Published in final edited form as:

Urology. 2014 August ; 84(2): 327–332. doi:10.1016/j.urology.2014.02.044.

Can selective arterial clamping with fluorescence imaging preserve kidney function during robotic partial nephrectomy?

Tyler R. McClintock, Marc A. Bjurlin, James S. Wysock, Michael S. Borofsky, Tracy P. Marien, Chinonyerem Okoro, and Michael D. Stifelman

Department of Urology, New York University, Langone Medical Center, New York, NY, USA

Abstract

Objectives—To compare renal functional outcomes in robotic partial nephrectomy (RPN) with selective arterial clamping guided by near infrared fluorescence (NIRF) imaging to a matched cohort of patients who underwent RPN without selective arterial clamping and NIRF imaging.

Methods—From April 2011 to December 2012, NIRF imaging-enhanced RPN with selective clamping was utilized in 42 cases. Functional outcomes of successful cases were compared with a cohort of patients, matched by tumor size, preoperative eGFR, functional kidney status, age, sex, body mass index, and American Society of Anesthesiologists score, who underwent RPN without selective clamping and NIRF imaging.

Results—In matched-pair analysis, selective clamping with NIRF was associated with superior kidney function at discharge, as demonstrated by postoperative eGFR (78.2 vs 68.5 ml/min per 1.73m²; $P=0.04$), absolute reduction of eGFR (−2.5 vs −14.0 ml/min per 1.73m²; $P<0.01$) and percent change in eGFR (−1.9% vs −16.8%, $P<0.01$). Similar trends were noted at three month follow up but these differences became non-significant ($P[\text{eGFR}]=0.07$), $P[\text{absolute reduction of eGFR}]=0.10$, and $P[\text{percent change in eGFR}]=0.07$). In the selective clamping group, a total of four perioperative complications occurred in three patients, all of which were Clavien I-III.

Conclusion—Utilization of NIRF imaging was associated with improved short-term renal functional outcomes when compared to RPN without selective arterial clamping and NIRF imaging. With this effect attenuated at later follow-up, randomized prospective studies and long-term assessment of kidney-specific functional outcomes are needed to further assess the benefits of this technology.

Keywords

Carcinoma; renal cell; fluorescence; indocyanine green; kidney; partial nephrectomy; robotic

Reprint requests: Michael D. Stifelman, New York University, Department of Urology, Langone Medical Center, 150 East 32nd Street, 2nd Floor, New York, NY 10016, michael.stifelman@nyumc.org, Tel: 001.646.825.6325.

Financial Disclosure:

Michael D. Stifelman is a lecturer for Intuitive Surgical and a consultant for Vascular Technology Inc.

This abstract was presented at the American Urological Association meeting, San Diego, CA, 2013.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

INTRODUCTION

Partial nephrectomy (PN) has become the standard of care for most small renal tumors,¹ achieving oncologic effectiveness comparable to radical nephrectomy along with reduced incidence of chronic kidney disease,² cardiovascular events, and mortality.^{3,4} Since its initial description in 2004, robotic partial nephrectomy (RPN) has gained acceptance as a PN technique that possesses many of the minimally invasive benefits of a laparoscopic approach, though with a learning curve that is not nearly as steep.⁵ Studies have shown RPN to be suitable for T1a renal masses, as well as for more complex cases, including tumors near the hilum or greater than four centimeters in diameter.^{6,7}

With the functional benefits of RPN largely a byproduct of the functional tissue that remains following tumor resection, focus has turned to enabling the surgeon to excise or damage as little normal renal tissue as possible while still conducting an oncologically complete procedure. This has prompted the development of selective renal ischemia in RPN such that main artery clamping, which damages healthy tissue through global ischemia and reperfusion injury,⁸ is no longer necessary.⁹ A novel method of intraoperative functional imaging, near infrared fluorescence (NIRF), may further enhance segmental arterial clamping techniques by aiding in identification of renal vasculature and assessment of associated renal perfusion and ischemia.

NIRF imaging involves intravenous administration of a fluorescent contrast agent, which emits light in the near infrared wavelength after activation by a light emitting diode. Light in this wavelength (700–850nm) is not visible to the naked eye and must be captured by a specialized charge-coupled device (CCD) camera to be visualized. Utilizing the most widely studied fluorescent tracer to date, indocyanine green (ICG) (Akorn, Lake Forest, IL), NIRF imaging can be integrated into the da Vinci Si Surgical System (Intuitive Surgical, Sunnyvale, CA) and allows the surgeon to toggle between standard white light and fluorescence-enhanced views in real time within the preexisting console display. We have previously described our technique of NIRF-enhanced selective clamping in RPN, and reported initial outcomes as part of a multi-institutional study.^{10,11} Here, we present a matched-pair analysis of associated postoperative renal function at both discharge and three-month follow-up in 42 patients at our own institution, compared with a cohort who underwent RPN with conventional main artery clamping during a similar time period.

MATERIALS AND METHODS

Our prospectively maintained, institutional review board-approved database was queried to identify consecutive patients who underwent RPN with selective clamping guided by NIRF imaging between April 2011 and December 2012. Patients with more than two renal tumors removed in a single session were excluded from the analysis. Four patients during the study period were not eligible to receive ICG due to a known contraindication, which includes a previous reaction to ICG, iodine allergy, uremia or liver disease. All procedures were conducted by one expert robotic surgeon (MS). Informed consent was obtained prior to surgery, and comprehensive demographic, intraoperative, and outcomes-related data were prospectively entered into the aforementioned database.

Each NIRF-enhanced selective clamping case was retrospectively matched with a control patient who had undergone RPN with conventional main artery clamping technique by the same single surgeon at the same institution. These controls were sourced from the same prospectively maintained database, though from the three-year period immediately preceding the integration of selective clamping with NIRF into our partial nephrectomy technique (2008–2011). Our approach during this period has been described elsewhere.¹² A representative description of functional outcomes in our institution's pre-NIRF partial nephrectomies has been published as a part of a multi-institutional control group for a recent pilot study.¹¹ Matched cases were nonconsecutive as each was individually paired on the basis of most similar radiologic tumor size, baseline eGFR, and RENAL nephrometry score, as well as age, sex, body mass index (BMI), and American Society of Anesthesiologists (ASA) score. The experimental and control groups were also characterized in terms of diabetes mellitus and hypertension prevalence, as well as by number of patients using angiotensin-converting-enzyme (ACE) inhibitors or angiotensin receptor blockers (ARBs) at time of surgery. Outcome parameters included operative time, estimated blood loss (EBL), warm ischemia time (WIT), length of hospital stay, and pathological features, along with pre- and post-operative laboratory values. We defined WIT as the selective arterial clamp time required for each renal tumor excision. Postoperative complications were classified according to the Clavien system.¹³ Renal functional outcomes were estimated using the Modification of Diet in Renal Disease (MDRD) equation at discharge.¹⁴ Demographic and outcomes-related data were compared using Student's t-test and chi square analyses where appropriate. All statistical analyses were conducted using SPSS 20.0®, and statistical significance was determined by a two-tailed $\alpha=0.05$.

A description of the surgical technique utilized in this study has recently been published.¹¹ Briefly, standard preoperative cross-sectional imaging is conducted for each patient using either computed tomography or magnetic resonance imaging to characterize tumor location, size, endophytic nature, and proximity to the collecting system, and a RENAL nephrometry score is calculated. Intraoperatively, careful dissection of the renal arterial branches is performed. A flexible drop-in robotic Doppler probe (Vascular Technology Inc., Nashua, NH, USA) is utilized to identify the arterial branches. Hilar microdissection is performed in a medial-to-lateral direction to identify the specific arterial branch or branches supplying the tumor and its local target area. (Figure 1). Robotic mini-bulldog clamps (Scanlan International, St. Paul, MN, USA) are applied to the secondary, tertiary, or quaternary level arterial branches at the discretion of the console surgeon using the robotic ProGrasp in order to induce local ischemia in the tumor and immediate surrounding renal segment. ICG is then administered at a dose of 5–7.5 mg intravenously (Akorn, Lake Forest, IL). Perfused renal parenchyma appears fluorescent green under NIRF imaging, while ischemic tissue and tumor do not fluoresce under NIRF imaging. Hence, the surgeon is provided with real-time verification that the correct arterial branch has been controlled.

If peritumoral arterial flow continues despite selective arterial clamping, additional arterial branches may be sought and selectively clamped. In the event this also fails to adequately devascularize the tumor and surrounding tissue, main artery clamping can then be implemented. When the tumor and peritumoral parenchyma is demonstrated to be ischemic, the tumor is resected along the previously scored margin using cold scissors. Excision and

reconstruction have previously been described.^{6,10,11} After mini bulldogs are removed and hemostasis confirmed, an additional bolus of ICG is administered to confirm global reperfusion of the kidney.

RESULTS

The 42 cases of selective clamp RPN with NIRF were appropriately matched for analysis, as shown by no statistically significant differences between baseline characteristics of the selective clamping and main artery clamping cohorts (Table 1). Diabetes mellitus and hypertension prevalence did not vary significantly between groups, nor did use of ACE inhibitors or ARBs at time of surgery. Similarly, no intergroup differences in operative time, warm ischemia time, estimated blood loss, or length of stay were observed (Table 2). Compared to main artery clamping, selective clamping with NIRF was associated with superior kidney function, as manifested through postoperative eGFR (78.2 vs 68.5 ml/min per 1.73m²; P=0.04), absolute reduction of eGFR (−2.5 vs −14.0 ml/min per 1.73m²; P<0.01), and percent change in eGFR (−1.9% vs −16.8%, P<0.01) at discharge (Table 3). While these trends persisted at three-month follow-up, the differences did not reach conventional statistical significance: eGFR (76.7 vs 66.7 ml/min per 1.73m²; P=0.07), absolute reduction of eGFR (−4.7 vs −12.9 ml/min per 1.73m²; P=0.10), and percent change in eGFR (−3.1% vs −14.6%, P=0.07).

Final histology reviewed by urologic pathologists confirmed organ confined disease in all patients within the selective clamp cohort, with a mean tumor size of 2.67 cm (Table 4). Overall, 66.7% of tumors were malignant, with renal cell carcinoma, clear cell subtype, being the most common (53.6% of malignant tumors). Among the malignant tumors, the pathologic stage distribution was pT1a (89.3%), pT1b (7.1%), or pT3a (3.6%). Negative surgical margins were obtained for all cases. Four short-term perioperative complications (0–30 d) occurred in three different patients (7.1%), with each being Clavien grade I–III, including transfusion (2), ileus requiring nasogastric decompression (1), and urine leak requiring stent (1). This was comparable to the rate observed in the main artery cohort, as complications occurred in two patients and included multilobar pneumonia treated with antibiotics (Clavien II) as well as bleeding managed by angioembolization (Clavien IIIa). No patient sustained a vascular injury during the dissection of the accessory branches of the renal artery.

COMMENT

NIRF imaging is an adjunct technology with the potential to improve outcomes in RPN by facilitating both delineation of benign from malignant tissue and identification of the intra-renal vasculature to aid in selective clamping. With recent studies having focused primarily on how NIRF imaging may aid in differentiation of tumor borders, only two analyses has thus far investigated the latter application of NIRF imaging.^{10,11} To our knowledge, the present description of 42 cases represents the largest single-institution experience with NIRF imaging to facilitate selective arterial clamping in RPN. We have demonstrated significant short-term preservation of renal function, with NIRF-enhanced selective clamp cases displaying superior postoperative eGFR and significantly minimized loss in eGFR when

compared to standard RPN with main artery clamping. Similar trends were noted at 3-month follow-up, however, the differences did not reach statistical significance, similar to a recent study.¹⁵ The decrease in eGFR observed in our main artery clamping cohort (−12.9 ml/min) is comparable to what has previously been reported in the literature for similar populations. A comparison of outcomes in robotic and laparoscopic patients by Aron et al. showed loss of eGFR equal to −13 ml/min in both groups at three months after surgery.¹⁶ Likewise, a single surgeon matched cohort study by Haber et al. found a decrease in eGFR of −9.3% in a robotic partial nephrectomy cohort whose postoperative outcomes were compared to a laparoscopic cohort at three months.¹⁷

Preexisting renal function, volume of preserved parenchyma, and warm ischemia time have been suggested as primary determinants of postoperative renal function after partial nephrectomy. Given that the control cohort here was matched on the basis of RENAL score, tumor size, and renal function, we believe effectively targeted ischemia was the driving factor of improved postoperative renal function in the cohort presented in this study. We specifically evaluated eGFR rather than creatinine as creatinine is heavily based on hydration status, oral and protein intake, and can depend on time of day drawn. Among the evidence supporting this notion is a recent multivariate analysis by Choi et al. of 37 partial nephrectomies showing that preoperative GFR ($p=0.027$), WIT ($p=0.015$), and resected normal tissue volume ($p=0.046$) each had a significant influence on three-month GFR, while WIT was, in fact, the only independent predictor of a reduction in ipsilateral GFR at one-year postoperatively.¹⁸ Additional studies and reviews have further underscored the importance of ischemia in PN,^{8,19–21} and, despite a variety of WIT time thresholds having been reported in literature, the Society of Urologic Oncology went as far as to state that truly every minute affects functional outcome and no threshold can be deemed a “safe” ischemia time.²² Hence, given that preoperative renal function is a nonmodifiable variable and extent of kidney preservation reaches a maximal value in minimal-margin PN, it stands to reason that optimizing ischemia may yield the largest marginal gain in postoperative renal function relative to conventional PN. To this end, selective clamping has emerged as a technique that negates the need for global ischemia. This approach, in theory, allows the surgeon to anatomically target ischemia by clamping only those subsegmental arterial branches that supply the tumor and its immediate margin, maintaining perfusion in the remaining healthy parenchyma. Effective arterial clamping is understandably reliant on a comprehensive understanding of a patient’s unique vascular anatomy; initial studies have demonstrated selective hilar microdissection and clamping under the guidance of intraoperative visualization alone as well as with the addition of preoperative or intraoperative imaging.^{9,11,23}

Real-time, enhanced intraoperative imaging has clear advantages in facilitating effective vascular dissection and confirming selective ischemia in selective-clamping RPN. Even with magnified high-definition capabilities of the robotic console display, standard anatomical landmarks remain the only guidance. Preoperative imaging cannot account for organ shift or interval changes in anatomy since image acquisition, and neither of these techniques can provide confirmation of ischemia in associated vascular distributions. Even intraoperative color Doppler ultrasound has its own drawbacks, as its use is heavily skill- and operator-dependent. Similarly, demarking area of blanching during selective clamping with NIRF

imaging is challenging for hilar tumors. NIRF imaging with ICG may overcome the innate limitations in each of these methods. ICG is a water-soluble tricarbo-cyanine dye that is injected intravenously and can be visualized throughout the vascular system in less than one minute.²⁴ Prior to its introduction in urologic surgery, NIRF imaging has been safely employed in ophthalmic angiography, organ transplantation, determination of cardiac output as well as hepatic function, and sentinel lymph node identification in breast and colon cancer.^{25–28}

Applied to RPN, ICG has thus far been utilized almost solely for differentiation of tumor margins, as it may display differential fluorescence in normal parenchyma versus tumors, cysts, and fat necrosis. Though studies detailing this application of NIRF imaging have been conflicting²⁹ and do not speak to its utility in selective clamping, they lend support to the general feasibility and reproducibility of this imaging modality. Distinguished from these prior studies, we have evaluated NIRF imaging specifically for aiding selective arterial clamping. It has been suggested that this use may enhance the reproducibility of selective clamping during RPN and impact postoperative functional outcomes through decreasing ischemia in normal tissue. NIRF imaging allows the surgeon to simultaneously confirm devascularization of a segment of kidney and continued perfusion of unclamped segments. If ischemia cannot be confirmed despite selective arterial clamping, additional branches can be sought and selectively clamped, after which ICG can be readministered to confirm ischemia. In large tumors, we often selectively clamp several higher order arterial branches, administer ICG, and sequentially release the micro bulldogs. This technique allows us to determine the distribution of the renal tumor blood supply and delineate areas of ischemia by performing a real-time renal angiogram. In any tumor that crosses Brodel's line, it is necessary to clamp both posterior and anterior arterial branches. In this respect, selective clamping may be most favorable for tumors that are completely anterior or posterior tumors to Brodel's line. If tumor or adjacent parenchyma remain perfused despite clamping several higher order arterial branches, global ischemia can be achieved by clamping the main renal artery(ies), thereby avoiding what may have otherwise resulted in poor visualization and large blood loss with an off-clamp RPN.

This technique is reproducible and supported by a recent multicenter pilot study of 34 patients who underwent RPN with selective clamping utilizing NIRF imaging with ICG. A matched pair analysis showed the ICG-based selective clamping procedures to correspond with superior kidney function at two-week postoperative follow-up (eGFR of -1.8% vs. -14.9% , $P=0.03$) when compared to a control group of patients who underwent conventional RPN with main renal artery clamping.¹¹ Prior to NIRF imaging, we were not performing robotic partial nephrectomies with selective clamping. This technology has facilitated the development of this surgical procedure at our institution.

We hypothesize that two primary mechanisms may be responsible for the decreased significance of three-month functional outcomes in this cohort. First, increased exposure to renal ischemia in the control group may have left those patients more susceptible to acute tubular necrosis, producing a lower discharge eGFR that would have gradually risen during the recovery phase. Second, while immediate postoperative eGFR in the NIRF group may reflect lesser intraoperative ischemic trauma in the affected kidney, any related benefit could

be masked at later follow-up as patients with a normal contralateral kidney (the vast majority of participants in both study groups) are presumably capable of at least some degree of compensation for lost renal function over time, thereby achieving partial normalization of eGFR.³⁰ As a result, in patients with a normal contralateral kidney, serum eGFR may not be a sensitive tool for assessing any long-term benefit of the technique presented here. Future studies of NIRF-enhanced selective clamping are needed to address this issue, and could overcome the innate limitations of serum eGFR through assessment of kidney-specific function (for example, magnetic resonance renography), utilization of single-kidney cohorts, or by quantifying progression to chronic kidney disease.

The present study benefits from utilizing a comprehensive, prospectively maintained database containing patient characteristics and perioperative outcomes, as well as rigorous characterization of functional outcomes and all complications for both cohorts. The findings in this study are further reinforced by our appropriately matched analysis. Additionally, this is a single surgeon retrospective study and is subject to innate weaknesses associated with the study design and a potential influence of the procedural learning curve. Lastly, our center has a large experience with NIRF imaging in robotic partial nephrectomy, potentially limiting the generalizability of our findings among less experienced surgical teams.

CONCLUSION

In conclusion, our initial experience with RPN selective clamping guided by NIRF imaging illustrates its safety, efficacy, and reproducibility. Our use of NIRF imaging with ICG facilitates selective arterial clamping and thereby negates the need for global ischemia by allowing for real-time confirmation of targeted ischemia in the tumor and immediate borders as well as maintenance of perfusion in normal tissue. In this largest single-institution experience with NIRF-enhanced selective clamping, we have found an association with improved short-term functional outcomes, as measured through postoperative eGFR. This measured benefit in serum eGFR did not reach statistical significance at three months postoperatively. Given these findings, larger randomized studies with longer follow-up and more sensitive assessments of functional outcomes are warranted to investigate the long-term benefits of NIRF imaging and further define the most appropriate indications for its use.

Acknowledgments

Funding Support:

Tyler R. McClintock, Marc A. Bjurlin, and James S. Wysock are supported in part by grant UL1 TR000038 from the National Center for the Advancement of Translational Science (NCATS), National Institutes of Health.

References

1. Campbell SC, Novick AC, Belldgrun A, et al. Guideline for management of the clinical T1 renal mass. *J Urol*. 2009; 182:1271–1279. [PubMed: 19683266]
2. Huang WC, Levey AS, Serio AM, et al. Chronic kidney disease after nephrectomy in patients with renal cortical tumours: a retrospective cohort study. *Lancet Oncol*. 2006; 7:735–740. [PubMed: 16945768]

3. Huang WC, Elkin EB, Levey AS, et al. Partial nephrectomy versus radical nephrectomy in patients with small renal tumors--is there a difference in mortality and cardiovascular outcomes? *J Urol.* 2009; 181:55–61. [PubMed: 19012918]
4. Weight CJ, Lieser G, Larson BT, et al. Partial nephrectomy is associated with improved overall survival compared to radical nephrectomy in patients with unanticipated benign renal tumours. *Eur Urol.* 2010; 58:293–298. [PubMed: 20546991]
5. Gettman MT, Blute ML, Chow GK, et al. Robotic-assisted laparoscopic partial nephrectomy: technique and initial clinical experience with DaVinci robotic system. *Urology.* 2004; 64:914–918. [PubMed: 15533477]
6. Dulabon LM, Kaouk JH, Haber GP, et al. Multi-institutional analysis of robotic partial nephrectomy for hilar versus nonhilar lesions in 446 consecutive cases. *Eur Urol.* 59:325–330. [PubMed: 21144643]
7. Petros F, Sukumar S, Haber GP, et al. Multi-institutional analysis of robot-assisted partial nephrectomy for renal tumors >4 cm versus ≤ 4 cm in 445 consecutive patients. *J Endourol.* 2012; 26:642–646. [PubMed: 22050488]
8. Thompson RH, Lane BR, Lohse CM, et al. Every minute counts when the renal hilum is clamped during partial nephrectomy. *Eur Urol.* 2010; 58:340–345. [PubMed: 20825756]
9. Gill IS, Eisenberg MS, Aron M, et al. "Zero ischemia" partial nephrectomy: novel laparoscopic and robotic technique. *Eur Urol.* 2011; 59:128–134. [PubMed: 20971550]
10. Bjurlin MA, Gan M, McClintock TR, et al. Near infrared fluorescence imaging: Emerging applications in robotic upper urinary tract surgery. *Eur Urol.* 2013
11. Borofsky MS, Gill IS, Hemal AK, et al. Near-infrared fluorescence imaging to facilitate super-selective arterial clamping during zero-ischaemia robotic partial nephrectomy. *BJU Int.* 2013; 111:604–610. [PubMed: 23253629]
12. Benway BM, Bhayani SB, Rogers CG, et al. Robot assisted partial nephrectomy versus laparoscopic partial nephrectomy for renal tumors: a multi-institutional analysis of perioperative outcomes. *J Urol.* 2009; 182:866–872. [PubMed: 19616229]
13. Dindo D, Demartines N, Clavien PA. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. *Ann Surg.* 2004; 240:205–213. [PubMed: 15273542]
14. Levey AS, Bosch JP, Lewis JB, et al. A more accurate method to estimate glomerular filtration rate from serum creatinine: a new prediction equation. Modification of Diet in Renal Disease Study Group. *Annals of Internal Medicine.* 1999; 130:461–470. [PubMed: 10075613]
15. Harke N, Schoen G, Schiefelbein F, Heinrich E. Selective clamping under the usage of near-infrared fluorescence imaging with indocyanine green in robot-assisted partial nephrectomy: a single-surgeon matched-pair study. *World J Urol.* 2013
16. Aron M, Koenig P, Kaouk JH, et al. Robotic and laparoscopic partial nephrectomy: a matched-pair comparison from a high-volume centre. *BJU Int.* 2008; 102:86–92. [PubMed: 18336600]
17. Haber GP, White WM, Crouzet S, et al. Robotic versus laparoscopic partial nephrectomy: single-surgeon matched cohort study of 150 patients. *Urology.* 2010; 76:754–758. [PubMed: 20646744]
18. Choi JD, Park JW, Lee SY, et al. Does prolonged warm ischemia after partial nephrectomy under pneumoperitoneum cause irreversible damage to the affected kidney? *J Urol.* 2012; 187:802–806. [PubMed: 22245321]
19. Hung AJ, Tsai S, Gill IS. Does eliminating global renal ischemia during partial nephrectomy improve functional outcomes? *Curr Opin Urol.* 2013; 23:112–117. [PubMed: 23287461]
20. Kim SP, Thompson RH. Kidney function after partial nephrectomy: current thinking. *Curr Opin Urol.* 2013; 23:105–111. [PubMed: 23321635]
21. Thompson RH, Frank I, Lohse CM, et al. The impact of ischemia time during open nephron sparing surgery on solitary kidneys: a multi-institutional study. *J Urol.* 2007; 177:471–476. [PubMed: 17222613]
22. Patel AR, Eggener SE. Warm ischemia less than 30 minutes is not necessarily safe during partial nephrectomy: every minute matters. *Urol Oncol.* 2011; 29:826–828. [PubMed: 22078406]

23. Shao P, Tang L, Li P, et al. Precise segmental renal artery clamping under the guidance of dual-source computed tomography angiography during laparoscopic partial nephrectomy. *Eur Urol*. 2012; 62:1001–1008. [PubMed: 22695243]
24. Tobis S, Knopf JK, Silvers CR, et al. Near infrared fluorescence imaging after intravenous indocyanine green: initial clinical experience with open partial nephrectomy for renal cortical tumors. *Urology*. 2012; 79:958–964. [PubMed: 22336035]
25. Polom K, Murawa D, Rho YS, et al. Current trends and emerging future of indocyanine green usage in surgery and oncology: a literature review. *Cancer*. 2011; 117:4812–4822. [PubMed: 21484779]
26. Sevick-Muraca EM. Translation of near-infrared fluorescence imaging technologies: emerging clinical applications. *Annu Rev Med*. 2012; 63:217–231. [PubMed: 22034868]
27. Handa T, Katare RG, Nishimori H, et al. New device for intraoperative graft assessment: HyperEye charge-coupled device camera system. *Gen Thorac Cardiovasc Surg*. 2010; 58:68–77. [PubMed: 20155342]
28. Sekijima M, Tojimbara T, Sato S, et al. An intraoperative fluorescent imaging system in organ transplantation. *Transplant Proc*. 2004; 36:2188–2190. [PubMed: 15518796]
29. Manny T, Krane LS, Hemal AK. Indocyanine green cannot predict malignancy in partial nephrectomy: histopathologic correlation with fluorescence pattern in 100 patients. *J Endourol*. 2013; 27:918–921. [PubMed: 23442199]
30. Chapman D, Moore R, Klarenbach S, Braam B. Residual renal function after partial or radical nephrectomy for renal cell carcinoma. *Can Urol Assoc J*. 2010; 4:337–343. [PubMed: 20944808]

Figure 1. Identification and dissection of tertiary level arterial branches (A). Selective arterial clamping with mini bull-dog clamp (B). Near infrared fluorescence imaging demonstrating ischemic renal tumor (dark) and well perfused uninvolved renal parenchyma (fluorescent green) (C).

Table 1
Baseline characteristics within NIRF-enhanced selective clamp and main artery clamp cohorts

Variables	NIRF-enhanced selective clamp cohort (range)	Main artery clamp cohort (range)	P
Patients, no.	42	42	
Age, years, mean $\pm$ SD	59.0 $\pm$ 12.6 (22–87)	59.4 $\pm$ 12.2 (34–81)	0.86
Male patients, no. (%)	30 (71.4)	26 (61.9)	0.36
BMI, kg/m ² , mean $\pm$ SD	29.0 $\pm$ 6.1 (19.5–44.5)	28.2 $\pm$ 4.9 (18.6–42.8)	0.53
On ACE inhibitor, no (%)	2 (4.8)	3 (7.1)	0.80
On ARB	9 (21.4)	11 (26.2)	0.57
Diabetic	2 (4.8)	3 (7.1)	0.38
Hypertensive	18 (42.9)	17 (40.5)	0.83
ASA score, mean $\pm$ SD	2.49 $\pm$ 0.71 (1–4)	2.32 $\pm$ 0.67 (1–4)	0.30
Preoperative eGFR, ml/min per 1.73 m ² , mean $\pm$ SD	79.9 $\pm$ 22.5 (29–133)	82.8 $\pm$ 23.1 (33–131)	0.56
RENAL nephrometry score, mean $\pm$ SD	6.67 $\pm$ 1.75 (4–10)	7.35 $\pm$ 1.94 (4–11)	0.22
Tumor size, cm, mean $\pm$ SD	2.81 $\pm$ 1.48 (0.7–6.5)	2.97 $\pm$ 1.59 (1.0–7.7)	0.65

Table 2

Comparison of perioperative outcomes in NIRF-enhanced selective clamp and main artery clamp cohorts

Variables	NIRF-enhanced selective clamp cohort (range)	Main artery clamp cohort (range)	P
Intraoperative			
Operative time, min, mean $\pm$ SD	176.1 $\pm$ 50.7 (60–318)	195.6 $\pm$ 59.2 (60–351)	0.11
Warm ischemia time, min, mean $\pm$ SD	20.4 $\pm$ 7.0 (8–38)	22.9 $\pm$ 8.8 (0–41)	0.17
Estimated blood loss, ml, mean $\pm$ SD	210.7 $\pm$ 164.8 (25–600)	206.8 $\pm$ 243.4 (10–1400)	0.93
Postoperative			
Length of stay, days, mean $\pm$ SD	2.33 $\pm$ 0.85 (2–6)	2.37 $\pm$ 0.79 (1–6)	0.84
eGFR at discharge, ml/min per 1.73 m ² , mean $\pm$ SD	78.2 $\pm$ 23.3 (32–123)	68.5 $\pm$ 18.5 (26–107)	0.04
Change in eGFR, ml/min per 1.73 m ² , mean $\pm$ SD	–2.5 $\pm$ 16.1 (–31–38)	–14.0 $\pm$ 16.4 (–64–28)	< 0.01
Percent change in eGFR, mean $\pm$ SD	–1.9 $\pm$ 20.7 (–34.6–59.3)	–16.8 $\pm$ 17.2 (–62.4–36.3)	< 0.01

Table 3

Comparison of functional outcomes in NIRF-enhanced selective clamp and main artery clamp cohorts at discharge and three-month follow-up

Variables	Discharge		Three-month follow-up		P
	NIRF-enhanced selective clamp cohort	Main artery clamp cohort	NIRF-enhanced selective clamp cohort	Main artery clamp cohort	
eGFR, ml/min per 1.73 m ² , mean ± SD	78.2 ± 23.3	68.5 ± 18.5	76.7 ± 20.4	66.7 ± 25.7	0.07
Change in eGFR, ml/min per 1.73 m ² , mean ± SD	-2.5 ± 16.1	-14.0 ± 16.4	-4.7 ± 20.5	-12.9 ± 22.0	0.10
Percent change in eGFR, mean ± SD	-1.9 ± 20.7	-16.8 ± 17.2	-3.1 ± 26.3	-14.6 ± 26.9	0.07

Table 4

Pathological findings within the NIRF-enhanced selective clamp cohort

All patients	
Malignant, no. (%)	28 (66.7)
Benign, no. (%)	14 (33.3)
Pathologic tumor size, cm, mean $\pm$ SD (range)	2.67 $\pm$ 1.47 (0.5–6.9)
Positive surgical margins, no. (%)	0 (0)
Malignant, no. (%)	
RCC, clear cell	15 (53.6)
RCC, papillary	9 (32.1)
RCC, chromophobe	2 (7.1)
RCC, unclassified	2 (7.1)
RCC pathologic stage	
pT1a	25 (89.3)
pT1b	2 (7.1)
pT2	0 (0)
pT3a	1 (3.6)
Benign, no. (%)	
Oncocytoma	9 (64.3)
Angiomyolipoma	3 (21.4)
Adenoma	1 (7.1)
Other benign	1 (7.1)