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Original Article

Robotic ultrasound probe for tumor identification in robotic partial nephrectomy: Initial series and outcomes

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Abbreviations & Acronyms
ASA = American Society of Anesthesiologist's physical status classification system
eGFR = estimated glomerular filtration rate
LPN = laparoscopic partial nephrectomy
RCC = renal cell carcinoma
RPN = robotic partial nephrectomy

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Objectives: Accurate tumor identification during partial nephrectomy is essential for successful tumor control. Intraoperative laparoscopic ultrasonography is useful for tumor localization, but the ultrasound probe is controlled by the assistant rather than the surgeon. We evaluated our initial experience using a robotic ultrasound probe that is controlled by the console surgeon.
Methods: Partial nephrectomy was carried out in 22 consecutive patients between November 2010 and March 2011. A robotic ultrasound probe under console surgeon control was used in all the cases. All patients had at least 1 year follow up.
Results: Mean patient age was 59 years and mean tumor size was 2.7 cm. There were six hilar tumors (27%) and 21 (95%) endophytic tumors. Mean R.E.N.A.L. nephrometry score was 6.9 (range 6–9). Mean operative time was 205.7 min and mean warm ischemia time was 17.9 min (range 6–28 min). All patients had negative tumor margins and were free of disease recurrence at a mean follow up of 13 months.
Conclusion: The use of a robotic ultrasound probe during partial nephrectomy allows the surgeon to optimize tumor identification with maximal autonomy, and to benefit from the precision and articulation of the robotic instrument during this key step of the partial nephrectomy procedure.

Key words: kidney cancer, nephron sparing, robotic partial nephrectomy, robotic ultrasound probe, tumor identification.

Introduction

Intraoperative ultrasonography is often used during partial nephrectomy to improve tumor localization and to facilitate complete tumor resection.[1–4] RPN offers technical advantages with a shorter learning curve[5] and decreased warm ischemia time[6] compared with LPN. A laparoscopic ultrasound probe can be used for minimally-invasive partial nephrectomy.[7,8] During RPN, the assistant rather than the surgeon controls the laparoscopic ultrasound probe, which might limit surgeon autonomy and precision.[8,9] We evaluate our experience with a robotic ultrasound probe that is controlled by the surgeon during RPN, and we present our initial series and perioperative outcomes.

Methods

Our RPN technique and subsequent modifications have been previously described in detail.[10,11] We used a medial camera port placement, transperitoneal approach, a three arm-technique, hilar clamping for tumor excision under warm ischemia, and renal reconstruction using the sliding clip renorrhaphy technique.[12] All RPN procedures using the robotic ultrasound probe were carried out by an experienced robotic kidney surgeon (CR) and a single experienced robotic assistant on 22 consecutive patients between November 2010 and March 2011. All patients had at least 1 year of follow up.

The variables evaluated in the study included tumor size (maximum radiographic diameter), hilar tumors (abutting renal hilar vessels), endophytic tumors (≥50% endophytic

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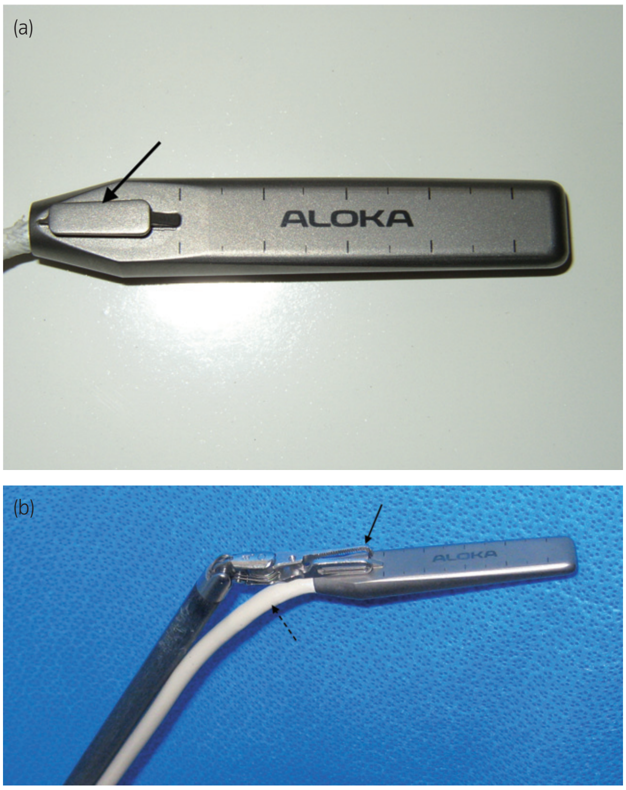

Fig. 1 (a) Robotic ultrasound probe used for tumor identification during RPN. The robotic ultrasound probe has a grooved ridge on its ventral aspect (solid black arrow) that fits the robotic grasping instrument. (b) Robotic ultrasound probe with notch attached to robotic instrument (solid black arrow). The probe has a flexible cable (dashed black arrow) that allows passage through the assistant port and allows for full articulation of the robotic instrument.

Table 1 Characteristics and outcomes of 22 patients undergoing RPN with a robotic ultrasound probe

Mean age (years)	58.5 (32–75)
Sex-male, *n* (%)	9 (41)
Mean follow up (months)	13 (12–16.1)
ASA	2.9 (2–3)
Right-sided, *n* (%)	10 (45.5)
Mean tumor size (cm)	2.7 (1–5.9)
Hilar tumors, *n* (%)	6 (27.3)
Endophytic ≥50%, n (%)	21 (95.5)
Mean R.E.N.A.L. nephrometry score	6.9 (6–9)
Mean operative time (min)	205.7 (123–273)
Mean warm ischemia time (min)	17.9 (6–28)
Postoperative complications	1
Positive surgical margin, n (%)	0
Mean preoperative eGFR	78 (45–119.1)
Mean postoperative eGFR	69.8 (39.3–119.1)
Mean % Change in eGFR	10 (37 to −17)
Histology, *n* (%)	
Clear cell RCC	15 (68.2)
Papillary RCC	4 (18.1)
Chromophobe RCC	1 (4.6)
Benign tumor	2 (9.1)

component). The R.E.N.A.L. nephrometry scores were assessed by a single doctor based on preoperative imaging studies. Postoperative complications were measured with the Clavien classification system (eGFR was calculated using the Modification of Diet in Renal Disease formula).

Intraoperative ultrasonography was used to define tumor location and extent before hilar clamping and tumor excision. After the Gerota's fascia was opened and the renal capsule in the region of the tumor was exposed, the ultrasound probe was introduced through the assistant port. Ultrasound images were shown as a picture-on-picture image on the console screen using the TilePro feature[9] of the da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA, USA). The junction between the tumor and normal renal parenchyma was identified and the renal capsule was scored with cautery to mark the margins of resection, making allowances to include a rim of normal parenchyma. The hilum was then clamped and tumor excision was carried out along the scored margin.

The robotic ultrasound probe (Hitachi-Aloka, Tokyo, Japan) is shown in Figure 1. A grooved ridge on the ventral aspect of the robotic probe fits the robotic grasping instrument or fenestrated bipolar instrument and a thin flexible cable allows for easy maneuverability, without the rigid shaft of a laparoscopic ultrasound probe. The robotic ultrasound probe is passed into the operative field by the assistant and the surgeon engages the notch with the robotic instrument, allowing the surgeon to control the probe with full articulation of the robotic instrument. The probe has a linear array with a 33-mm width and a frequency range of 4–13 MHz.

Results

The robotic ultrasound probe was used during RPN in 22 consecutive patients. Preoperative and perioperative variables for patients undergoing RPN are shown in Table 1. The mean patient age was 58.5 years and the mean tumor size was 2.7 cm. Two patients had multiple tumors, one patient had four tumors and the other had two tumors. Three patients had tumors >4 cm. Tumors were endophytic in 21 patients (96%) and hilar in six patients (27%). Mean R.E.N.A.L. nephrometry score was 6.86 (range 6–9). Mean warm ischemia time was 17.9 min (6–28 min). All patients had negative surgical margins and there was no evidence of cancer recurrence with a minimum of 1 year of follow up (mean 13 months, range 11.6–16.1). There were no intraoperative complications and one postoperative complication of

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an abdominal wall hematoma at the trocar site that resolved spontaneously after transfusion (Clavien II classification).

Discussion

Intraoperative ultrasonography is useful during partial nephrectomy for tumor identification to facilitate complete tumor removal.[1–4] Gilbert *et al.* reported the use of intraoperative ultrasonography to help identify renal cell carcinoma in patients with poorly-visualized and non-palpable disease.[1] Assimos *et al.* reported using intraoperative ultrasonography for tumor identification to achieve negative surgical margins during partial nephrectomy and recommended its use to facilitate precise identification of adequate resection margins.[2] Marshall *et al.* reported their experience with intraoperative ultrasonography in 41 kidney surgeries, and found intraoperative ultrasonography to be most beneficial for the identification of extrarenal venous extension, multifocality and the identification of associated renal cysts.[3] In a subsequent analysis of 100 cases, Marshall *et al.* reported that use of intraoperative ultrasonography influenced the choice of surgical approach in 13% of cases.[4]

Matin and Gill described laparoscopic ultrasonography for laparoscopic kidney surgery.[7] Gill *et al.* described laparoscopic ultrasonography as a routine step for deciding on the line of parenchymal incision during LPN.[13] Fazio *et al.* reviewed outcomes for intraoperative laparoscopic ultrasonography in 50 laparoscopic renal procedures, including 35 LPN procedures.[14] All surgical margins were negative and in nine cases ultrasonography was considered essential for completion.

Rogers *et al.*[9] and Bhayani *et al.*[15] described the use of intraoperative ultrasonography for tumor identification during RPN procedures using TilePro to superimpose the laparoscopic ultrasound image as a picture on picture display on the console screen. Several larger series of RPN[6,16,17] have incorporated laparoscopic ultrasonography for tumor identification. However, a drawback of laparoscopic ultrasonography during RPN is that the assistant rather than the surgeon controls the laparoscopic ultrasound probe, which might limit surgeon autonomy and precision. Additionally, the laparoscopic probe might require adjustment of probe positioning with a robotic instrument to reduce probe slippage from tumor surface (Fig. 2a). The robotic ultrasound probe and its improved usability have been previously described, but only in laboratory conditions.[18] The study showed that the robotic ultrasound probe eliminated the issue of instrument clashing in the operating field.

The present study aimed to assess the feasibility of a robotic ultrasound probe controlled directly by the surgeon in clinical conditions. It is the first to present the clinical experience of a robotic ultrasound probe in RPN. Our patient cohort had relatively difficult tumor characteristics

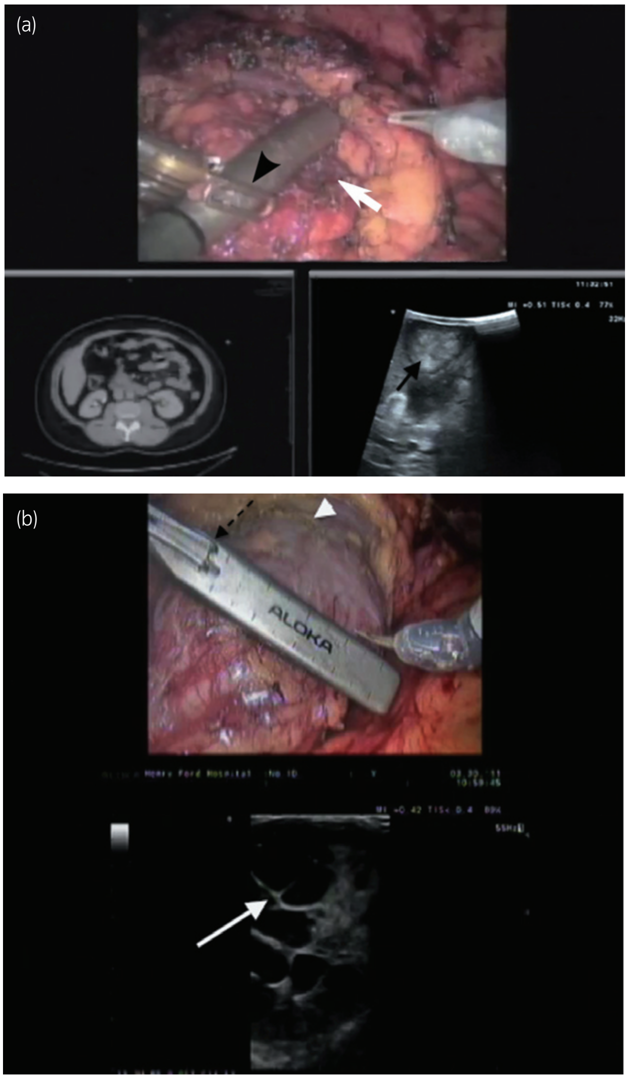

Fig. 2 (a) Laparoscopic ultrasound probe being used for identification of a right renal mass (solid white arrow on upper console image; solid black arrow on lower TilePro ultrasound image). The surgeon is trying to grab the laparoscopic probe with the robotic instrument to adjust the position (black arrowhead). (b) Robotic ultrasound probe being used to identify a right renal cystic renal cell carcinoma (solid white arrow). The robotic instrument is engaged with the notch on the probe (dashed black arrow), allowing the surgeon to independently maneuver the probe to identify tumor margins. The arrowhead notes the scored resection margin of the far side of the tumor.

expressed by a high percentage of endophytic (96%) and hilar tumors (27%), and a mean R.E.N.A.L. nephrometry score of 7.

In our previous experience using a laparoscopic ultrasound probe, we found the near and far tumor border plane to be the most challenging to identify, because when the laparoscopic probe is turned at a right angle, the transducer is not exactly perpendicular to the surface of the kidney

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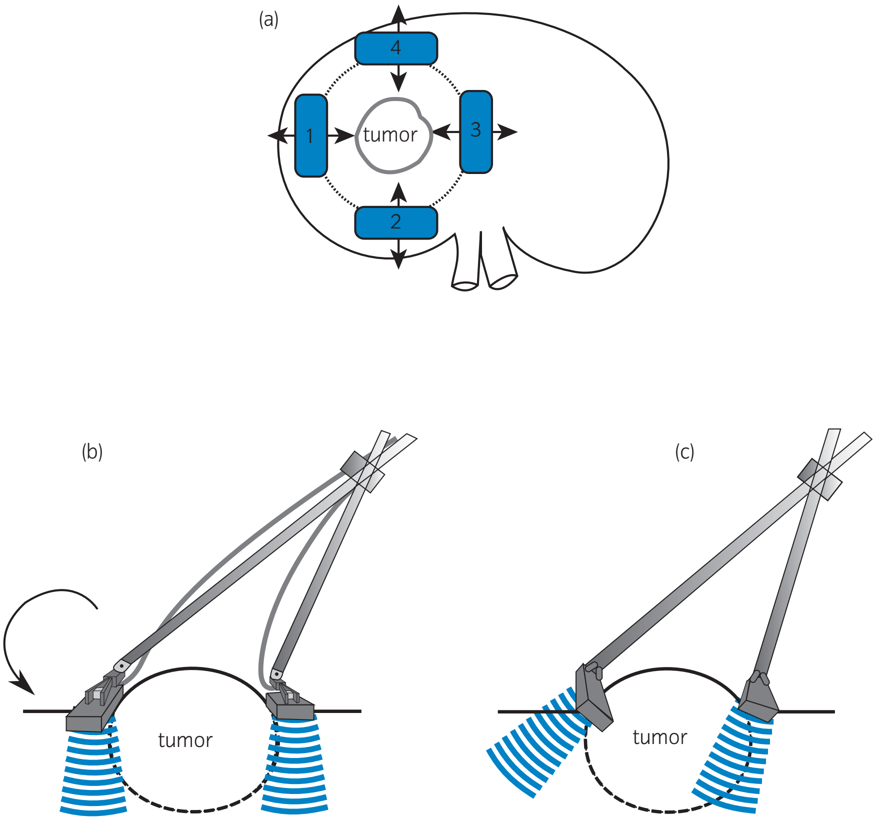

Fig. 3 (a) Tumor margins identification and marking of the margins. The ultrasound probe localizes tumor margins in four planes around the tumor (numbers 1–4). The surface is scored once measurement of each plane is complete. Gaps between the ultrasound measurements are connected (dash line). (b) Robotic ultrasound probe at the near and far border of the tumor (plane #2 and plane #4). The probe can be articulated by the surgeon, maintaining perpendicular contact of the transducer with the kidney surface. (c) Laparoscopic ultrasound probe at the near and far borders of the tumor (plane #2 and plane #4). When the laparoscopic probe is turned at a right angle, it might be difficult to maintain perpendicular contact of the transducer to the kidney surface.

(Fig. 3). The robotic ultrasound probe can be maneuvered independently by the surgeon, achieving difficult angles while maintaining perpendicular contact of the probe with the kidney surface.

The present report was not designed to determine whether a robotic ultrasound probe offers improved outcomes. It might be challenging to prove the clinical importance of the robotic probe beyond the autonomy given the surgeon. All 22 patients achieved negative surgical margins despite a high proportion of endophytic and hilar tumors, and were free of disease recurrence at 1-year follow up. The small sample size and lack of objective methods helpful in determining tumor identification precision are the main limitations of the present study. Further studies in larger cohorts of cases comparing the robotic ultrasound probe to the laparoscopic ultrasound probe are required. It should also be emphasized that having a surgeon-controlled robotic ultrasound probe does not entirely eliminate the need for a skilled assistant, who remains important for other steps, such as exposure during tumor excision and efficient passage of sutures during renal reconstruction.

A robotic ultrasound probe controlled independently by the surgeon is a feasible tool for identifying tumor margins during RPN, even with challenging tumors.

Conflict of interest

None declared.

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