Published in final edited form as:

J Am Coll Surg. 2008 June ; 206(3): 1159–1166. doi:10.1016/j.jamcollsurg.2008.01.013.

Enhanced Surgical Imaging: Laparoscopic Vessel Identification and Assessment of Tissue Oxygenation

Nicole J. Crane, PhD¹, Ben McHone, MD², Jason Hawksworth, MD³, Jonathan P. Pearl, MD FACS^{4,5}, John Denobile, MD FACS^{4,5}, Doug Tadaki, PhD^{1,5}, Peter A. Pinto, MD⁶, Ira W. Levin, PhD⁷, and Eric A. Elster, MD FACS^{1,4,5,*}

¹ Naval Medical Research Center, Combat and Casualty Care, Silver Spring, MD

² Department of Urology, George Washington University, Washington, DC

³ Department of Surgery, Walter Reed Army Medical Center, Washington, DC

⁴Department of Surgery, National Naval Medical Center, Bethesda, MD

⁵Department of Surgery, Uniformed Services University, University of Health Sciences, Bethesda, MD

⁶Urologic Oncology, National Cancer Institute, National Institutes of Health, Bethesda, MD

⁷Laboratory of Chemical Physics, National Institute of Diabetes and Digestive and Kidney Diseases, National Institutes of Health, Bethesda, MD

Abstract

Background—Inherent to minimally invasive procedures are loss of tactile feedback and loss of three dimensional assessment. Tasks such as vessel identification and dissection are not trivial for the inexperienced laparoscopic surgeon. Advanced surgical imaging, such as 3-CCD (charge-coupled device) image enhancement, can be used to assist with these more challenging tasks and, in addition, offers a method to non-invasively monitor tissue oxygenation during surgery.

Study Design—In this study, 3-CCD image enhancement is used for the identification of vessels in 25 laparoscopic donor and partial nephrectomy cases. The algorithm is then applied to two laparoscopic nephrectomy cases involving multiple renal arteries. We also utilize the 3-CCD camera to qualitatively monitor renal parenchymal oxygenation during 10 laparoscopic donor nephrectomies (LDNs).

Results—The mean ROI (region of interest) intensity values obtained for the renal artery and vein (68.40 ± 8.44 and 45.96 ± 8.65 , respectively) are used to calculate a threshold intensity value (59.00) that allows for objective vessel differentiation. In addition, we examined the renal parenchyma during LDNs. Mean ROI intensity values were calculated for the renal parenchyma at two distinct time points, prior to vessel stapling (non-ischemic) and just before extraction from the abdomen (ischemic). The non-ischemic mean ROI intensity values are statistically different from the ischemic mean ROI intensity values ($p < 0.05$), even with short ischemia times.

Conclusions—We have developed a technique, 3-CCD image enhancement, for the identification of vasculature and for the monitoring of parenchymal oxygenation. This technique requires no additional laparoscopic operating room equipment and has real-time video capability.

*Corresponding Author: Eric A. Elster, Naval Medical Research Center, Combat and Casualty Care, 503 Grant Avenue, Silver Spring, MD 20910. (301) 319-8632; phone, (301) 295-1234; fax, Eric.Elster@med.navy.mil.

Introduction

The implementation of minimally invasive surgery has rapidly increased in the last decade. Many procedures are now performed almost exclusively laparoscopically. Proponents of laparoscopic surgery cite reduced risks of infection, shorter hospital stay, faster return to work, and improved cosmesis as incentives.(1,2)

Minimally invasive procedures, however, result in a loss of tactile feedback and three dimensional assessment for the surgeon. Laparoscopy has a steep learning curve, and increased rates of complications are common early in the surgeon's experience. As indications for laparoscopic surgery expand, many complex procedures require additional fellowship training. New technology may alleviate some of the training burden and improve safety during laparoscopy.

Visible reflectance spectroscopy is a proven modality for noninvasive tissue oxygenation monitoring.(3-9) Spectroscopy takes advantage of the unique spectral properties of hemoglobin to infer tissue oxygenation. Visible reflectance spectroscopy is possible with the 3-CCD camera, which is standard in operating room laparoscopic towers. In this study, we use the spectral response of the 3-CCD camera to differentiate renal vessels and to monitor renal parenchymal oxygenation during LDNs and laparoscopic partial nephrectomies (LPNs).

Methods

Patients and Procedures

Informed consent was obtained for all patients, who underwent either a laparoscopic donor nephrectomy (N=15) or a laparoscopic partial nephrectomy (N=10). All patients were participating in an Institutional Review Board approved protocol. Three of the LPNs were right kidneys, while the remainder were left partial and donor nephrectomies. Patient demographics for the LDNs are outlined in Table 1. Mean estimated blood losses for LDNs and LPNs were 435 ± 306 and 275 ± 241 , respectively. Operating room times included anesthesia time (364 ± 81 minutes for LDNs and 471 ± 51 minutes for LPNs). On average, more than 5 liters of lactate ringers were administered for each case.

3-CCD Image Enhancement

All nephrectomies were recorded on DVD-R media using a Storz laparoscopic tower (Tuttlingen, Germany) equipped with a 3-CCD camera. A standard 10mm 30 degree laparoscope was utilized in all cases. Video footage of the surgery was transferred from the DVD to a personal computer, where all subsequent analysis was carried out. Videos were loaded into Adobe Premier 6.0 to review footage and to extract individual frames, containing exposed hilar structure and/or exposure of the renal parenchyma, as tagged image format files (TIFFs). First, the extracted image (Figure 1a) is decomposed into the three individual CCD signal responses. Next, the blue CCD signal response (Figure 1c) is subtracted from the red CCD signal response (Figure 1b). The resulting image (Figure 1d) is colorized such that an intense red color denotes the greatest tissue oxygenation and an intense blue color indicates a lack of tissue oxygenation. Finally, the calculated image is overlaid onto the original extracted image (Figure 1e), enabling visual registration and enhancement simultaneously.

The differences in the oxygenated and deoxygenated regions of tissue are detectable because of the inherent absorbance of hemoglobin in the visible region of the electromagnetic spectrum. Oxygenated hemoglobin has major absorption bands at 416, 541, and 577 nm, while deoxygenated hemoglobin has major absorption bands at 430 and 556 nm. The individual responses of the CCDs act as filters for three different regions of the visible spectrum (Figure 2). Thus, by subtracting the blue CCD signal response from the red CCD signal response, we

are effectively amplifying the absorbance differences between oxygenated and deoxygenated blood in tissue.(9) There is a direct correlation between the mean ROI intensity values and blood oxygen saturation as well as tissue oxygenation.(10)

For each extracted frame, mean intensity values were calculated for regions of interest (ROIs), i.e. areas with adequate hilar or renal exposure and minimal glare. The ROIs consisted of rectangles containing ~30 to 44,000 pixels, and, at least three ROIs were examined for each frame. Variable rectangle size is attributed to the changing orientation of the kidney throughout the surgery, along with changes in illumination.

Statistical Analysis

Differences between mean ROI intensity values were assessed using the student's t-test. For vessel images, where the same image conditions existed for both the artery and the vein, a paired sample means t-test was used. For renal parenchyma images, where the orientation of the kidney had changed after vessel clamping, an unpaired two-tailed t-test assuming equal variances was used. Mean differences were considered significant with a p -value less than 0.05; differences with a p -value less than 0.01 were considered statistically significant.

Results

Spectroscopic Results

1. Vessel Differentiation—The overall mean ROI intensity value calculated for the renal vein, 45.96 ± 8.65 , was significantly different from the overall mean ROI intensity value calculated for the renal artery, 68.40 ± 8.44 ($p = 8.0 \times 10^{-8}$). As shown in Figure 3, a comparison of the mean ROI intensity values of the renal arteries and the renal veins for each case revealed a significant difference between these two values ($p < 0.05$). In fact, a threshold value for discrimination of vessel type (venous or arterial) can be calculated from taking the mean of the vein mean ROI intensity value plus one standard deviation and the artery mean ROI intensity value minus one standard deviation; it was determined to be 59.00. Thus, a vessel with a mean ROI intensity value greater than 59.00 would be categorized as an artery, while any vessel with a mean ROI intensity value less than 59.00 would be categorized as a vein. We next validated the utility of this approach with two cases exhibiting accessory vessels.

Figures 4A & B display two cases with multiple vessels (LPN and LDN, respectively), with the veins and arteries clearly marked. The additional vessels were identified during the nephrectomies by an experienced laparoscopic surgeon but were used to illustrate the possibility of rapid *in vivo* vessel identification. In both cases, the enhanced images (Figures 4C & D) overlay a red color onto the additional vessels, indicating oxygenation and thus, arteries. Vessel identification is then confirmed using mean ROI intensity values. Regions of interest for each vessel are outlined in white (vein), yellow (left artery) and green (right artery) rectangles. In the first case (Figures 4A & C), the mean ROI intensity values are 48.25 ± 1.30 , 61.65 ± 2.32 , and 66.91 ± 6.47 , for the vein, left artery, and right artery, respectively. The calculated values correctly assign each vessel and a comparison of the vessels reveals a significant difference between the vein and left and right arteries ($p = 0.007$ and $p = 0.025$, respectively). Similar results are seen for the second case (Figures 4B & D), with mean ROI intensity values of 43.35 ± 3.34 , 65.14 ± 5.61 , and 60.68 ± 4.85 , for the vein, left artery, and right artery, respectively. In addition, statistically significant differences are found when comparing the vein to the left and right arteries ($p = 0.007$ and $p = 0.017$, respectively).

2. Parenchymal Oxygenation—In addition to vessel identification, the mean ROI intensity values were calculated for comparisons of the renal parenchyma prior to vessel occlusion (non-ischemic) and after vessel occlusion (ischemic) for ten LDN cases. The vessel clamp time prior

to kidney extraction varied from 30 seconds to 2 minutes. It is clear from Figure 5, however, that the calculated mean ROI intensity values change drastically after inducing ischemia, even after only 30 seconds of ischemia (Case 5). The percent difference in the mean ROI intensity values for pre- and post-clamp images is not proportional to vessel clamp time or pre-operative creatinine clearance levels (Table 2). Preliminary results indicate that 3-CCD image enhancement can be used not only to identify accessory vessels but also to monitor renal parenchymal oxygenation *in vivo*.

Discussion

This manuscript is the first report of the use of 3-CCD visual enhancement for vessel differentiation/identification. In addition, this technique is used for assessment of renal parenchymal oxygenation during laparoscopic surgery, specifically during LPNs and LDNs. While this technique is presented for laparoscopic nephrectomies, its potential use extends into all aspects of laparoscopic and open surgery. We present a novel, noninvasive method capable of intraoperative tissue oxygenation monitoring *in vivo* that does not require the incorporation of additional equipment into the laparoscopic operating room.

We utilized the 3-CCD image enhancement analysis for non-lymphatic vessels, yielding a threshold value for vessel identification (Figure 3). A mean ROI intensity value above 59.00 indicates the presence of an artery, and a mean ROI intensity value below 59.00 indicates the presence of a vein. When applied to two laparoscopic nephrectomy cases (Figure 4), accessory vessels encountered during dissection of the renal hilum were identified as arteries. The calculated results were validated by the laparoscopic surgeons who preformed the nephrectomies; thus, with calculations performed blinded, the vessels were correctly identified.

We also examined the renal parenchyma during the ten LDNs; 3-CCD image enhancement was able to monitor the relative oxygenation values over time. A clear drop in the mean ROI intensity value was observed (Figure 5), even with ischemia times as short as 30 seconds. 3-CCD image enhancement demonstrates the ability to monitor subtle changes in renal parenchymal oxygenation.(10) Though all of the differences are significantly different, they vary for each case. This may be a consequence of imaging variables, such as laparoscopic illumination, kidney orientation and exposure. Intrinsic renal physiology may also affect the parenchymal oxygenation values. This is made apparent by the lack of correlation between the mean ROI intensity values and ischemia time or pre-operative donor creatinine clearance (Table 2).

The popularity of LDN and LPN has grown since its introduction in the 1990s.(11-14) However, performing these procedures requires specialized training and a high level of technical ability.(15) In particular, differentiating and identifying vessels in laparoscopy, without the use of tactile feedback, can be challenging. The overall intraoperative complication rate for LDNs is approximately 2.8%, and the majority are related to bleeding.(16) In a comparison study of multiple renal artery LPNs and single artery LPNs, Singh et al speculate whether current preoperative imaging is sufficient for identifying multiple renal arteries. (17) In fact, all bleeding complications in this study arose from an overlooked accessory artery. Improved ability to identify aberrant vascular anatomy in a two-dimensional field may decrease bleeding complications. This technology may also help laparoscopic surgeons preserve adequate vessel length, a critical component to laparoscopic donor nephrectomies.(18) In addition, it could also reduce the increased warm ischemia times and the consequent ureteral complications associated with multiple artery LDNs.(19)

Current methods of vessel identification and differentiation in laparoscopy are limited to visual cues (color, pulsations, etc.). This, however, is highly subjective and dependent on surgeon

experience. Intraoperative Doppler ultrasound can be used but also requires specialized equipment and personnel. Vascular surgeons have used laser Doppler flowmetry(20) and venous sampling(21) to assess adequate perfusion and oxygenation to tissues, respectively. These however, have not been adapted to the laparoscopic setting and are limited in that they do not allow for real-time imaging. Methods developed for vessel identification specifically during laparoscopic surgery include an endoscopic pulse detector(22) and infrared imaging (23). Both of these methods, however, require additional equipment that must be incorporated into an already crowded operating space. We propose a novel means of intraoperative assessment of vascular differentiation and identification that requires no additional equipment and provides surgeons with a quantifiable means of identifying and distinguishing between blood vessels. We are currently working on software solutions that would allow for real-time 3-CCD imaging that integrates the color picture with the 3-CCD enhanced picture.

Visual reflectance spectroscopy clearly has a potentially wide range of applications in laparoscopic and open surgery. For example, transplant surgeons currently rely largely on visual signs to determine the functional capacity of a renal graft during surgery, as well as urine output. It has been noted that the current methods used for clinical evaluation of ischemia are undervalued, providing less than desirable specificities and sensitivities.(24) Methods for assessing renal ischemia via serum and urine monitoring are neither immediate nor easily accessible during a surgical procedure. Total organ quantifiable oxygenation levels, a true indicator of ischemia, provided in real-time to the transplant surgeon, may provide critical data in the operating room to maximize graft function. Of those studies attempting to measure end-organ oxygenation, oxymeters(21) and spectrophotometer probes(25) have been utilized and were found either to be ineffective or provided only a limited sampling of tissue oxygenation. Many technologies employed by other specialties measure flow to an organ and not actual tissue oxygenation(26-30), or measure postoperative oxygenation(31,32). 3-CCD enhancement allows for a quantifiable, intraoperative assessment of renal oxygenation and could provide critical data about the blood supply to the kidney.

Other examples in which 3-CCD enhancement may improve procedural ease and safety include laparoscopic colectomy, splenectomy, and inguinal hernia repair (IHR). Laparoscopic colon resections are in greater demand due to decreased time to return of bowel function and analgesic requirements and improved cosmetic results.(33-35) In ways similar to colon surgery, laparoscopic surgery is supplanting the open splenectomy for selected patients(36,37). As with laparoscopic colectomies, vessel differentiation and parenchymal assessment during this surgery are key elements. Finally, vessel identification during laparoscopic IHR would be a useful adjunct to this commonly performed operation.

The role of 3-CCD enhancement can also be utilized in open surgery. Vascular surgeons, during open and endovascular abdominal aortic aneurysm (AAA) repair have sought ways to detect ischemic colitis intraoperatively before the procedure is completed(20,21,25,38). Similar technology is being investigated by cardiac surgeons to assess graft-patency intraoperatively during coronary artery bypass grafts(26-28). Infrared imaging has been investigated in cardiac surgery; however, this technique does not give actual values for oxygen saturations(27,28).

In conclusion, our results demonstrate the advantageous capability of 3-CCD image enhancement during laparoscopic nephrectomy. With current laparoscopic cameras already containing 3-CCD chips, no change in hardware is warranted, allowing for easier integration into the armament of laparoscopic surgeons. Thus, the techniques presented here allow for real-time, quantitative analysis of oxygenation, allowing for assessment of ischemia and identification of vascular anatomy. As more cases are approached laparoscopically, advancements in imaging technology are needed to facilitate the incorporation of laparoscopy

into a broader range of procedures. The applications of 3-CCD enhancement will continue to grow as surgeons apply this technology to benefit their patients and improve outcomes.

Acknowledgments

The views expressed in this article are those of the author and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, nor the U.S. Government. This work was prepared as part of the official duties of a military service member (E. E.). Title 17 U.S.C. § 105 provides that 'Copyright protection under this title is not available for any work of the United States Government.' Title 17 U.S.C. § 101 defines a U.S. Government work as a work prepared by a military service member or employee of the U.S. Government as part of that person's official duties. We also acknowledge support from the intramural program of the National Institute of Diabetes and Digestive and Kidney Diseases, National Institutes of Health.

References

1. Khauli RB, El-Hout Y, Hussein M, et al. A controlled sequential evaluation of laparoscopic donor nephrectomy versus open donor nephrectomy: an update. *Transplant Proc* 2005;37:633–634. [PubMed: 15848482]
2. Lind MY, Ijzermans JNM, Bonjer HJ. Open vs laparoscopic donor nephrectomy in renal transplantation. *Br J Urol Int* 2002;89:162–168.
3. Bykowski J, Kollias N, LaMuraglia GM. Evaluation of peripheral arterial occlusive disease and postsurgical viability using reflectance spectroscopy of skin. *Microvasc Res* 2004;67:152–158. [PubMed: 15020206]
4. Knoefel WT, Kollias N, Rattner DW, Nishioka NS, Warshaw AL. Reflectance soectroscopy of pancreatic microcirculation. *J Appl Physiol* 1996;80:116–123. [PubMed: 8847291]
5. Kostenich G, Kimel S, Peled S, Orenstein A. Monitoring PDT-induced damage using spectrally resolved reflectance imaging of tissue oxygenation. *Cancer Letters* 2005;219:169–175. [PubMed: 15723716]
6. Yeong EK, Hsiao TC, Chiang HK, Lin CW. Prediction of burn healing time using artificial neural networks and reflectance spectrometer. *Burns* 2005;31:415–420. [PubMed: 15896502]
7. Zonios G, Bykowski J, Kollias N. Skin melanin, hemoglobin, and light scattering properties can be quantitatively assessed *in vivo* using diffuse reflectance spectroscopy. *J Invest Dermatol* 2001;117:1452–1457. [PubMed: 11886508]
8. Zuzak KJ, Gladwin MT, Cannon RO, Levin IW. Imaging hemoglobin oxygen saturation in sickle cell disease patients using noninvasive visible reflectance hyperspectral techniques: effects of nitric oxide. *Am J Physiol: Heart Circul Physiol* 2003;285:H1183–H1189.
9. Crane NJ, Schultz ZD, Levin IW. Contrast enhancement for in vivo visible reflectance imaging of tissue oxygenation. *Appl Spectrosc* 2007;61:797–803. [PubMed: 17716397]
10. Crane NJ, Pinto PA, Hale D, et al. Non-invasive monitoring of tissue oxygenation during laparoscopic donor nephrectomy. *BMC Surgery*. submitted
11. Clayman RV, Kavoussi LR, Soper NJ, et al. Laparoscopic nephrectomy. *N Engl J Med* 1991;324:1370–1. [PubMed: 1826761]
12. Clayman RV, Kavoussi LR, Soper NJ, et al. Laparoscopic nephrectomy: initial case report. *J Urol* 1991;146:278–82. [PubMed: 1830346]
13. Gill IS, Carbone JM, Clayman RV, et al. Laparoscopic live-donor nephrectomy. *J Endourol* 1994;8:143–8. [PubMed: 8061673]
14. Ratner LE, Ciseck LJ, Moore RG, Cigarroa FG, Kaufman HS, Kavoussi LR. Laparoscopic live donor nephrectomy. *Transplantation* 1995;60:1047–9. [PubMed: 7491680]
15. Su L, Ratner LE, Montgomery RA, et al. Laparoscopic live donor nephrectomy: trends in donor and recipient morbidity following 381 consecutive cases. *Ann Surg* 2004;240:358–363. [PubMed: 15273562]
16. Sundaram CP, Martin GL, Guise A, et al. Complications after a 5-year experience with laparoscopic donor nephrectomy: the Indiana University experience. *Surg Endosc* 2007;21:724–728. [PubMed: 17334861]

17. Singh D, Finelli A, Rubinstein M, Desai MM, Kaouk J, Gill IS. Laparoscopic partial nephrectomy in the presence of multiple renal arteries. *Urology* 2007;69:444–447. [PubMed: 17382140]
18. Mandal AK, Cohen C, Montgomery RA, Kavoussi LR, Ratner LE. Should the indications for laparoscopic live donor nephrectomy of the right kidney be the same as for the open procedure? Anomalous left renal vasculature is not a contraindication to laparoscopic left donor nephrectomy. *Transplantation* 2001;71:660–664. [PubMed: 11292298]
19. Carter JT, Freise CE, McTaggart RA, et al. Laparoscopic procurement of kidneys with multiple renal arteries is associated with increased ureteral complications in the recipient. *Am J Transplant* 2005;5:1312–1318. [PubMed: 15888035]
20. Matsukura I, I Y, Iwai T. Transanal laser doppler flowmetry to assess microcirculation in the upper rectum during abdominal aortic aneurysmectomy. *Surg Today* 2003;33:812–816. [PubMed: 14605951]
21. Delaney CP, Couse NF, Mehigan D, Keaveny TV. Inferior mesenteric venous sampling, pulse oximetry, and assessment of colonic perfusion during aortic aneurysm surgery. *Dig Dis Sci* 1999;44:1786–1791. [PubMed: 10505715]
22. Glavic Z, Begic L, Rozman R. A new device for the detection and recognition of blood vessels in laparoscopic surgery. *Surg Endosc* 2002;16:1197–200. [PubMed: 12189481]
23. Roberts WW, Dinkel TA, Schulam PG, Bonnell L, Kavoussi LR. Laparoscopic infrared imaging. *Surg Endosc* 1997;11:1221–1223. [PubMed: 9373300]
24. Lau J, Ioannidis JPA, Balk EM, et al. Diagnosing acute cardiac ischemia in the emergency department: a systematic review of the accuracy and clinical effect of current technologies. *Ann Emerg Med* 2001;37:435–460.
25. Lee ES, Bass A, Arko FR, et al. Intraoperative colon mucosal oxygen saturation during aortic surgery. *J Surg Res* 2006;136:19–24. [PubMed: 16978651]
26. Balacumaraswami L, Abu-Omar Y, Choudhary B, Pigott D, Taggart DP. A comparison of transit-time flowmetry and intraoperative fluorescence imaging for assessing coronary artery bypass graft patency. *J Thorac Cardiovasc Surg* 2005;130:315–320. [PubMed: 16077393]
27. Garbade J, Ullman C, Hollenstein M, et al. Modeling of temperature mapping for quantitative dynamic infrared coronary angiography for intraoperative graft patency control. *J Thorac Cardiovasc Surg* 2006;131:1344–1351. [PubMed: 16733168]
28. Sonmez B, Arbatli H, Tansal S, et al. Real-time patency control with thermal coronary angiography in 1401 coronary artery bypass grafting patients. *Eur J Cardio-Thoracic Surg* 2003;24:961–966.
29. Futran ND, Stack BC, Hollenbeak C, Scharf JE. Green light photoplethysmography monitoring of free flaps. *Arch Otolaryngol Head Neck Surg* 2000;126:659–662. [PubMed: 10807336]
30. Krishnan KG, Schackert G, Steinmeier R. The role of near-infrared angiography in the assessment of post-operative venous congestion in random pattern, pedicled island and free flaps. *Br J Plast Surg* 2005;58:330–338. [PubMed: 15780227]
31. Scheufler O, Exner K, Andresen R. Investigation of TRAM flap oxygenation and perfusion by near-infrared reflection spectroscopy and color-coded duplex sonography. *Plast Reconstr Surg* 2004;113:141–152. [PubMed: 14707632]
32. Udesen A, Lontoft E, Kristensen SR. Monitoring of free tram flaps with microdialysis. *J Reconstr Microsurgery* 16:101–106.
33. Delaney CP, Kiran RK, Senagore AJ, Brady K, Fazio VW. Case-matched comparison of clinical and financial outcome after laparoscopic or open colorectal surgery. *Ann Surg* 2003;238:67–72. [PubMed: 12832967]
34. Katz L, Nauriyal V, Nagaral S, et al. Infrared imaging for detection of compartment syndrome. *Acad Emerg Med* 2007;14:S41.
35. Law WL, Lee YM, Choi HK, Seto CL, Ho JWC. Impact of laparoscopic resection for colorectal cancer on operative outcomes and survival. *Ann Surg* 2007;245:1–7. [PubMed: 17197957]
36. Brunt LM, Langer JC, Quasebarth MA, Whitman ED. Comparative analysis of laparoscopic versus open splenectomy. *Am J Surg* 1996;172
37. Peters MB, Camacho D, Ojeda H, et al. Defining the learning curve for laparoscopic splenectomy for immune thrombocytopenia purpura. *Am J Surg* 2004;188:522–525. [PubMed: 15546563]

38. Gardner GP, LaMorte WW, Obi-Tabot ET, Menzoian JO. Transanal intracolonic pulse oximetry as a means of monitoring the adequacy of colonic perfusion. *J Surg Res* 1994;57:537–540. [PubMed: 7967590]

Figure 1.

A) Original laparoscopic image extracted from video footage of surgery. The stapler is at the base of the artery and the vein is immediately to the right of the artery. B) Grayscale tagged image file format (TIFF) of the red CCD response. C) Grayscale TIFF of the blue CCD response. D) Calculated image (red CCD response minus blue CCD response). The vein and artery are indicated by yellow dashed lines. E) The enhanced image consisting of the calculated image overlaid onto the original laparoscopic image.

Figure 2. Visible absorbance spectra of oxygenated and deoxygenated hemoglobin (HbO₂ and Hb, respectively) with overlaid estimated individual CCD responses (red, green and blue, from top to bottom).

Figure 3.

Mean ROI intensity values for arteries and veins in 15 nephrectomy cases (LDNs and LPNs). A dashed threshold to distinguish arteries and veins is drawn at 59.00. The bars indicate one standard deviation, σ .

Figure 4.

A) Laparoscopic image of renal vessels extracted from video footage of a partial nephrectomy. Note the presence of multiple arteries. B) The enhanced 3-CCD image of the vein and arteries. Note, the vein is clearly shaded in blue and the arteries in red. C) Laparoscopic image of renal vessels extracted from video footage of a donor nephrectomy. In this case, multiple renal arteries are also present. D) The enhanced 3-CCD image clearly depicts the vein in blue and the arteries in red. For both cases, ROIs used for mean intensity value calculations are indicated by white, yellow, and green rectangles (vein, left artery, and right artery, respectively).

Figure 5. Mean ROI intensity values calculated for the renal parenchyma prior to vessel clamping (black) and after vessel clamping (gray) for each LDN case. The single asterisk (*) is displayed for $p \leq 0.05$, while a double asterisk (**) is shown for $p \leq 0.01$.

Table 1

Patient demographics for LDNs.

Case	Donor Age (yrs)	BMI (kg/m ²)	Gender	OR time (min)	EBL (ml)	Fluid (ml)*	Urine (ml)
1	26	22.0	F	339	200	6000	1900
2	39	26.8	M	240	400	8500	2400
3	48	26.3	F	465	650	8600	1400
4	50	26.7	M	445	300	6600	1950
5	48	24.5	F	240	400	6200	3000
6	61	20.3	F	340	1200	6200	550
7	39	26.4	M	390	300	8000	1000
8	44	27.9	M	460	200	5000	1600
9	30	22.1	F	360	500	7100	4700
10	24	21.5	F	365	200	6700	1500

BMI — body mass index; OR — operating room; EBL — estimated blood loss

* Fluid was lactated ringers in all cases.

Table 2

Donor creatinine clearance as compared to mean ROI Intensity values pre- and post-clamp and ischemic time. Normal creatinine clearance is 90-140 mL/min for males and 87-107 mL/min for females. Note, in this study, ischemic time is the time lapse between the time of arterial occlusion and the time at which the image of the kidney is taken in the video footage.

Case	Mean ROI Intensity Value (a.u.)		% Difference	Ischemic time (min)	Donor Creatinine Clearance (mL/min)
	<i>pre-clamp</i>	<i>post-clamp</i>			
1	62.56	37.02	-40.8	1.5	115
2	61.18	25.94	-57.6	1.5	104
3	82.54	71.69	-13.2	2.0	94
4	92.45	66.49	-28.1	2.0	151
5	84.15	64.88	-22.9	0.5	105
6	79.64	58.43	-26.6	1.5	84
7	86.59	34.73	-59.9	1.0	104
8	84.57	78.57	-7.1	1.5	105
9	76.78	44.15	-42.5	1.0	99
10	81.08	36.83	-54.6	2.0	142