length of tumor thrombi cannot be haptically detected, the laparoscopic resection of RCC with a venous thrombus involves a greater risk than open surgery.[13] The results of the preoperative imaging examination cannot facilitate the intraoperative location of a completely endogenous tumor.[14] In contrast, LUS can provide tissue ultrasonic images, which deliver the location, size, and range information of endogenous lesions and thrombi to overcome the shortcomings of traditional laparoscopy.

INTRAOPERATIVE ULTRASONOGRAPHY IN THE EARLY APPLICATION OF RENAL CELL CARCINOMA

The development of intraoperative ultrasonography (IUS) was a necessary precondition for the emergence of LUS. IUS has been used as a real-time imaging technique in radical nephrectomy for a long time. In 1988, Gilbert *et al*. reported two cases in which IUS was used to localize tumors not palpable at operation.[15] In 1991, Assimos *et al*. found that IUS could identify the location and range of deep intraparenchymal lesions. IUS also provides a guide for more accurate tumorectomy, which improves the attainment of negative resection margins during PN.[16] In 1995, Polascik *et al*. evaluated 100 kidneys using a triple-head sector ultrasonic transducer and identified that IUS is a useful adjunct for the dynamic evaluation of renal tumors in the surrounding environment of renal cysts, the renal vasculature, and the collecting system.[17] However, Trombetta *et al*. reported in 1996 that the IUS detection rate of multifocal renal tumors was not superior to that of computed tomography (CT).[18] Between 1991 and 2000, Choyke *et al*. performed 68 partial nephrectomies in 53 patients with hereditary RCC. Their results showed that IUS could be performed after all visible lesions had been removed and identified additional tumors in a quarter of patients with hereditary renal cancer; thus ensuring that as many tumors as possible had been removed during renal parenchymal-sparing surgery.[19]

Although IUS has been playing an important role in surgery of renal tumors over the past 30 years, most of the previous studies lacked high-level evidence to prove that it is preferable to employ IUS-assisted rather than non-IUS-assisted open surgery for the removal of renal masses. However, it is undeniable that IUS may be useful in the identification and location of endogenetic and multifocal genetic lesions.

LAPAROSCOPIC ULTRASONOGRAPHY AND RENAL CELL CARCINOMA

LUS is superior to conventional ultrasound (US) in characterizing tumor boundaries. Wang *et al*. compared LUS with preoperative conventional US for RCC boundary location with a sample of 28 cases. Compared with conventional US, LUS could more clearly show the tumor interior structure and blood supply, as well as the relationship with the surrounding tissue. It could also provide doctor assistance with real-time tumor resection, reducing operative complications.[20]

Exposure of the renal pedicle

The anatomical location of the renal pedicle is imperative during operation. When kidneys are bleeding profusely, it is necessary to immediately determine whether the renal arteries are blocked or not. LUS can locate the pedicle quickly and conserve time on renal-vessel dissection. A prospective study evaluated the objective benefits of laparoscopic Doppler US during robotic-assisted laparoscopic PN. Fifty-three consecutive patients underwent laparoscopic PN (LUS: non-LUS = 27:26). The result showed that the total length of renal artery dissection time in the LUS group was significantly shorter than that in the non-LUS group (7.2 min *vs*. 11.0 min); however, there was no difference in estimated blood loss. The evidence supported the use of LUS during minimally invasive PN.[21]

Change in surgical strategy

LUS changed surgical strategy. Kidneys that may have been resected (for example, in case of endogenous or central RCC) in the past could be successfully preserved with the help of LUS.[14,22] However, in the case of locally advanced RCC confirmed by postoperative pathology, when LUS encounters neoplasms invading renal sinus fat during operation, the planned PN for renal resection should be replaced by radical nephrectomy. LUS could deliver additional findings compared with preoperative examination with CT or magnetic resonance imaging (MRI) and may alter surgical management.[23] The discovery of LUS changed 26% of the vascular control strategies.[21] The number of accessory vessels (AVs) used to be recorded based on surgeon review of the preoperative imaging. Any patient with more than a single renal artery or vein was considered to have AVs. Increased detection of AVs compared with the preoperative imaging led to surgical strategy change in operative management based on discovery of AVs and change in arterial clamp management.[21] LUS examination can avoid excessive bleeding caused by incomplete blocking. Moreover, it provides accurate evidence for selective renal artery clamping.[24-26]

Locating renal cell carcinoma

Partial nephrectomy

Laparoscopic PN and robotic PN (RPN) has become focal topics in academic study. PN is widely accepted in the treatment of RCC, and the indication is gradually expanding, since the principle is to preserve as many renal units as it is feasible.[27-29] Renal artery blockage in PN can reduce intraoperative bleeding. However, warm ischemia may cause ischemia-reperfusion injury. To preserve the renal perfusion function, urologists are concerned with how to reduce the blockage time of renal arteries. Specific blockage of the renal arteries in the tumor area without blocking the renal pedicle is the most common method used to reduce the impact of the operation on renal function.[30-34] During PN, LUS can locate the tumors accurately, display the internal structure of the tumors clearly, and is indispensable for the observation of renal perfusion [Figures 1 and 2]. Alenezi *et al*. described a novel technique of real-time "*in situ* mapping" and "sequential selective occlusion angiography" for selective ischemia RPN using laparoscopic, contrast-enhanced US (CEUS).[24]

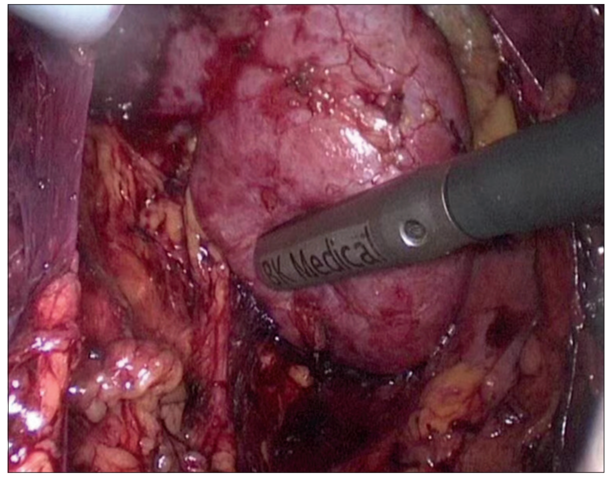

Figure 1. Laparoscopic ultrasonagraphy is locating the tumor

Kutikov *et al*. developed a standardized nephrometry scoring system (RENAL Nephrometry Score) to quantify the anatomical characteristics of renal masses on CT and MRI.[35] The weight of the score mainly reflects the size of the tumor, the distance of the tumor from the renal sinus, the exogenous ratio, and the relationship between the tumor and the renal pole position. According to the nephrometry score, tumors were categorized into those with low (4–6), moderate (7–9), and high (10–12) score, respectively.[36] Since the RENAL score can predict the complexity of PN before operation, it plays an auxiliary role in selecting surgical protocols, *i.e*., either open or laparoscopic surgery and either radical or PN. Endogenous renal tumors have always had radical nephrectomy in the past because it is difficult to locate the tumor for PN [Figure 3]. Dong *et al*. performed laparoscopic PN with LUS on 19 cases of centrally located renal tumors, the RENAL Nephrometry Score was 6–10, with an average of 7.79, including 4 low-risk, 12 intermediate-risk, and 3 high-risk cases.[14] Sun *et al*. reported relevant evidence of using IUS in a retrospective study. The study, which was based on the imaging examination of 44 cases, showed that the urologist's practice pattern, tumor size, and "percentage exophytic" were most predictive of surgical recommendation.[37]

Ablative therapies

Ablative therapies mainly include cryoablation and RFA, both methods can be employed in percutaneous or laparoscopic treatment of renal neoplasms.[25,38-40]

However, ablative therapies cannot be the first choice of treatment for RCC. These methods are only applicable to small RCCs when the patients are elderly and/or have complications such as cardiopulmonary dysfunction. In addition, LUS can be used to monitor the treatment of cryoablation and RFA.[26,41,42] However, as cryoablation under the laparoscope is safe and effective, the use of LUS is not essential.[12,41] A study showed that there were no differences in the incomplete ablation rate and local tumor control rate between a CEUS group (87.5%) and a control group (100%) (P = 0.073). Although there were no significant differences between the two groups, laparoscopic CEUS has the potential to aid complete ablation and more studies are needed to support the value of CEUS during laparoscopic RFA surgery.[11,42]

Locally advanced renal cell carcinoma

Surgery remains the standard of care for patients with localized RCC. However, compared to patients with low-stage, low-grade disease, patients with locally advanced RCC, including venous involvement, extracapsular extension, and involvement of adjacent lymph nodes or organs, demonstrate a high risk for both recurrence and progression of disease with decreased survival despite surgical therapy. Regardless, aggressive surgical resection, when feasible, remains the best treatment option for locally advanced RCC. A pure laparoscopic approach to inferior vena cava (IVC) thrombectomy may be technically challenging because precise vascular control is needed to prevent catastrophic outcomes. Although the operation for IVC tumor thrombus (IVTT) is quite complicated, radical nephrectomy and tumor thrombus removal are recommended because patients are able to achieve long-term survival.[43]

Thrombectomy

Preoperative enhanced CT or MRI can evaluate the clinical stage of tumor thrombi and assist in the initial determination of tumor thrombus length and thrombus transmural conditions.[44,45] The Mayo Clinic classified 349 vein tumor thrombi of RCC into five levels based on surgical treatment, complications, and prognosis [Table 1].[46]

One important technical caveat of thrombectomy is the necessity to identify the thrombus extent before stapling the renal vein.[47] If visual inspection is insufficient, IUS can identify the thrombus to ensure its complete removal. A flexible LUS probe should be readily available.[13]

Tumor thrombi confined to the renal vein generally do not require LUS. After renal artery division, the proximal renal vein was found to be flat because of a lack of blood flow, which allowed easy visual identification of the proximal extent of the tumor thrombus.[48] When needed, IUS was used to identify the extent of the renal vein thrombus. The renal vein and vena cava were dissected to allow a 1–2 cm margin distal to the thrombus. An endovascular stapler was used to staple the renal artery, and then the stapler was guided to the uninvolved portion of the renal vein using LUS.[13]

Table 1. Mayo clinic classification of tumor thrombus level in renal cell carcinoma

Level	Anatomic landmark
0	Thrombus limited to the renal vein
I	Thrombus extending ≤2 cm above the renal vein
II	Thrombus extending ≥2 cm above the renal vein, but below the hepatic veins
III	Thrombus at the level of or above the hepatic veins but below the diaphragm
IV	Thrombus extending above the diaphragm

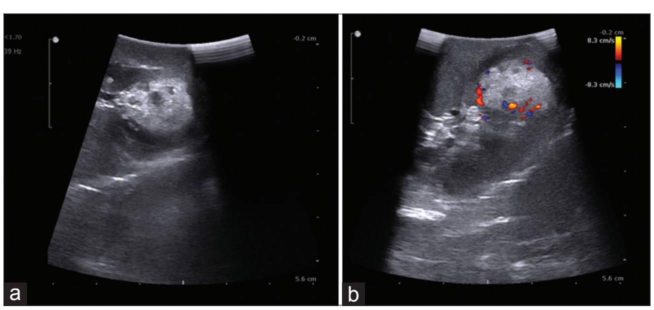

Figure 2. Real-time images of intraoperative laparoscopic ultrasonography in laparoscopic partial nephrectomy. (a) B-mode imaging. (b) Color Dopplor imaging

Figure 3. Endogenous kidney neoplasm imaging in computed tomography arterial phase

Renal tumors with thrombi extending into the IVC require more extensive vascular reconstruction, making the laparoscopic approach more challenging. When the thrombus extends into the IVC and cannot be milked back, vascular staplers are ineffective; thus, vascular clamps are necessary to control the IVC distally and proximally. Demarcation of the thrombus with LUS is useful in delineating the extent of necessary IVC dissection during the initial laparoscopic part of the procedure.[47]

Other urologic applications in renal cell carcinoma

LUS PN has been in use for >10 years, since it was initially introduced for locating renal tumor boundaries.[26] In a study, the laparoscopic probe was placed into the endobag, and a sequential ultrasonographic scan was performed to evaluate if the tumor's pseudocapsule was resected. The mean US examination duration was 42 ± 9 s, which increased the warm ischemia injury time.[49] Preplacement of bolster sutures before vascular clamping using the suture needles as a guide for resection is a feasible method of performing laparoscopic PN and may reduce warm ischemia time and blood loss.[50] Moreover, it can significantly improve the outcome of robotic-assisted, nephron-sparing surgery by increasing precision and diagnostic insight for urologists. Further refinement and investigation of this technique may be necessary to optimize results in human patients and is currently underway.

LAPAROSCOPIC ULTRASOUND

Contrast-enhanced ultrasound

CEUS is an advanced technique that utilizes US contrast agents to improve lesion visualization in difficult cases.[51] Microbubbles vibrate under the pressure changes induced by the probe transmitter. This oscillation produces energy that is detected by the transducer and converted into an image.[52] The microbubble contrast agent in CEUS technology has increased the image quality and signal uptake of the US probe. As an effective diagnostic modality, this method leads to better, enhanced scanning of the macro and microvasculature of the kidneys. However, the higher US transmission power may result in microbubble destruction.[53] The contrast enhancement mode uses a lower frequency than noncontrast imaging to avoid damaging the microbubbles and to minimize transmitted signals from the tissue to obtain a series of contrast-specific images in real time.[54]

US has evolved from initial B mode imaging to color, energy, and pulse Doppler. Renal US can assess disseminated tissue disorders, focal lesions, and renal perfusion.[54] Conventional LUS techniques are used for tumor location and perfusion detection in RCC. Recently, laparoscopic CEUS has become the focus of RCC diagnosis, especially in the field of PN.[24,52,55] In practice, power Doppler may only be more useful over the renal hilum where the vessels are much larger and minor movement artifacts relatively less important. CEUS is not affected by movement artifacts caused by the US probe and may, therefore, be a better technique than the power Doppler.[55]

CEUS provides superior imaging compared to other US methods. As the malignant tumor is rich in blood supply, this feature improves the quality of the CEUS detection signal compared to other ultrasonographic methods such as power Doppler. The combination of selective occlusion angiography and CEUS provides a more effective assessment of renal ischemia and of the perfusion area.[32]

The contrast microbubble agent used in the CEUS procedure is nonallergenic and does not interfere with renal function, as it is not excreted by the kidneys;[24] thus, it can also be used by patients with impaired renal function. In the case of reduced renal perfusion, ischemia, and diabetic nephropathy, under-intake is safely overcome by multiple injections.[56] However, CEUS is limited by the fact that the contrast agents used in CEUS imaging are contraindicated in patients with underlying cardiopulmonary disorders, since the lungs and liver excrete the microbubbles.[57]

Robotic-assisted laparoscopic ultrasonography versus laparoscopic-assisted laparoscopic ultrasonography

Although adequate mobilization of the kidney can allow a LUS probe to achieve sufficient identification of tumors in challenging locations during RPN, this requires more dissection by the surgeon and less autonomy over probe control. LUS probes for intraoperative scanning have limitations and may reduce surgical precision, as the assistant holds and manipulates the LUS probe. The LUS probe is also prone to slipping off the kidney surface and requires the assistance of a robotic instrument for repositioning the probe or to prevent it from slipping off the kidney.[58]

Examples of challenging angles for LUS include the far edges of the tumor, in which the probe and/or the kidney should be turned to place the probe flat on the kidney surface parallel to the tumor edge. It can be especially challenging with tumors in a posterolateral or upper pole location. Challenging angles for US include the near and far edges of the tumor, in which the angulation of the LUS probe may make it difficult to place the probe flat on the kidney surface parallel to the tumor edge without extra mobilization of the kidney. The robotic US probe angle can be adjusted with the robotic instrument.[59] A robotic US probe affords the surgeon full autonomy in the surgical field, as the fin is placed just over the transducer array and is controlled by the surgeon. The robotic US probe also eliminates the issue of instrument clashing in the operating field.[58]

CONCLUSION

The use of LUS in RCC is indispensable, either for localized RCC or for locally advanced RCC with IVTT. It is particularly helpful for endogenous and completely endogenous renal masses. LUS reduces the difficulty of thrombus removal in locally advanced RCC operations and may be a promising modality in the future for use in nonuniform surgical regimens for removing thrombi.

LUS is the focus of PN for RCC. Especially in fully endogenous and endogenous RCCs, LUS improves tumor identification and precise resection and the mapping of renal blood vessels. With LUS, the association between the tumor and the structure of the renal sinus can be determined so that the temporary change from PN to radical resection may bring greater benefits to the patient. The laparoscopic approach in the treatment of RCC with IVTT is challenging and technically demanding. LUS decreases the difficulty of thrombectomy such as in the cases of Level I and Level II thrombi. LUS can also deliver real-time monitoring for complete blockage in nephron-preserving renal surgery. Superselective blockage of the renal artery for PN is currently at the forefront of research. LUS can identify the blocked kidney segments to determine whether the blocking position and the blocking effect are satisfactory. However, long-term study is still needed to expound and prove that LUS brings benefits to patients requiring superselective clamping.

The application of LUS technology is closely associated with the development of US. Nowadays, Doppler US and CEUS are currently available for LUS. Therefore, it is expected that with the further development of US imaging quality, LUS will play a crucial role in urology.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Matin SF, Gill IS. Laparoscopic ultrasonography. *J Endourol* 2001;15:87-92.
2. Aziz O, Ashrafian H, Jones C, *et al.* Laparoscopic ultrasonography versus intra-operative cholangiogram for the detection of common bile duct stones during laparoscopic cholecystectomy: A meta-analysis of diagnostic accuracy. *Int J Surg* 2014;12:712-9.
3. Jamal KN, Smith H, Ratnasingham K, *et al.* Meta-analysis of the diagnostic accuracy of laparoscopic ultrasonography and intraoperative cholangiography in detection of common bile duct stones. *Ann R Coll Surg Engl* 2016;98:244-9.
4. Dili A, Bertrand C. Laparoscopic ultrasonography as an alternative to intraoperative cholangiography during laparoscopic cholecystectomy. *World J Gastroenterol* 2017;23:5438-50.
5. Zhu LH, Cai XJ, Liang X, *et al.* Laparoscopic ultrasonography in laparoscopic hepatectomy: Experience with 22 cases. *Zhonghua Yi Xue Za Zhi* 2008;88:1059-61.
6. Wu M, Wang H, Zhang X, *et al.* Efficacy of laparoscopic ultrasonography in laparoscopic resection of insulinoma. *Endosc Ultrasound* 2017;6:149-55.
7. Li SJ, Li XF, Zhang J, *et al*. Clinical value of assisted laparoscopic ultrasonography in laparoscopic myomectomy. *Zhonghua Yi Xue Za Zhi* 2016;96:2652-4.
8. Cheung TH, Lo KW, Yim SF, *et al*. Clinical use of laparoscopic ultrasonography in detecting nodal metastasis in advanced-stage cervical carcinoma. *Int J Gynaecol Obstet* 2011;112:154-8.
9. Hekman MC, Rijpkema M, Langenhuijsen JF, *et al.* Intraoperative imaging techniques to support complete tumor resection in partial nephrectomy. *Eur Urol Focus* 2017. pii: S2405-4569(17)30114-1.
10. Wang M, Ping H, Niu Y, *et al*. Pure conventional laparoscopic radical nephrectomy with level II vena cava tumor thrombectomy. *Int Braz J Urol* 2014;40:266-73.
11. Yang R, Lian H, Zhang G, *et al.* Laparoscopic radiofrequency ablation with intraoperative contrast-enhanced ultrasonography for T1bN0M0 renal tumors: Initial functional and oncologic outcomes. *J Endourol* 2014;28:4-9.
12. Badger WJ, de Araujo HA, Kuehn DM, *et al*. Laparoscopic renal tumor cryoablation: Appropriate application of real-time ultrasonographic monitoring. *J Endourol* 2009;23:427-30.
13. Steinnerd LE, Vardi IY, Bhayani SB. Laparoscopic radical nephrectomy for renal carcinoma with known level I renal vein tumor thrombus. *Urology* 2007;69:662-5.
14. Dong D, Ji Z, Li H, *et al*. Laparoscopic nephron sparing surgery assisted with laparoscopic ultrasonography on centrally located renal tumor – Single center experience. *Urol Int* 2016;97:195-9.
15. Gilbert BR, Russo P, Zirinsky K, *et al.* Intraoperative sonography: Application in renal cell carcinoma. *J Urol* 1988;139:582-4.
16. Assimos DG, Boyce H, Woodruff RD, *et al.* Intraoperative renal ultrasonography: A useful adjunct to partial nephrectomy. *J Urol* 1991;146:1218-20.
17. Polascik TJ, Meng MV, Epstein JI, *et al*. Intraoperative sonography for the evaluation and management of renal tumors: Experience with 100 patients. *J Urol* 1995;154:1676-80.
18. Trombetta C, Lissiani A, Moro U, *et al*. Infrequent application of intraoperative ultrasonography in urology. *Arch Ital Urol Androl* 1996;68:31-6.

19. Choyke PL, Pavlovich CP, Daryanani KD, *et al.* Intraoperative ultrasound during renal parenchymal sparing surgery for hereditary renal cancers: A 10-year experience. *J Urol* 2001;165:397-400.
20. Wang XZ, Yu ZX, Guo RJ, *et al*. Application of laparospic ultrasonography in surgery of small renal cell carcinoma. *Asian Pac J Cancer Prev* 2014;15:9113-6.
21. Hyams ES, Perlmutter M, Stifelman MD. A prospective evaluation of the utility of laparoscopic doppler technology during minimally invasive partial nephrectomy. *Urology* 2011;77:617-20.
22. Kang N, Niu Y, Zhang J, *et al.* Intraoperative ultrasonography: A useful tool in retrolaparoscopic nephron-sparing surgery. *Urol Int* 2012;88:338-42.
23. Bhosale PR, Wei W, Ernst RD, *et al*. Intraoperative sonography during open partial nephrectomy for renal cell cancer: Does it alter surgical management? *AJR Am J Roentgenol* 2014;203:822-7.
24. Alenezi A, Motiwala A, Eves S, *et al.* Robotic assisted laparoscopic partial nephrectomy using contrast-enhanced ultrasound scan to map renal blood flow. Int J Med Robot 2017;13:e1738.
25. Trudeau V, Larcher A, Boehm K, *et al.* Comparison of postoperative complications and mortality between laparoscopic and percutaneous local tumor ablation for T1a renal cell carcinoma: A population-based study. *Urology* 2016;89:63-7.
26. Fazio LM, Downey D, Nguan CY, *et al.* Intraoperative laparoscopic renal ultrasonography: Use in advanced laparoscopic renal surgery. *Urology* 2006;68:723-7.
27. Volpe A, Blute ML, Ficarra V, *et al.* Renal ischemia and function after partial nephrectomy: A collaborative review of the literature. *Eur Urol* 2015;68:61-74.
28. Thompson RH. To clamp or not to clamp during partial nephrectomy. *Eur Urol* 2015;68:641-2.
29. Potretzke AM, Bhayani SB. Laparoscopic partial nephrectomy: Rest in peace. *Eur Urol* 2015;67:902-3.
30. Funahashi Y, Hattori R, Yamamoto T, *et al.* Ischemic renal damage after nephron-sparing surgery in patients with normal contralateral kidney. *Eur Urol* 2009;55:209-15.
31. Thompson RH, Lane BR, Lohse CM, *et al.* Every minute counts when the renal hilum is clamped during partial nephrectomy. *Eur Urol* 2010;58:340-5.
32. Springer C, Veneziano D, Wimpissinger F, *et al.* Clampless laparoendoscopic single-site partial nephrectomy for renal cancer with low PADUA score: Technique and surgical outcomes. *BJU Int* 2013;111:1091-8.
33. Boyarsky L, Stein A, Konstantinovsky A, *et al.* Retrospective analysis of laparoscopic partial nephrectomies using the zero ischemia technique. *Urol Int* 2017;99:257-61.
34. Dagenais J, Maurice MJ, Mouracade P, *et al.* The synergistic influence of ischemic time and surgical precision on acute kidney injury after robotic partial nephrectomy. *Urology* 2017;107:132-7.
35. Kutikov A, Uzzo RG. The R.E.N.A.L. Nephrometry score: A comprehensive standardized system for quantitating renal tumor size, location and depth. *J Urol* 2009;182:844-53.
36. Dagenais J, Maurice MJ, Mouracade P, *et al.* Excisional precision matters: Understanding the influence of excisional volume loss on renal function after partial nephrectomy. *Eur Urol* 2017;72:168-70.
37. Sun MR, Wagner AA, San Francisco IF, *et al.* Need for intraoperative ultrasound and surgical recommendation for partial nephrectomy: Correlation with tumor imaging features and urologist practice patterns. *Ultrasound Q* 2012;28:21-7.
38. Young EE, Castle SM, Gorbatiy V, *et al*. Comparison of safety, renal function outcomes and efficacy of laparoscopic and percutaneous radio frequency ablation of renal masses. *J Urol* 2012;187:1177-82.
39. Sisul DM, Liss MA, Palazzi KL, *et al.* RENAL nephrometry score is associated with complications after renal cryoablation: A multicenter analysis. *Urology* 2013;81:775-80.
40. Kim EH, Tanagho YS, Saad NE, *et al*. Comparison of laparoscopic and percutaneous cryoablation for treatment of renal masses. *Urology* 2014;83:1081-7.
41. Wright AD, Turk TM, Nagar MS, *et al*. Endophytic lesions: A predictor of failure in laparoscopic renal cryoablation. *J Endourol* 2007;21:1493-6.
42. Chen Y, Huang J, Xia L, *et al.* Monitoring laparoscopic radiofrequency renal lesions in real time using contrast-enhanced ultrasonography: An open-label, randomized, comparative pilot trial. *J Endourol* 2013;27:697-704.
43. Skinner DG, Pritchett TR, Lieskovsky G, *et al*. Vena caval involvement by renal cell carcinoma. Surgical resection provides meaningful long-term survival. *Ann Surg* 1989;210:387-92.
44. Sokhi HK, Mok WY, Patel U. Stage T3a renal cell carcinoma: Staging accuracy of CT for sinus fat, perinephric fat or renal vein invasion. *Br J Radiol* 2015;88:20140504.
45. Mueller-Lisse UG, Mueller-Lisse UL. Imaging of advanced renal cell carcinoma. *World J Urol* 2010;28:253-61.
46. Blute ML, Leibovich BC, Lohse CM, *et al*. The mayo clinic experience with surgical management, complications and outcome for patients with renal cell carcinoma and venous tumour thrombus. *BJU Int* 2004;94:33-41.
47. Varkarakis IM, Bhayani SB, Allaf ME, *et al.* Laparoscopic-assisted nephrectomy with inferior vena cava tumor thrombectomy: Preliminary results. *Urology* 2004;64:925-9.
48. Savage SJ, Gill IS. Laparoscopic radical nephrectomy for renal cell carcinoma in a patient with level I renal vein tumor thrombus. *J Urol* 2000;163:1243-4.
49. Doerfler A, Oitchayomi A, Tillou X. A simple method for ensuring resection margins during laparoscopic partial nephrectomy: The intracorporeal ultrasonography. *Urology* 2014;84:1240-2.
50. Abaza R, Picard J. A novel technique for laparoscopic or robotic partial nephrectomy: Feasibility study. *J Endourol* 2008;22:1715-9.
51. O'Neal D, Cohen T, Peterson C, *et al*. Contrast-enhanced ultrasound-guided radiofrequency ablation of renal tumors. *J Kidney Cancer VHL* 2018;5:7-14.
52. Alenezi AN, Karim O. Role of intra-operative contrast-enhanced ultrasound (CEUS) in robotic-assisted nephron-sparing surgery. *J Robot Surg* 2015;9:1-0.
53. Morel DR, Schwieger I, Hohn L, *et al.* Human pharmacokinetics and safety evaluation of SonoVue, a new contrast agent for ultrasound imaging. *Invest Radiol* 2000;35:80-5.
54. Correas JM, Anglicheau D, Joly D, *et al.* Ultrasound-based imaging methods of the kidney-recent developments. *Kidney Int* 2016;90:1199-210.
55. Rao AR, Gray R, Mayer E, *et al.* Occlusion angiography using intraoperative contrast-enhanced ultrasound scan (CEUS): A novel technique demonstrating segmental renal blood supply to assist zero-ischaemia robot-assisted partial nephrectomy. *Eur Urol* 2013;63:913-9.
56. Robbin ML, Eisenfeld AJ. Perflenapent emulsion: A US contrast agent for diagnostic radiology – Multicenter, double-blind comparison with a placebo. EchoGen contrast ultrasound study group. *Radiology* 1998;207:717-22.
57. Clark MA, Shikanov S, Raman JD, *et al.* Chronic kidney disease before and after partial nephrectomy. *J Urol* 2011;185:43-8.
58. Kaczmarek BF, Sukumar S, Petros F, *et al.* Robotic ultrasound probe for tumor identification in robotic partial nephrectomy: Initial series and outcomes. *Int J Urol* 2013;20:172-6.
59. Kaczmarek BF, Sukumar S, Kumar RK, *et al.* Comparison of robotic and laparoscopic ultrasound probes for robotic partial nephrectomy. *J Endourol* 2013;27:1137-40.