Background: Near-infrared fluorescence (NIRF) imaging is a technology with emerging applications in urologic surgery.

Objective: To describe surgical techniques and provide clinical outcomes for robotic partial nephrectomy (RPN) with selective clamping and robotic upper urinary tract reconstruction featuring novel applications of NIRF imaging.

Design, setting, and participants: Data from 90 patients who underwent successful RPN with selective clamping or upper urinary tract reconstruction utilizing NIRF imaging between April 2011 and October 2012 were reviewed.

Surgical procedure: We performed RPN utilizing NIRF imaging to aid with selective arterial clamping and upper tract reconstruction with NIRF imaging, the details of which are outlined in this paper and the accompanying video.

Outcome measurements and statistical analysis: Patient characteristics, perioperative outcomes, and complications were analyzed.

Results and limitations: Of the 48 RPN patients for whom selective clamping was attempted successfully, median estimated blood loss was 200.0 ml, warm ischemia time was 17.0 min, and median change in estimated glomerular filtration rate was −6.3%. There was a 12.5% complication rate, and all complications were Clavien grade 1–3 (14.3%). The upper urinary tract reconstruction utilizing NIRF imaging was performed in 42 patients and included pyeloplasty (n = 20), ureteral reimplant (n = 13), ureterolysis (n = 7), and ureteroureterostomy (n = 2). Radiographic and symptomatic improvement was observed in 100% of the pyeloplasty, ureteral reimplant, and ureteroureterostomy patients and 71.4% of ureterolysis patients, for an overall success rate of 95.2%. This study is limited by the small sample size, the short follow-up period, and the lack of a comparative cohort.

Conclusions: Our technique of RPN with selective arterial clamping and robotic upper urinary tract reconstruction utilizing NIRF imaging is presented. This technology provides real-time intraoperative angiogram to confirm selective ischemia and may be an adjunct technology to confirm well-perfused tissue within a reconstruction anastomosis. Further investigation is needed to evaluate long-term outcomes of NIRF imaging in robotic upper urinary tract surgery and to delineate its indications.
1. Introduction

Since its introduction into the field of urologic surgery, the use of robotics has been integrated into a growing number of procedures [1,2]. Along with more widespread adoption of this surgical platform have come recent developments in functional intraoperative imaging that stand to further enhance its utility [3]. One such innovation is the use of fluorescent contrast agents, which emit light in the near-infrared wavelength after activation by a light-emitting diode. Light in this wavelength (700–850 nm) is not visible to the naked eye and must be captured by a specialized charge-coupled device camera to be visualized. To date, the most widely studied fluorescent tracer is indocyanine green (ICG), which can be used as part of a near-infrared fluorescence (NIRF) imaging system to allow the surgeon to toggle between standard white light and fluorescence-enhanced views in real time within the preexisting robotic console display [3].

Although NIRF imaging applications within urology are still in their infancy, they are being tested as an adjunct technology in a variety of procedures. In robotic partial nephrectomy (RPN), for example, NIRF imaging has been used in an attempt to distinguish benign from malignant tissue, with varying success, as well as for identification of the intrarenal vasculature [4–6]. In addition, NIRF imaging may potentially be useful in confirming tissue perfusion in upper tract reconstruction, similar to its use in other surgical fields [7–10]. The objective of the present study is to provide a detailed description of our surgical technique using NIRF imaging to facilitate selective arterial clamping during RPN along with a description of our novel use of NIRF imaging in upper urinary tract robotic reconstruction to aid in identifying well-perfused and devascularized tissue. We focus on functional renal outcomes in our partial nephrectomy cohort and on radiographic and symptomatic improvement in our reconstruction cohort. Furthermore, we describe technical challenges and recommendations to optimize NIRF imaging in robotic upper urinary tract surgery.

2. Patients and methods

2.1. Study population

Medical data of consecutive patients undergoing robotic upper tract procedures utilizing NIRF imaging between April 2011 and October 2012 at two referral centers were retrieved from a prospectively maintained, institutional review board (IRB)-approved database. Database variables include preoperative imaging, clinical stage, RENAL nephrometry score, laterality, procedure planned, procedure performed, surgical approach, success or failure of selective arterial clamping, hilar microdissection time, ICG dose, complications, and management, in addition to standard pre- and postoperative laboratory analyses and renal function. Procedures included in this study are RPN and robotic upper tract reconstruction (consisting of pyeloplasty, ureteral reimplant, ureterolysis, and ureteroureterostomy). In total, there were 74 instances of RPN for which NIRF imaging was attempted; NIRF was used in 42 upper urinary tract reconstructive procedures (20 robotic pyeloplasties, 13 ureteral reimplants, 7 ureterolyses, and 2 ureteroureterostomies). This study received IRB approval, and informed consent was obtained prior to surgery. Comprehensive demographic, intraoperative, and outcomes-related data were entered into the aforementioned database.

2.2. Surgical technique

A detailed illustration of the surgical technique for ICG-guided NIRF imaging for upper tract robotic surgery used at our institution can be found in the accompanying video material.

2.2.1. Preoperative planning

All patients have preoperative abdominal computed tomography or magnetic resonance imaging, and a RENAL nephrometry score is calculated for partial nephrectomy candidates. A comprehensive staging assessment is also completed in addition to standard preoperative blood work. Absolute and elective indications for RPN have been applied and based on a variety of factors, including tumor factors (size, location, nephrometry score, and multifocality), and patient factors (sex, comorbidities, body mass index, previous surgical procedures, presence of renal insufficiency or anatomic anomalies, and personal preferences). Inclusion criteria included any patient with a renal mass that was amenable to partial nephrectomy or any patient requiring upper tract renal reconstruction. Exclusion criteria included an iodine allergy or elevated liver functions tests, which are contraindications for ICG administration. Surgical candidates for upper tract reconstruction also undergo relevant renal functional studies and generally have any indwelling stents removed 3–7 d prior to surgery. Anticoagulants are discontinued for 7 d prior to surgery when feasible, and a mechanical bowel preparation is done the day before the operation.

2.2.2. Robotic partial nephrectomy with selective arterial clamping using near-infrared fluorescence imaging

Our technique of a four-arm transperitoneal and retroperitoneal RPN with or without selective arterial clamping has been described previously [11–13]. All steps of exposure, preparing tumor for excision, and preparing the hilum for clamping are similar to a full main renal artery clamp technique. However, prior to applying any clamps, a flexible drop-in robotic Doppler probe (Vascular Technology Inc., Nashua, NH, USA) is introduced 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. Hilar fat is removed to improve access as the renal vein and artery branches enter the kidney. If required, small venous branches can be sacrificed to improve exposure. If the tumor is completely anterior or posterior to Brodel’s line, we typically only dissect out the anterior and posterior branches. Before clamping, mannitol 12.5 g is given intravenously to aid in renal protection. Robotic mini-bulldog clamps (Scanlan International, St. Paul, MN, USA) are then applied to the secondary-, tertiary-, or quaternary-level arterial branches at the discretion of the console surgeon using the robotic ProGrasp in an attempt to induce local ischemia in the tumor and the immediately surrounding renal segment. ICG is administered at a dose of 5–10 mg intravenously (IC-Green; Akorn, Lake Forest, IL, USA). Well-perfused renal parenchyma appears fluorescent green under NIRF imaging. Ischemic tissue and tumor do not fluoresce under NIRF imaging (Fig. 1), verifying that the correct arterial branch has been controlled. If peritumoral arterial flow continues despite selective arterial clamping, either additional arterial branches may be sought and selectively clamped or complete arterial clamping may be utilized (Fig. 2). In tumors that appear to have multiple arterial branches, we often dissect and selectively clamp each individual higher-order artery, administer ICG, and sequentially unclamp each artery under NIRF imaging. This technique allows us to perform a renal arteriogram, which, under NIRF imaging, defines the specific higher-order artery or arteries supplying the tumor. When the tumor and
peritumoral parenchyma are demonstrated to be ischemic, the tumor is resected along the previously scored margin using cold scissors. Excision and reconstruction are similar to the procedure previously described [11–13]. We attempt to ligate large intrarenal vessels heading toward resection as they are encountered during excision. If bleeding occurs from the tumor bed after resection, a figure-of-eight suture can be used for hemostasis in cases of a single vessel. Diffuse bleeding can be controlled with a running V-Loc suture (Covidien, Mansfield, MA, USA), or, in rare cases, global ischemia can be achieved if needed by main renal artery clamping. After mini-bulldogs are removed and hemostasis is confirmed, an additional bolus of ICG can be administered to confirm global perfusion of the kidney and no injury to vessels.

2.2.3. Robotic upper tract reconstruction using near-infrared fluorescence imaging

We use NIRF imaging with ICG for all robotic upper urinary tract reconstruction procedures to aid in objective assessment of tissue perfusion during anastomosis. Our robotic upper urinary tract reconstruction techniques have been described previously, including transperitoneal robotic primary [14,15] and secondary [16] pyeloplasty, ureteral reimplantation [17], and robotic ureterolysis and ureteroureterostomy [17,18]. The principles of open urinary reconstruction—including a watertight, tension-free, well-perfused anastomosis—are described in this section and have been described using robotics [14,15]. For each procedure, the area of interest is dissected from the surrounding tissue. We commonly use Potts scissors to aid in dissection and excision of the fibrotic scar. Prior to performing the anastomosis, reimplant, or omental wrap, ICG is administered intravenously (5–10 mg), and NIRF imaging is used to evaluate perfusion of the tissue planned for reconstruction.

For robotic pyeloplasties, we focus on perfusion of the ureter and renal pelvis. NIRF imaging with ICG is particularly useful in cases of secondary ureteropelvic junction (UPJ) repair, as poorly perfused fibrotic scar tissue tends to appear dark during NIRF imaging, whereas a well-perfused renal pelvis and ureter appear fluorescent green (Fig. 3). If poorly perfused tissue is noted at the renal pelvis or ureter, additional tissue is resected until fluorescent green well-perfused tissue is visualized at the margins. The ureter is inspected in a similar manner during ureteral reimplantation using NIRF imaging to confirm well-perfused tissue amenable to a watertight, tension-free, anastomosis. If the distal ureter is found fibrotic, strictured, or without adequate perfusion, additional tissue is resected until fluorescent green well-perfused tissue is visualized.

During robotic ureterolysis or ureteroureterostomy, the healthy distal and proximal portions of the ureter are isolated, and the diseased, entrapped ureteral segment is dissected free by splitting the fibrous capsule anteriorly using the Potts scissors so that the adventitia of the ureter is visible. If an area of devascularized or strictured ureter is noted using NIRF imaging, a Heineke-Mickulicz strictureplasty, ureteroureterostomy, or ureterovesical reimplant can be performed depending on the location and length of devascularized area. In cases planned for ureteroureterostomy, we administer ICG prior to excising the stricture, which allows for demarcation of the location and length of stricture, as the stricture appears dark compared with the fluorescent green well-perfused adjacent ureter. The well-perfused transected ends of the ureter are spatulated, and a watertight, tension-free anastomosis is performed (Fig. 4). In all ureterolysis cases and most ureteroureterostomies, we utilize an omental wrap to protect, isolate, and increase vascularity to the repair. Again, NIRF imaging with ICG can be used to help confirm that the omental flap remains well perfused.
2.3. Data analysis

Descriptive statistics were performed for all variables including mean and standard deviation, median and interquartile range, and frequencies and percentages, as appropriate. Variables analyzed included patient demographics, perioperative variables, tumor characteristics, renal function, pathology, and complications. Renal functional outcomes were estimated using the Modification of Diet in Renal Disease equation. Total and percent change in creatinine and estimated glomerular filtration rate (eGFR) were determined. Chronic kidney disease (CKD) was reported according to the stages defined by the Kidney Disease Outcomes Quality Initiative [19]. Reconstruction outcomes were evaluated in terms of radiologic and symptomatic improvement. For all procedures, postoperative complications were classified according to the Clavien system [20].

3. Results

3.1. Robotic partial nephrectomy results

Patient demographics and preoperative variables are shown in Table 1. Of the 74 patients in whom selective clamping was attempted, it was successful in 48 (64.9%); this yielded a total of 52 RPNs with selective clamping using NIRF. The remaining 26 patients required main renal artery clamping due to continued tumor perfusion despite selective clamping. Of the patients who underwent a successful procedure, the median tumor size was 2.6 cm and the median RENAL nephrometry score was 6.0. Intraoperative and postoperative data are summarized in Table 2. Mean operative time, warm ischemia time (WIT), and estimated blood loss were 155.0 min, 17.0 min, and 200.0 ml, respectively. At 2-wk follow-up, there was a median decline of ~3.5 ml/min per 1.73 m² in eGFR, which equated to a ~6.3% change in eGFR relative to the preoperative value. Median follow-up was 21 mo. Of the three patients whose preoperative eGFR was >60 ml/min per 1.73 m² and decreased to a range consistent with stage 3 CKD, two had preoperative stage 2 CKD (64.1 and 64.4 ml/min per 1.73 m²) that decreased to stage 3 CKD (43.2 and 50.7 ml/min per 1.73 m², respectively) and one had stage 1 CKD (eGFR 90.1 ml/min per 1.73 m²) that decreased to stage 3 CKD (55.4 ml/min per 1.73 m²).

Final histology reviewed by urologic pathologists is shown in Table 3. Overall, 75.0% of tumors were malignant.

Table 1 – Demographics of patients undergoing robotic partial nephrectomy with selective arterial clamping using near-infrared fluorescence imaging

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients, no.</td>
<td>48</td>
</tr>
<tr>
<td>Partial nephrectomies, no.</td>
<td>52</td>
</tr>
<tr>
<td>Age, yr</td>
<td>Median (IQR) 54.0 (51.0–64.0)</td>
</tr>
<tr>
<td>Male patients, no. (%)</td>
<td>32 (66.6)</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>Median (IQR) 27.5 (25.0–33.0)</td>
</tr>
<tr>
<td>ASA score</td>
<td>Median (IQR) 2.0 (2.0–3.0)</td>
</tr>
<tr>
<td>Solitary kidney, no. (%)</td>
<td>2 (4.1)</td>
</tr>
<tr>
<td>Preoperative creatinine, ml/min</td>
<td>Median (IQR) 0.9 (0.9–1.1)</td>
</tr>
<tr>
<td>Preoperative eGFR, ml/min per 1.73 m²</td>
<td>Median (IQR) 85.0 (89.5–92.0)</td>
</tr>
<tr>
<td>Tumor size, cm (radiographic)</td>
<td>Median (IQR) 2.6 (1.6–3.7)</td>
</tr>
<tr>
<td>Nephrometry score</td>
<td>Median (IQR) 6.0 (6.0–8.0)</td>
</tr>
<tr>
<td>Tumor laterality (left:right)</td>
<td>29:23</td>
</tr>
</tbody>
</table>

ASA = American Society of Anesthesiologists; BMI = body mass index; eGFR = estimated glomerular filtration rate; IQR = interquartile range.
with renal cell carcinoma, the clear cell subtype being most common (56.8% of malignant tumors). Among the malignant tumors, stages were pT1a (89.2%), pT1b (10.3%), and pT3 (2.7%). There were two positive surgical margins (PSMs; 3.8%). Both patients were followed with twice yearly imaging for the first 2 yr and had no evidence of recurrence.

Complications are presented in Table 4. Short-term perioperative complications (0–30 d) occurred in six patients (12.5%) and were all Clavien grade 1–3.

### 3.2. Robotic upper tract reconstruction results

Patient demographics as well as intraoperative and postoperative data are summarized in Table 5. Median operative time ranged from 111.5 min (ureteroureterostomy) to 236.0 min (ureteral reimplant). Mean estimated blood loss was ≤100 ml for all reconstruction procedures. Of all urinary tract reconstructive procedures, 38% were secondary repairs (20% pyeloplasties, 54% ureteral reimplants, 43% ureterolysis, and 100% ureteroureterostomies) that failed primary surgical management. Radiographic and symptomatic improvement was observed in 100% of the pyeloplasty, ureteral reimplant, and ureteroureterostomy patients, whereas five of seven ureterolysis patients (71.4%) showed improvement by both metrics, as one patient was subsequently treated successfully with a robotic auto-transplant and the other underwent robotic nephrectomy for a nonfunctioning kidney. This resulted in an overall success rate of 95.2%. The median follow-up was 7 mo for pyeloplasties and ureteral reimplants, 8 mo for ureterolysis, and 5 mo for ureteroureterostomies.

Complications are presented in Table 6. Short-term perioperative complications (0–30 d) occurred in six patients (14.3%), and all were Clavien grade 1–3, which included transient lower extremity weakness (one patient), enterotomy requiring small bowel resection (one patient), ureteral stone requiring nephrostomy tube (one patient), postoperative bleed requiring surgical exploration (one patient), and ureteral stent migration requiring repositioning (two patients).

### 4. Discussion

ICG is a water-soluble tricarbocyanine dye that, when injected intravenously, is transported in the blood in two different forms, unbound or bound to serum proteins, mainly globulins and lipoproteins. Because 98% of ICG is bound to serum proteins, it remains predominantly

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**Table 2 – Perioperative outcomes for robotic partial nephrectomy with selective arterial clamping using near-infrared fluorescence imaging**

<table>
<thead>
<tr>
<th>Intraoperative variable</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operative time, min</td>
<td>Median (IQR) 155.0 (130.0–195.0)</td>
</tr>
<tr>
<td>Successful selective clamping, no. (% attempted)</td>
<td>48.0 (64.9)</td>
</tr>
<tr>
<td>Length of selective dissection, min</td>
<td>Median (IQR) 9.0 (4.0–14.0)</td>
</tr>
<tr>
<td>Warm ischemia time, min</td>
<td>Median (IQR) 17.0 (12.8–25.0)</td>
</tr>
<tr>
<td>Estimated blood loss, ml</td>
<td>Median (IQR) 200.0 (100.0–300.0)</td>
</tr>
</tbody>
</table>

**Postoperative variable | Result |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of stay, d</td>
<td>2.0 (2.0–4.0)</td>
</tr>
<tr>
<td>Postoperative creatinine, mg/dl</td>
<td>0.9 (0.8–1.1)</td>
</tr>
<tr>
<td>Change in creatinine, mg/dl</td>
<td>0.08 (0.0–0.1)</td>
</tr>
<tr>
<td>Postoperative eGFR, ml/min per 1.73 m²</td>
<td>75.5 (62.8–89.0)</td>
</tr>
<tr>
<td>Change in eGFR, ml/min per 1.73 m²</td>
<td>−3.5 (−13.7 to 0.0)</td>
</tr>
<tr>
<td>Change in eGFR, %</td>
<td>−6.3 (−16.4 to 0.0)</td>
</tr>
</tbody>
</table>

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

1 Data not available for two patients.

**Table 3 – Renal tumor pathology of robotic partial nephrectomy with selective arterial clamping using near-infrared fluorescence imaging**

<table>
<thead>
<tr>
<th>All patients</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malignant, no. (%)</td>
<td>39 (75.0)</td>
</tr>
<tr>
<td>Benign, no. (%)</td>
<td>13 (25.0)</td>
</tr>
<tr>
<td>Pathologic tumor size, cm</td>
<td>Mean (SD) 2.5 (1.3)</td>
</tr>
<tr>
<td>Median (IQR) 2.4 (0.7–4.1)</td>
<td></td>
</tr>
<tr>
<td>Positive surgical margins, no. (%)</td>
<td>2 (3.8)</td>
</tr>
</tbody>
</table>

**Malignant, no. (%)**

| RCC, clear cell | 21 (56.8) |
| RCC, papillary | 7 (18.9) |
| RCC, chromophobe | 7 (18.9) |
| RCC, unclassified | 2 (5.4) |
| RCC pathologic stage | pT1a 33 (89.2) |
| pT1b | 3 (8.1) |
| pT3a | 1 (2.7) |

**Benign, no. (%)**

| Oncocytoma | 8 (61.5) |
| Angiomyolipoma | 3 (21.3) |
| Adenoma | 1 (7.7) |
| Other benign | 1 (7.7) |

IQR = interquartile range; RCC = renal cell carcinoma; SD = standard deviation.
intravascular until hepatobiliary excretion [21,22]. Unbound ICG is quickly removed from the vascular system by the liver and is transported into the bile by protein glutathione S-transferase without modification. Bound ICG allows fluorescence to be visualized throughout the vascular system in <1 min [23]. ICG is well suited to diagnostic purposes because it has no known metabolites. Furthermore, ICG shows a low incidence of adverse reactions [24,25], and its pharmacokinetics have been well studied [26,27].

Prior to the application in urologic surgery, NIRF imaging with ICG was used in a variety of surgical specialties [16–20]. NIRF imaging with ICG has been adopted in urology with special focus on both open and robotic renal surgery [4,5,23,28]. In the kidney, NIRF imaging with ICG displays differential fluorescence in normal parenchyma versus tumors, cysts, and fat necrosis, as these abnormal regions will typically appear hypofluorescent relative to the remainder of the perfused organ. This is likely due to the absence of bilitranslocase, a carrier protein that is present only in normal proximal tubule cells [29]. A notable exception to this rule, however, is in oncocytomas, where bilitranslocase is also expressed and the tumor appears isofluorescent [4].

Initial trials of NIRF imaging in RPN have yielded promising results. Tobis et al. published their experience with an initial set of 19 patients, removing 13 hypo- fluorescent malignant masses and 6 benign masses that ranged from isofluorescent to hyperfluorescent [23]. Krane et al. reported subjective improvement in the ability to discern vascular anatomy when they compared a cohort of 47 patients who underwent RPN utilizing ICG with a matched cohort of 47 patients who underwent RPN without ICG, also finding WIT to be significantly decreased in the ICG group (15 min vs 17 min, p = 0.01). However, there was no statistical difference between the groups for positive margin rate or Clavien grade 3–4 complications [5]. These findings may be partially explained by the already low rate of PSMs (2%) and complications in RPN (5%) [13].
Our use of NIRF is novel and differs from the above-mentioned studies, as we utilize NIRF imaging specifically to aid with selective arterial clamping. Prior to NIRF imaging, we were not performing RPNs with selective clamping. This technology has facilitated the development of this surgical procedure at our institutions. We believe this use may simplify the procedure and stands to have the greatest impact on functional outcome (eGFR) through decreasing ischemia in normal tissue. NIRF imaging allows the surgeon to confirm devascularization of a tumor and the local area and continued perfusion of normal tissue. If devascularization cannot be confirmed despite selective arterial clamping, additional arterial branches can be sought and selectively clamped, after which NIRF imaging can be reused to confirm ischemia. In large tumors that cross Brodel’s line or in cases of complex hilar tumors, the selective clamping approach involves clamping both posterior and anterior arterial branches. In situations where the peritumoral tissues remain perfused under NIRF imaging even though several higher-order arterial branches are clamped, global ischemia can be achieved by clamping the main renal artery, thereby avoiding what may have otherwise resulted in large blood loss and poor visualization with an off-clamp RPN. In this way, NIRF imaging aids in confirmation of a bloodless field and may also offset some of the skill- and operator-dependent properties of selective clamping guided by intraoperative ultrasound.

Throughout the process of integrating NIRF imaging into RPN at our institutions, we have refined our approach and noted several technical points that we believe are valuable for those attempting this procedure. First, one may start a NIRF imaging-enhanced RPN by clamping secondary arterial branches and moving up to higher-order branches as one becomes more comfortable. Occasionally we have noted that what we initially believed was the arterial branch feeding the renal tumor instead perfused a separate area of healthy parenchyma. To compensate, we have begun to clamp several higher-order arterial branches, inject ICG, and sequentially unclamp, essentially performing an intraoperative renal angiogram. In cases where we interpret the arterial vasculature incorrectly or have difficulty identifying the correct arterial branch, we may clamp the main artery rather than wait the requisite 30 min for ICG washout (a recognized limitation of this technique). Second, even though ICG detects only surface perfusion, we have found that if the tumor does not cross Brodel’s line on preoperative imaging, there have been no issues with excessive bleeding from the tumor bed when NIRF imaging has shown surface ischemia around the tumor. We have learned that because selective clamping does not allow for clamping of the renal vein, we have experienced more venous back bleeding, which occasionally has made the renorrhaphy more challenging. Last, an important advantage of using ICG fluorescence is the opportunity to check the perfusion of healthy renal parenchyma after conclusion of the renorrhaphy. In one case in our series, the ICG test allowed us to avoid the hypoperfusion of a large part of the remaining kidney by releasing and partially removing the hemostatic sutures on the renal breach.

Reports on the use of NIRF imaging in upper urinary tract reconstruction are decidedly more limited, as we believe this to be the first published description of its implementation for such procedures. It should be noted, however, that animal models and other surgical reconstruction techniques have used ICG to evaluate perfusion intraoperatively with the potential to improve anastomotic outcomes. Cardiothoracic surgeons have shown its applications in evaluating muscle flap perfusion in bronchial anastomosis after sleeve lobectomy. ICG fluorescence demonstrated high efficacy in the assessment of intercostal muscle blood perfusion, was superior to macroscopic evaluation, and also influenced surgical proceedings [7]. Gastrointestinal surgeons have used ICG tissue angiography to evaluate the gastric conduit intraoperatively before gastroesophageal anastomosis to identify areas of ischemia [8]. Robotic surgeons performing rectal surgery have used NIRF imaging with ICG to appraise microcirculation before formation of the anastomosis, which has allowed the surgeon to choose the point of transection at an optimally perfused area and may affect the anastomotic leak rate [9]. ICG angiography has also been shown to be a better predictor of mastectomy skin flap necrosis than fluorescein dye angiography and clinical judgment in a recent prospective analysis of breast reconstruction [10]. In animal models, intraoperative fluorescent molecular imaging during pyeoplasty has been shown to provide visualization of the vasculature of the obstructed UPJ [30]. Its use may improve the quality of the anastomosis, ensuring that viable tissues are reapproximated. The authors of this study hypothesize that use of NIRF imaging has the potential to predict and prevent postoperative obstruction and pyeloplasty failure. However, it must be highlighted that several of these studies are single-institution experiences with small cohorts. Consequently, larger prospective studies are needed to further validate this novel technology.

NIRF imaging with ICG has provided a simple method to confirm tissue perfusion during our robotic upper urinary tract reconstruction experience. However, the success rate of some reconstruction techniques, such as primary UPJ repair, may ultimately not be influenced by NIRF imaging, as the success rate of these repairs is already high. This technology may be more suited for secondary repairs, as anecdotally it has changed how the renal pelvis and ureter are excised during our secondary pyeloplasties. Long-term data and proven clinical value are not yet available. Further accrual of data with longer follow-up will better define the role of NIRF imaging in this cohort.

This study has several important strengths and limitations. Strengths of this initial feasibility study include a comprehensive, prospectively maintained database containing patient characteristics and perioperative outcomes as well as rigorous characterization of functional outcomes and all complications. It is the largest study to date using NIRF imaging with ICG in RPN with selective clamping and the first study demonstrating its potential use in robotic urinary tract reconstruction. This study focused on our surgical technique and was not a comparative study. Consequently, it was not powered to demonstrate a
difference in clinical outcomes compared with procedures performed without NIRF imaging. With continued accrual of data, we hope to be able to address this clinical concern. Although we perform a standardized technique for each procedure, there were no formal metrics of reproducibility in this study. Our study analysis did not include patients that required main renal artery clamping, and this may have introduced a patient selection bias. This is a retrospective study and is subject to associated weaknesses. It should also be noted that the our centers have much experience with NIRF imaging in robotic upper urinary tract surgery, potentially limiting the generalizability of our findings among less experienced surgical teams. Larger, randomized, prospective studies are required to confirm long-term clinical and functional advantages associated with NIRF imaging. As we await the results of such work, we believe this initial feasibility study illustrates the possible benefits of NIRF imaging with ICG and shows that this technology can be safely implemented in robotic surgery of the upper urinary tract.

5. Conclusion

Our technique for RPN with NIRF imaging to aid in selective arterial clamping and its use in robotic upper urinary tract reconstruction is detailed in this paper. This study illustrates its safety and efficacy and highlights potential specific advantages as an adjunct surgical technology in patients undergoing robotic upper urinary tract surgery. NIRF imaging allows objective assessment of renal ischemia and perfusion, thereby facilitating selective clamping in RPN and ultimately minimizing the decrease in renal function. Its application in robotic urinary tract reconstruction may potentially help ensure adequate anastomotic blood flow. Further investigation is needed to evaluate long-term outcomes of NIRF imaging in robotic upper urinary tract surgery and to delineate its indications.

Author contributions: Michael D. Stiefelman had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Bjurlin, Gan, McClintock, Volpe, Mottrie, Stiefelman.

Acquisition of data: Bjurlin, Gan, McClintock, Borofsky, Mottrie, Stiefelman.

Analysis and interpretation of data: Bjurlin, Gan, McClintock, Volpe, Mottrie, Stiefelman.

Drafting of the manuscript: Bjurlin, Gan, McClintock, Volpe, Mottrie, Stiefelman.

Critical revision of the manuscript for important intellectual content: Bjurlin, Gan, McClintock, Borofsky, Mottrie, Stiefelman.

Statistical analysis: Bjurlin, Gan, McClintock, Mottrie, Stiefelman.

Obtaining funding: None.

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Supervision: Mottrie, Stiefelman.

Other (specify): None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.eururo.2013.09.023.

References


