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Three-dimensional laparoscopic partial nephrectomy for hilar versus non-hilar tumors: outcomes from a large contemporary series

Nikolaos Grivas, Filippos Nikitakis, Christos Zabaftis, Athanasios Bouchalakis, Maria Chalkidou, Smaragda Tsela, Sotiria Tsogka, Markos Karavitakis

Second Department of Urology, Lefkos Stavros – The Athens Clinic, Greece

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Corresponding author
Nikolaos Grivas
Second Department of Urology, Lefkos Stavros – The Athens Clinic, Sisini 1-3, Athens 11528, Greece
nikolaosgrivas@hotmail.com

Introduction The management of renal hilar tumors remains a technically demanding aspect of nephron-sparing surgery. Although robotic partial nephrectomy has been widely reported in this setting, evidence from large series of purely laparoscopic procedures performed with three-dimensional vision is still limited.

Material and methods We retrospectively evaluated 342 consecutive patients who underwent 3D laparoscopic partial nephrectomy between July 2022 and July 2025 at a high-volume tertiary center. Tumors were stratified as hilar (n = 55) or non-hilar (n = 287). The primary endpoint was warm ischemia time. Secondary endpoints included operative time, estimated blood loss, perioperative complications, need for postoperative ureteric stenting, renal function preservation, and trifecta achievement.

Results Median operative time was modestly longer in the hilar group (78 min vs 73 min, p = 0.04). Median warm ischemia time was also higher for hilar tumors (24 min vs 16 min, p <0.001) but consistently remained within the accepted threshold (<25 min). Estimated blood loss was comparable (270 ml vs 250 ml, p = 0.39). Overall complication rates were similar, though postoperative stent placement was more frequent in the hilar cohort (28% vs 7%, p <0.001). Median postoperative eGFR decline at 3 months was similar between groups. Trifecta achievement was 67.2% for hilar and 71.1% for non-hilar tumors (p = 0.27).

Conclusions Three-dimensional laparoscopic partial nephrectomy for hilar tumors is associated with slightly longer operative and ischemia times and a higher need for postoperative stenting, but without an increase in major morbidity. In experienced hands, the functional and oncological outcomes were comparable between hilar and non-hilar tumors.

Key Words: hilar tumors ‹› nephron sparing surgery ‹› laparoscopic partial nephrectomy

INTRODUCTION

Partial nephrectomy (PN) is the standard of care for localized renal cell carcinoma, combining oncological control with renal preservation [1]. Even in the challenging setting of elderly and frail patients with renal masses, minimally invasive PN is considered a safe approach and demonstrates favorable oncological and functional results [2]. Tumors located at the renal hilum remain technically challenging because of their proximity to vessels and the collecting system and the lack of adequate parenchymal margin for renorrhaphy, raising concerns about warm ischemia time (WIT) and perioperative morbidity [3]. Apart from increased WIT, other potential intraoperative challenges include

longer operative time, increased intraoperative blood loss, and a higher rate of conversion to radical nephrectomy [4].

Most contemporary data on hilar tumors come from robotic-assisted partial nephrectomy (RAPN) series. Large multicenter cohorts and meta-analyses show that hilar location is associated with longer operative and ischemia times but without compromise in oncological or functional outcomes [5–7]. Evidence for laparoscopic PN (LPN) is more limited. The initial report of LPN for hilar tumors was introduced by Gill et al., indicating that LPN can be effectively performed in selected cases with hilar tumors, provided that the surgeon possesses adequate experience with laparoscopic surgery and especially LPN cases [8]. Subsequent single-center studies have confirmed the feasibility and safety of LPN even in complex hilar cases [9]. The need for surgical experience in the treatment of such complex tumors has been implied by simulation-based studies on laparoscopic partial nephrectomy, in which inexperienced surgeons required twice as much time for hilar control compared with senior surgeons [10]. The hilar location of a renal tumor can further complicate both hilar control and tumor excision, particularly in the absence of surgical expertise.

The advent of three-dimensional (3D) laparoscopy has improved depth perception and suturing accuracy, enhancing outcomes in complex PN. Improved visualization facilitates greater surgical precision and spatial accuracy, crucial parameters for the effective and safe execution of technically demanding PN cases, contributing to optimized surgical outcomes, including shorter WIT [11]. It has been previously demonstrated that 3D vision facilitates shorter WIT and operative times and expands the indications for PN to larger and more complex tumors [12].

Large series specifically addressing 3D LPN for hilar tumors are still scarce. The aim of the present study was to compare perioperative, functional, and oncological outcomes between hilar and non-hilar tumors treated with 3D LPN in a high-volume center.

MATERIAL AND METHODS

Study design and patient population

We retrospectively reviewed the records of all patients who underwent three-dimensional (3D) laparoscopic partial nephrectomy (LPN) at our institution between July 2022 and July 2025. A total of 342 consecutive patients were included. Tumors were stratified into two groups according to anatomical location: hilar (n = 55; 16.1%) and non-hilar (n = 287; 83.9%). Exclusion criteria were solitary kidney, prior renal surgery on the affected side, metastatic disease, or incomplete follow-up data.

The study was conducted with the informed consent of all patients. The study was approved by the local Institutional Ethics Committee and carried out in accordance with the guidelines of the Declaration of Helsinki.

Definition of hilar tumors

Hilar tumors were defined as renal masses abutting or encroaching upon the renal vessels or sinus, based on preoperative contrast-enhanced CT or MRI. Classification was performed independently by two urologists, with discrepancies resolved by consensus.

Surgical technique

All procedures were performed by experienced laparoscopic surgeons using a standardized transperitoneal (five ports) or retroperitoneal (three or four ports) approach. Tumor exposure was facilitated by meticulous dissection of the renal hilum. Vascular control was achieved by selective or main artery clamping according to anatomy. Tumor excision was performed with cold scissors, followed by renorrhaphy using sliding-clip technique. Three-dimensional laparoscopy was employed in all cases.

Endpoints

The primary endpoint was warm ischemia time (WIT). Secondary endpoints included operative time (OT), estimated blood loss (EBL), perioperative complications (Clavien–Dindo classification), need for postoperative ureteric stenting, conversions to open or radical nephrectomy, positive surgical margins (PSM), renal function preservation (assessed by serum creatinine and estimated glomerular filtration rate [eGFR] at baseline and three months postoperatively), and trifecta achievement (defined as WIT <25 min, negative surgical margins, and absence of complications).

Data collection

Demographic, clinical, and perioperative data were prospectively recorded in a departmental database and retrospectively analyzed. Tumor complexity was graded using the RENAL nephrometry score.

Statistical analysis

Normality of data distribution was assessed, and as the data were not normally distributed, non-parametric tests were applied. Continuous variables are presented as medians and interquartile ranges (IQR) and compared using the Mann–Whitney U test. Categorical variables are presented as counts and percentages and compared using the chi-square or Fisher's exact test. A p-value <0.05 was considered statistically significant. Statistical analyses were conducted using SPSS version 22 (IBM Corp., Armonk, NY, USA).

Bioethical standards

The study was approved by the Lefkos Stavros – The Athens Clinic Ethics Committee (approval number: 7/01-04-2025) and carried out in accordance with the guidelines of the Declaration of Helsinki.

RESULTS

Patient and tumor characteristics

A total of 342 patients underwent 3D laparoscopic partial nephrectomy (LPN) during the study period, including 55 hilar tumors (16.1%) and 287 non-hilar tumors (83.9%). Median age was 63 years (IQR 56–69), and 69% of patients were male. Median tumor size was 3.4 cm (IQR 2.6–4.2). The hilar group had significantly higher anatomical complexity, with a median RENAL score of 9 (IQR 8–10) compared to 7 (IQR 6–8) in the non-hilar group (p <0.001). Baseline renal function was similar between groups (median eGFR 86 vs 88 ml/min/1.73 m², p = 0.42). Baseline characteristics of patients are shown in Table 1.

Perioperative outcomes

Median operative time was 78 min (IQR 70–88) for hilar and 73 min (IQR 65–83) for non-hilar tumors (p = 0.04). Median warm ischemia time (WIT) was 24 min (IQR 21–28) in hilar and 16 min (IQR 14–20) in non-hilar tumors (p <0.001). Estimated blood loss was comparable (270 ml [200–350] vs 250 ml [180–330], p = 0.39). Collecting system entry was more common in hilar tumors (12.7% vs 3.1%, p = 0.01). Perioperative outcomes are shown in Table 2.

Complications and conversions

Overall complication rates were similar (12.7% vs 11.5%, p = 0.72), with most events being Clavien–Dindo grade I–II. A postoperative ureteric stent was placed in 28% of hilar and 7% of non-hilar cases (p <0.001). This reflected a proactive strategy by the surgical team: stents were routinely inserted whenever there was any intraoperative concern about the collecting system repair or potential postoperative leakage. No Clavien–Dindo ≥IIIb events occurred. There were no conversions to open surgery. Two patients (0.6%) required conversion to radical nephrectomy, one due to intraoperative venous bleeding and one for oncological safety.

Functional and oncological outcomes

At 3 months, median eGFR decline was −7.2% (IQR −9.5 to −5.8) in the hilar group and −6.1% (IQR −8.2 to −5.0) in the non-hilar group (p = 0.48). No patient had a positive surgical margin. Trifecta was achieved in 67.2% of hilar and 71.1% of non-hilar cases (p = 0.27).

Technical note

In 18 patients (5.3%), renorrhaphy was completed without an inner parenchymal layer, relying exclusively on cortical closure. None of these patients developed postoperative hemorrhage, urinary leakage, or deterioration in renal function (Tables 1 and 2).

Table 1. *Baseline characteristics of patients undergoing three-dimensional laparoscopic partial nephrectomy*

Variable	Hilar (n = 55)	Non-hilar (n = 287)	p-value
Age (years), median (IQR)	64 (57–70)	63 (56–69)	0.58
Male sex, n (%)	37 (67.3)	199 (69.3)	0.78
BMI (kg/m²), median (IQR)	27.4 (25.3–29.6)	26.9 (24.8–29.2)	0.44
Tumor size (cm), median (IQR)	3.6 (2.9–4.4)	3.3 (2.5–4.1)	0.09
RENAL score, median (IQR)	9 (8–10)	7 (6–8)	<0.001
Baseline eGFR (ml/min/1.73 m²), median (IQR)	86 (78–92)	88 (80–94)	0.42

BMI – body mass index; eGFR – estimated glomerular filtration rate; IQR – interquartile range

DISCUSSION

The management of renal hilar tumors continues to represent one of the most challenging scenarios in nephron-sparing surgery. Their proximity to the renal vasculature and collecting system increases the risk of prolonged warm ischemia, collecting system entry, and perioperative complications. In a multivariate analysis by Eyraud et al. [4], the location of renal tumors in the hilum was independently associated with increased WIT. In our series, hilar tumors were indeed associated with longer operative and ischemia times, as well as more frequent collecting system entry, compared with non-hilar lesions. Importantly, these factors did not translate into inferior functional or oncological outcomes, and no patient experienced a positive surgical margin.

Our results are consistent with the largest robotic and laparoscopic series published to date. The NEPRAH multicenter prospective study demonstrated that hilar tumors carry longer WIT and operative times and a higher risk for postoperative complications, but without compromise in trifecta achievement or long-term oncological safety [5]. Meta-analyses by Chen et al. [7] confirmed that hilar and endophytic tumors increase surgical complexity and are associated with longer warm ischemia time, greater blood loss, and higher rates of major complications, though cancer control and renal functional outcomes remain equivalent to non-complex lesions. Within the laparoscopic domain, Sergeev et al. [9] reported similar outcomes between hilar and cortical tumors, underscoring the feasibility of LPN even in anatomically demanding cases [9]. Interestingly, in a retrospective analysis by George et al. [13], laparoscopic partial nephrectomy for hilar tumors performed by experienced surgeons was associated with shorter mean operative and ischemia times compared to non-hilar tumors, although the difference in warm ischemia time between the study groups was not statistically significant. This study also demonstrated comparable perioperative outcomes between the hilar and non-hilar groups, with sustained functional and oncologic outcomes in the hilar tumor group despite the technical complexity of these cases [13].

Renal functional assessment in this study was based on changes in eGFR at three months postoperatively, a time point commonly reported in surgical series. The decline of renal function between the two groups was similar at three months, implying that 3D LPN can be safely used for the management of complex hilar tumors, without compromising kidney function. This is particularly important given that the alternative for such tumors is radical nephrectomy, which has been associated with significant deterioration in renal function.

In a multicenter study by Cerrato et al. [14], radical nephrectomy was associated with an increased risk of *de novo* eGFR<60 ml/min/1.73 m^2 and *de novo* eGFR <45 ml/min/1.73 m^2 postoperatively, whereas partial nephrectomy provided renal function preservation without a significant increase in major complications. Saitta et al. [15] proposed the RENSAFE nomograms to estimate the probability of postoperative acute kidney injury and renal functional decline after partial or radical nephrectomy, which may be helpful in the decision-making process for such complex cases.

Table 2. *Perioperative and postoperative outcomes*

Variable	Hilar (n = 55)	Non-hilar (n = 287)	p-value
Operative time (min), median (IQR)	78 (70–88)	73 (65–83)	0.04
Warm ischemia time (min), median (IQR)	24 (21–28)	16 (14–20)	<0.001
Estimated blood loss (ml), median (IQR)	270 (200–350)	250 (180–330)	0.39
Collecting system entry, n (%)	7 (12.7)	9 (3.1)	0.01
Overall complications, n (%)	7 (12.7)	33 (11.5)	0.72
Clavien–Dindo ≥IIIb, n (%)	0	0	–
Ureteric stent placement, n (%)	15 (28.0)	20 (7.0)	<0.001
Conversion to open, n (%)	0	0	–
Conversion to radical nephrectomy, n (%)	1 (1.8)	1 (0.3)	0.19
Positive surgical margins, n (%)	0	0	–
eGFR decline at 3 months, median (IQR)	−7.2 (−9.5 to −5.8)	−6.1 (−8.2 to −5.0)	0.48
Trifecta achievement, n (%)	37 (67.2)	204 (71.1)	0.27

eGFR – estimated glomerular filtration rate; IQR – interquartile range

Technical considerations

Careful surgical planning and technique are critical when addressing hilar tumors. Intraoperative laparoscopic ultrasound should be employed early in the procedure, particularly for completely endophytic lesions, to accurately define tumor borders, depth of invasion, and proximity to vessels and the collecting system. Tumor enucleation should follow the pseudocapsular plane, but the dissection strategy must be adapted to the vascular density of the hilar region. In many cases, blunt enucleation (i.e. gently mobilizing the lesion away from the parenchyma) is safer than sharp dissection, as it reduces the risk of injuring large segmental vessels. Conversely, sharp dissection is reserved for areas where the capsule is well defined and vessels are clearly identified. Equally important is the meticulous control of small hilar vessels. Liberal use of laparoscopic clips during tumor bed preparation ensures a bloodless field, which is essential in this anatomically crowded region and minimizes the risk of uncontrolled hemorrhage. With the aid of 3D laparoscopy, enhanced depth perception facilitates precise vascular identification and clip application, as well as controlled renorrhaphy in a narrow operative space. These steps, when combined, optimize both safety and efficiency in hilar partial nephrectomy.

In our cohort, postoperative ureteric stenting was performed more frequently in hilar cases (28%), reflecting a low-threshold, prophylactic policy rather than a true complication. This approach likely contributed to the absence of high-grade urinary leaks or fistulas. Additionally, there were no incidents of postoperative leakage in non-stented hilar cases, as the integrity of the collecting system was not in question and stent placement was therefore deemed unnecessary.

The complexity of hilar tumors has also prompted the development of dedicated classification systems. Lin et al. [16] recently proposed a novel categorization of hilar lesions, stratifying them into three subtypes with tailored surgical strategies. This effort underlines the need for more refined preoperative assessment tools beyond conventional nephrometry scores, aiming to standardize surgical planning and facilitate outcome comparisons across institutions. Our results support the concept that hilar tumors are not homogeneous and that refined classifications may be valuable in guiding operative decision-making.

The introduction of three-dimensional laparoscopic systems has revitalized the role of LPN in complex tumor settings. It has been previously demonstrated that 3D laparoscopy shortens ischemia times, reduces operative duration, and extends the indications of LPN to larger and more complex tumors [12]. The present study, the largest contemporary 3D LPN series focusing specifically on hilar tumors, reinforces the importance of this technology in enabling safe and effective management of lesions that were once considered the exclusive domain of robotic surgery.

Nevertheless, robotic partial nephrectomy (RAPN) currently dominates worldwide practice, supported by extensive published experience, ergonomics, and advanced suturing platforms. In previous studies, RAPN has been associated with favorable surgical outcomes for clinical T1 hilar tumors compared to standard LPN and remains the more accessible option for surgeons without specialized laparoscopic expertise [17]. However, a matched analysis by Ellison et al. demonstrated that, even after the learning curve for RAPN has been overcome, the perioperative outcomes and complication rates are comparable to those of laparoscopic partial nephrectomy performed by experienced surgeons [18]. Our findings confirm that in experienced hands, 3D LPN achieves perioperative, functional, and oncological outcomes similar to those of RAPN, offering a cost-effective and technically robust alternative.

Furthermore, the need to expand LPN to more complex PN cases raises important socioeconomic considerations, which constitute a challenge in contemporary global surgical care. While robotic-assisted surgery has established its feasibility and effectiveness in many aspects of urologic surgery, robotic platforms are inherently associated with procurement and operational expenses [19]. As a result, many surgical centers in developing and under-resourced countries worldwide rely solely on laparoscopy for the implementation of minimally invasive surgery, as the acquisition of robotic platforms in those countries is not an option [20]. Expanding the indications for LPN to more challenging cases and achieving optimized surgical outcomes is of great importance in these countries and contributes to the mitigation of disparities in healthcare across the globe.

Beyond confirming the technical feasibility of 3D LPN for hilar tumors, the present study also suggests its adequacy in terms of oncological outcomes and renal function preservation. The absence of positive surgical margins, comparable complication rates between groups without any Clavien–Dindo ≥IIIb events, and warm ischemia times consistently within accepted thresholds support the role of 3D LPN not only as a feasible approach but also as a valuable minimally invasive, nephron-sparing

option for the treatment of hilar tumors in experienced centers. In addition, this study provides practical technical insights regarding careful surgical planning, vascular control, enucleation techniques, and the selective use of prophylactic ureteric stenting, which may help guide the safe and effective execution of LPN in these complex cases.

However, this study is not without limitations. Its retrospective design inherently introduces potential biases that could influence data collection and the interpretation of the analysis. Additionally, although certain surgical outcomes, such as complication rates, were similar between the two groups, a larger sample size may be required to identify subtle differences in these parameters. Moreover, our results reflect the experience of highly skilled surgeons at a high-volume tertiary center, which may limit their generalizability to other institutions or surgeons with less experience. Therefore, the favorable outcomes observed in this study may, in part, be attributable to advanced technical expertise and surgical experience, and may not be directly reproducible in lower-volume centers or during the early phases of the laparoscopic learning curve. Finally, the study's follow-up period of three months may not be sufficient to assess long-term changes in renal function, and long-term follow-up would be valuable for evaluating renal function preservation. Unfortunately, longer follow-up data or alternative renal function metrics, such as postoperative acute kidney injury rates, are not available for all patients included in the study. Future multicenter clinical trials, with extended follow-up and larger sample sizes, are needed to confirm and validate the findings of our study.

CONCLUSIONS

In conclusion, 3D LPN for hilar tumors can be performed safely, with warm ischemia consistently maintained within safe thresholds, absence of positive surgical margins, and comparable short-term renal functional outcomes to non-hilar cases. While robotics has become the mainstream modality, advanced laparoscopy remains a valuable tool in high-volume centers, allowing expert surgeons to deliver outcomes on par with robotic platforms.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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ETHICS APPROVAL STATEMENT

The study was approved by the Lefkos Stavros – The Athens Clinic Ethics Committee (approval number: 7/01-04-2025).

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