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# Maximizing Console Surgeon Independence during Robot-Assisted Renal Surgery by Using the Fourth Arm and TilePro™

Craig G. Rogers, M.D., Rajesh Laungani, M.D., Akshay Bhandari, M.D.,
Louis Spencer Krane, M.D., Daniel Eun, M.D., Manish N. Patel, M.D.,
Ronald Boris, M.D., Alok Shrivastava, M.D., and Mani Menon, M.D.

## Abstract

***Purpose:*** We describe multiple uses of the fourth robotic arm and TilePro™ on the da Vinci® S surgical system to maximize console surgeon independence from the assistant during robot-assisted renal surgery.
***Materials and Methods:*** We prospectively evaluated the use of the fourth robotic arm and TilePro on the da Vinci S during robot-assisted radical nephrectomy (RRN) and robot-assisted partial nephrectomy (RPN). The fourth robotic arm was used to provide kidney retraction, place the renal hilum on stretch, control vascular structures, apply and remove bulldog clamps during partial nephrectomy, and secure renal capsular stitches. TilePro was used to project intraoperative ultrasonography and preoperative CT images onto the console screen.
***Results:*** From January 2006 to June 2008, 90 robot-assisted kidney procedures were performed, of which the fourth robotic arm was used in 46 cases (RRN, 18; RPN, 24; nephroureterectomy, 4). The fourth robotic arm facilitated consistent kidney retraction for dissection of the renal hilum and mobilization of the kidney. The robotic Hem-o-Lok clip applier effectively controlled renal hilar vessels during eight RPN cases and secured renal capsular stitches during two RPN cases. Bulldog clamps were successfully applied to the renal artery during RPN using the fourth arm in two cases. TilePro was used during 22 RPN cases to project intraoperative ultrasonographic images and preoperative CT images onto the console screen as a picture-on-picture image to guide tumor resection.
***Conclusions:*** Robotic instruments used with the fourth robotic arm may give the console surgeon greater independence from the assistant during robot-assisted kidney surgery by facilitating steps such as kidney retraction, hilar dissection, and vascular control. The TilePro feature of the da Vinci S can be used to project intraoperative ultrasonography and preoperative imaging onto the console screen, potentially guiding tumor localization and resection during RPN without the need to leave the console to view external images.

## Introduction

A SKILLED SURGICAL ASSISTANT is important for success in robot-assisted kidney surgery. The role of the bedside assistant and the fourth robotic arm has been described for robot-assisted radical prostatectomy.[1–4] Robot-assisted partial nephrectomy (RPN)[5–11] and robot-assisted radical nephrectomy (RRN)[12] have been described, but the role of the surgical assistant and the fourth robotic arm during these surgeries is not well defined.

During robot-assisted kidney surgery, the assistant may have to perform tasks often performed by the surgeon, such as kidney retraction, clipping vessels, and placement of clamps for hilar control. The console surgeon may lose some autonomy to the assistant during these steps. In addition, the surgeon may have to leave the console during RPN to view intraoperative ultrasonographic or preoperative axial images needed to guide tumor localization and resection.

TilePro™ is a multi-image display mode of the da Vinci® S surgical system (Intuitive Surgical, Sunnyvale, CA) that allows viewing of external images as a picture-on-picture display on the three-dimensional console screen. We hypothesized that the surgeon could gain greater independence during RPN and RRN by using the fourth robotic arm for

Vattikuti Urology Institute, Henry Ford Hospital, Detroit, Michigan.

self-assistance and TilePro for integration of radiographic images on the console screen to guide tumor localization and resection.

## Materials and Methods

Between January 2006 and June 2008, a total of 90 robot-assisted kidney procedures were completed at our institution by two surgeons (CR, MM), of which the fourth robotic arm was used in 46 cases (RRN, 18; RPN, 24; nephroureterectomy, 4). The use of the fourth robotic arm and TilePro were prospectively evaluated. The fourth robotic arm was used preferentially in patients with a smaller body habitus, less prominent hip bones, or more challenging kidney tumors based on size and location. The decision to use the fourth robotic arm was a subjective decision made in the operating room once the patient was placed in the flank position, the abdomen was insufflated, and the available space was assessed.

The robotic fourth arm was not used in 44 patients because of space limitations, including 22 obese patients (body mass index [BMI] $>30$ kg/m$^2$), and 6 patients in whom a retroperitoneal approach was used, precluding the use of the fourth robotic arm because of space limitations. A retroperitoneal approach was used for selected patients with posterior, middle area, or lower pole tumors and/or extensive previous abdominal surgery. TilePro was used during most RPN procedures for viewing of intraoperative ultrasonography and axial imaging except for small, exophytic tumors in which external imaging was not thought to be necessary.

### *Patient positioning, fourth arm setup, and use of fourth arm*

All robot-assisted kidney procedures were performed using the da Vinci S surgical system. Patients were positioned in full-flank position, and pneumoperitoneum was established using a Veress needle. Our technique of port placement and positioning has been described previously[8,13] and consists of a lateral camera port and a medial 12-mm assistant port. The fourth robotic arm port was positioned approximately 3 to 4 fingerbreadths medial to the inferior robotic instrument port (Fig. 1). The fourth robotic arm was used to provide kidney retraction, place robotic hemolock clips on vessels and sutures, and to apply a bulldog clamp on the renal artery during RPN.

**1. Kidney retraction using the fourth robotic arm.** Robotic instruments used with the fourth robotic arm for kidney retraction included the ProGrasp,™ dual blade retractor, and the double fenestrated retractor. The robotic fourth arm instrument was positioned under the ureter, and the fourth robotic arm was used to lift the kidney anteriorly to place the renal hilum on stretch for hilar dissection (Fig. 2a).

**2. Robotic Hemolock clip application.** The robotic hemolock clip applier was used with the fourth robotic arm or other robotic arms for clipping smaller vessels, renal hilar vessels (Fig. 3a), and for securing renal capsular stitches during RPN (Fig. 3b). The robotic hemolock clip applier holds a single 10 mm hemolock clip that is loaded externally and introduced by the assistant into the robotic port. The instrument is activated on the da Vinci S surgical system by rolling the wrist. Care must be taken not to inadvertently squeeze the fingers, which may cause the clip to misfire.

**3. Robotic placement of hilar clamps for warm ischemia and RPN technique.** We evaluated the ability of the console surgeon to apply a bulldog clamp on the renal artery to achieve warm ischemia during partial nephrectomy using the fourth robotic arm. A short, straight bulldog clamp (Klein Surgical, Inc, Bulverde, TX) was introduced into the abdomen by the assistant through the 12-mm assistant port. The robotic ProGrasp instrument on the fourth robotic arm was used to grasp the flat surface of the bulldog clamp at a 90-degree angle, which allowed it to be applied and removed from the renal artery for warm ischemia under control of the console surgeon (Fig. 4). After removal of the bulldog clamp from the renal artery by the console surgeon, the bulldog clamp was retrieved from the abdomen by the surgical assistant using the laparoscopic bulldog remover. RPN was performed as previously described[10] using robotic monopolar scissors to sharply excise tumors and by performing sutured reconstruction of the kidney (Fig. 2b and c). For two RPN cases, a suture-cut robotic needle driver was used in the left hand to allow the surgeon to cut sutures independently.

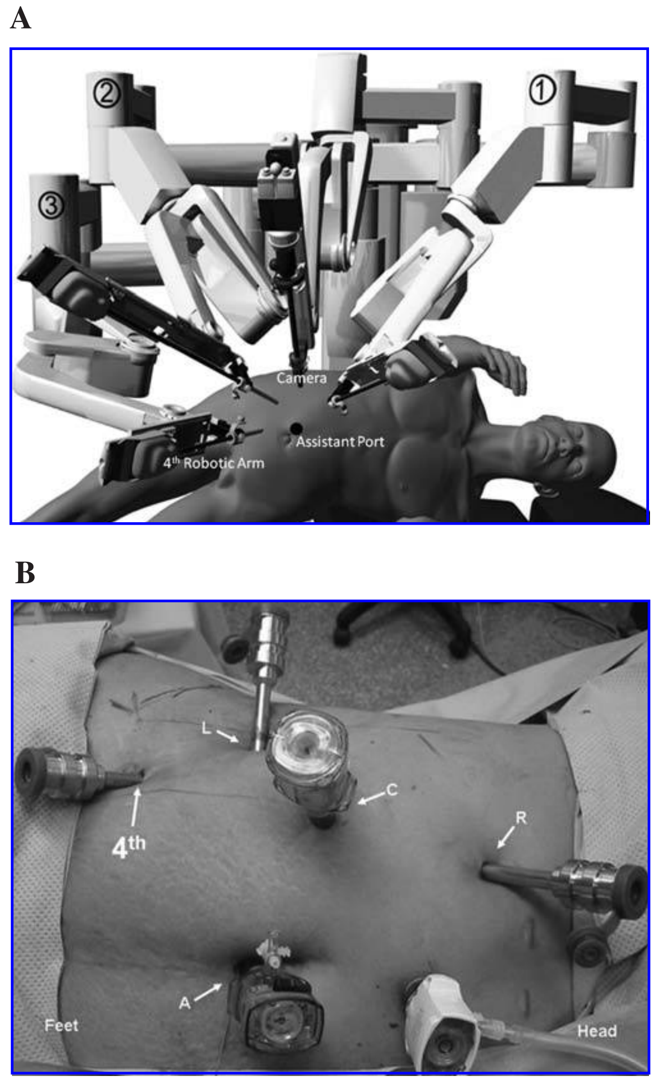


**FIG. 1.** Port placement strategies using the fourth robotic arm (arrow) for robot-assisted kidney surgery. (**A**) Lateral camera port and medial assistant port. (**B**) Modified lateral camera port placement. L = left robotic arm; C = camera; R = right robotic arm; A = assistant; 4th = robotic fourth arm.

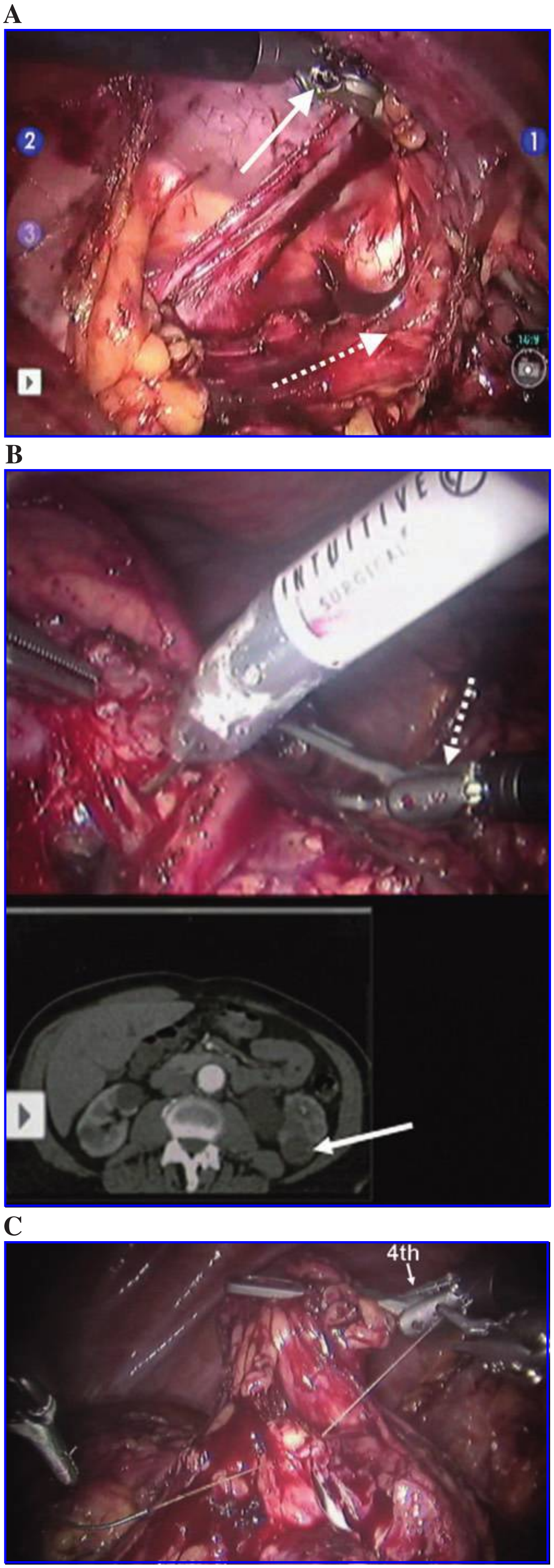


**FIG. 2.** Use of fourth robotic arm during robot-assisted kidney surgery. (**A**) Robotic double fenestrated grasper (solid arrow) used as a fourth arm instrument to elevate the kidney to place the renal hilum (dashed arrow) on stretch for subsequent dissection. (**B**) Use of fourth robotic arm (dashed arrow) to position the kidney to optimize tumor resection during robot-assisted partial nephrectomy (tumor marked with solid arrow on CT on lower left). (**C**) Use of fourth robotic arm to stabilize the kidney during suture closure of collecting system in robot-assisted partial nephrectomy.

### *Setup and use of TilePro*

TilePro is a multi-image video display mode of the da Vinci S surgical system that allows the surgeon to simultaneously view up to two additional images, such as intraoperative ultrasonography and preoperative CT images, as a picture-on-picture on the three-dimensional console screen and assistant monitors. TilePro was used during RPN cases to localize tumors and to delineate margins of resection (Fig. 5).

The TilePro setup was performed as demonstrated in Figure 6. The ultrasound machine (Alpha 5 model, Aloka Inc, Wallingford, CT) and the hospital computer with Picture Archiving and Communication System were connected to the back of the surgeon console and vision cart, respectively, using S-video connections. The surgeon can activate and switch back and forth from TilePro mode with a short tap on the camera pedal (Fig. 6a). The TilePro images can be viewed on other monitors for the assistant and for recording by having the assistant select "Surgeon's view" on the touch screen monitor (Fig. 6b). The size of the TilePro image can be increased or decreased by pushing the up or down arrows on the left side control panel (Fig. 6c). A wireless mouse taped to the console allowed the console surgeon to scroll through axial images independently.

## Results

A total of 90 robot-assisted kidney procedures were performed by the two surgeons during the study period. The fourth robotic arm was used in 46 cases (RRN, 18; RPN, 24; nephroureterectomy, 4) using robotic instruments, including the ProGrasp, dual blade retractor, and the double fenestrated retractor. Our study included 43 obese patients (BMI $>30$ kg/m$^2$). We were only able to use the robotic fourth arm on 21 patients because of body habitus, although we were able to successfully perform procedures with the fourth robotic arm on selected patients with a BMI as high as 48.8 kg/m$^2$. The fourth robotic arm facilitated consistent kidney retraction and exposure for dissection of the renal hilum and exposure of the kidney in all cases.

The robotic hemolock clip applier successfully achieved control of renal hilar vessels during eight RRN cases. During two RPN cases, renal capsular stitches were successfully secured with robotic hemolock clips applied by the fourth robotic arm. Bulldog clamps were successfully placed and removed from the renal artery during RPN using the robotic ProGrasp instrument on the fourth robotic arm in two cases. We did not experience any instances of misfiring of robotic hemolock clips.

The fourth robotic arm was associated with a shorter mean operative time for RRN (224 versus 322 min, $P < 0.001$), but there was no statistically significant improvement in mean operative time for RPN (255 versus 258 min, $P = 0.92$). Two

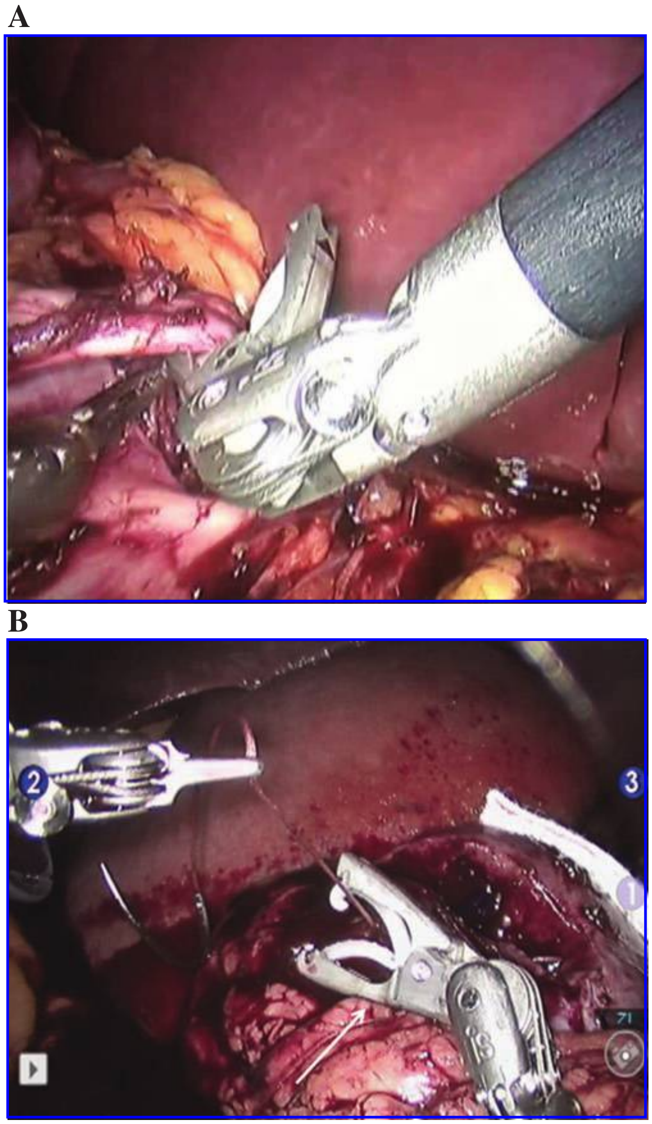

**FIG. 3.** Use of robotic Hem-o-Lok clip applier during robot-assisted kidney surgery. (**A**) Ligation of renal artery during robot-assisted nephrectomy using robotic hemolock clip under control of the console surgeon. (**B**) Securing renal capsular stitches during robot-assisted partial nephrectomy using robotic hemolock clip as a fourth arm instrument (arrow) under control of the console surgeon.

complications occurred after partial nephrectomy for large central tumors among the fourth arm group: A delayed urine leak necessitating ureteral stenting and a delayed renal parenchymal bleed necessitating embolization. There were no complications after partial nephrectomy in the group in which the fourth arm was not used.

After radical nephrectomy, two morbidly obese patients in each group had wound breakdown associated with infection. There was no statistically significant difference in complications between the fourth-arm and non–fourth-arm groups for partial nephrectomy ($P = 0.16$) or radical nephrectomy ($P = 0.81$).

TilePro successfully projected live intraoperative ultrasonographic images and preoperative CT images onto the console screen in 22 RPN cases to guide tumor localization and resection while avoiding the need for the surgeon to exit the console to view the images.

## Discussion

A skilled assistant is a key component to successful robot-assisted surgery. The fourth robotic arm allows the console surgeon to provide self-assistance. The role of the bedside assistant and the fourth robotic arm has been described for robot-assisted radical prostatectomy.[1-4] RPN and RRN have been described, [5–10] but the role of the fourth robotic arm and the bedside assistant in these procedures has not been clearly established.

In robot-assisted kidney surgery, the assistant often performs important steps, including kidney retraction, hilar traction, and ligation or clamping of hilar vessels. The fourth robotic arm could potentially help the console surgeon to perform these tasks independently. Bhayani[5]described a four-arm technique for partial nephrectomy. We expand on this initial report of technique with demonstration of the use of both the fourth robotic arm and TilePro in several different clinical situations during robot-assisted kidney surgery to offer the console surgeon greater autonomy from the assistant.

The fourth robotic arm of the da Vinci S surgical system may help maximize autonomy of the console surgeon during robot-assisted kidney surgery for performing tasks such as kidney retraction and hilar clamping during RPN. Upward retraction of the kidney with the fourth robotic arm can be used to place the renal hilum on stretch and facilitate two-handed, precise renal hilar dissection.

We found that the fourth arm, when used with the dual blade retractor, double fenestrated retractor, or ProGrasp retractor, provided consistent kidney retraction, leaving two robotic instruments available for precise dissection of the hilum. For kidney retraction, we prefer the long dual blade and double fenestrated retractors. The dual blade retractor has a wide surface area for atraumatic kidney retraction. The double fenestrated blade retractor provides comparable surface area with the added benefit of being able to be used as a grasper to grab perinephric fat for kidney positioning.

The robotic hemolock clip applier as a fourth arm instrument may be used to ligate renal hilar vessels during RRN and secure capsular sutures during RPN. The robotic-wristed hemolock clip applier allowed the console surgeon to place clips

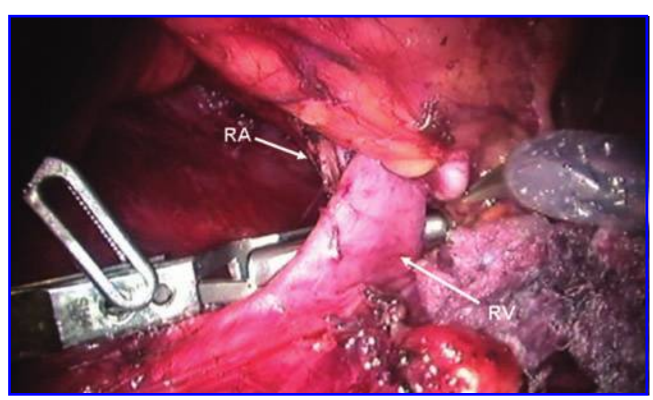


**FIG. 4.** Application of bulldog clamp during robot-assisted partial nephrectomy by the console surgeon using robotic ProGrasp as a fourth arm instrument. RA = renal artery; RV = renal vein.

A

B

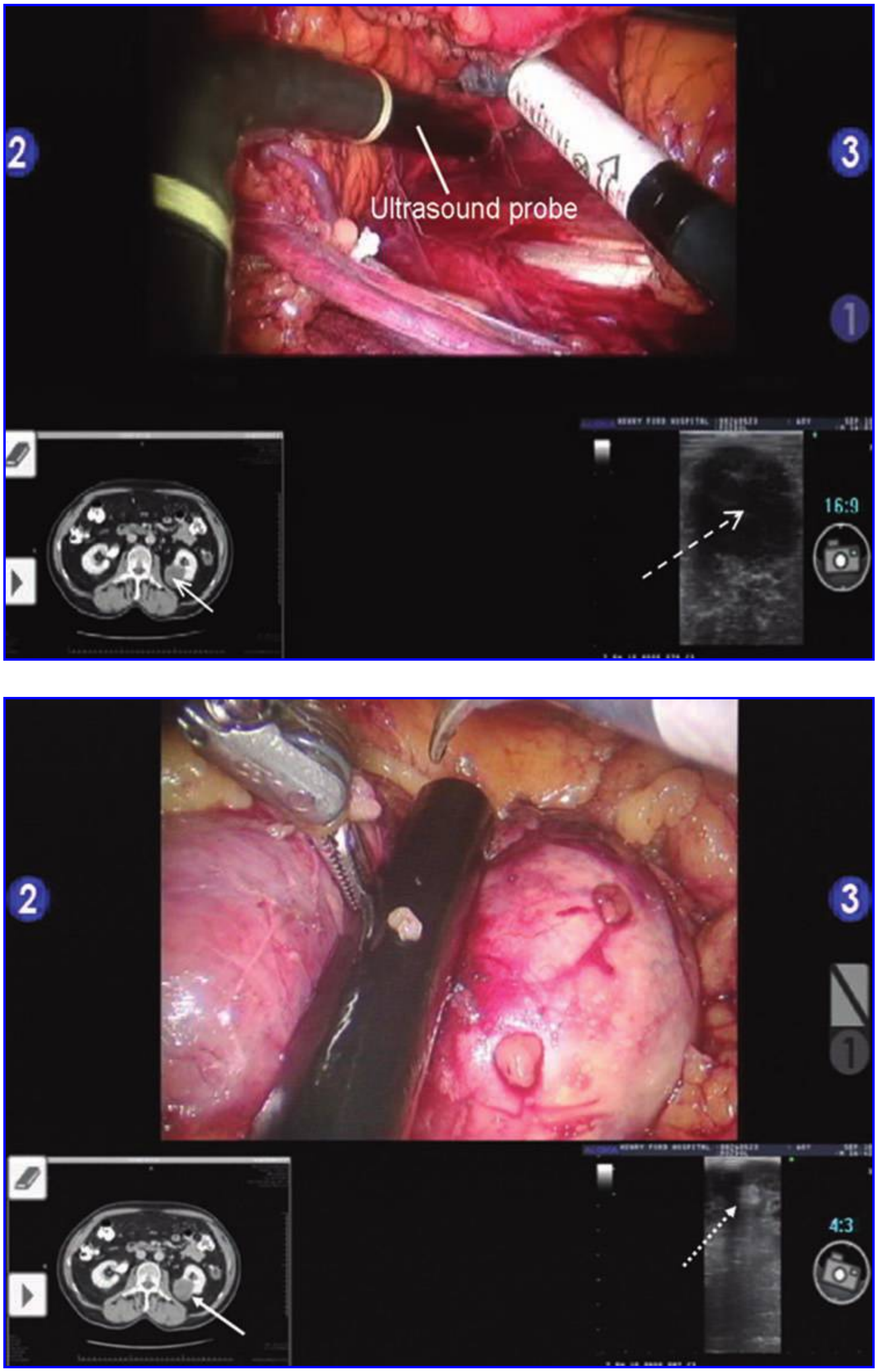


**FIG. 5.** Use of TilePro during robot-assisted partial nephrectomy. (**A**) TilePro image demonstrating ability to simultaneously view live intraoperative ultrasonographic image (lower right, dashed arrow points to tumor) and preoperative CT image (lower left, solid arrow points to tumor) on console screen. In this instance, TilePro images were used for tumor localization to guide appropriate entry into the Gerota capsule. (**B**) TilePro being used to delineate tumor margins. Tumor seen on intraoperative ultrasonography (dashed arrow) and CT images (solid arrow).

independently and accurately at angles that might be challenging for an assistant with a straight laparoscopic clip applier, potentially reducing the potential for the assistant past-pointing the clip or avulsing the vessel. The hemolock clip applier can be used as a fourth arm instrument or with other robotic arms to increase autonomy of the console surgeon.

We found application of robotic hemolock clips to be straightforward with a minimal learning curve. It is impor-

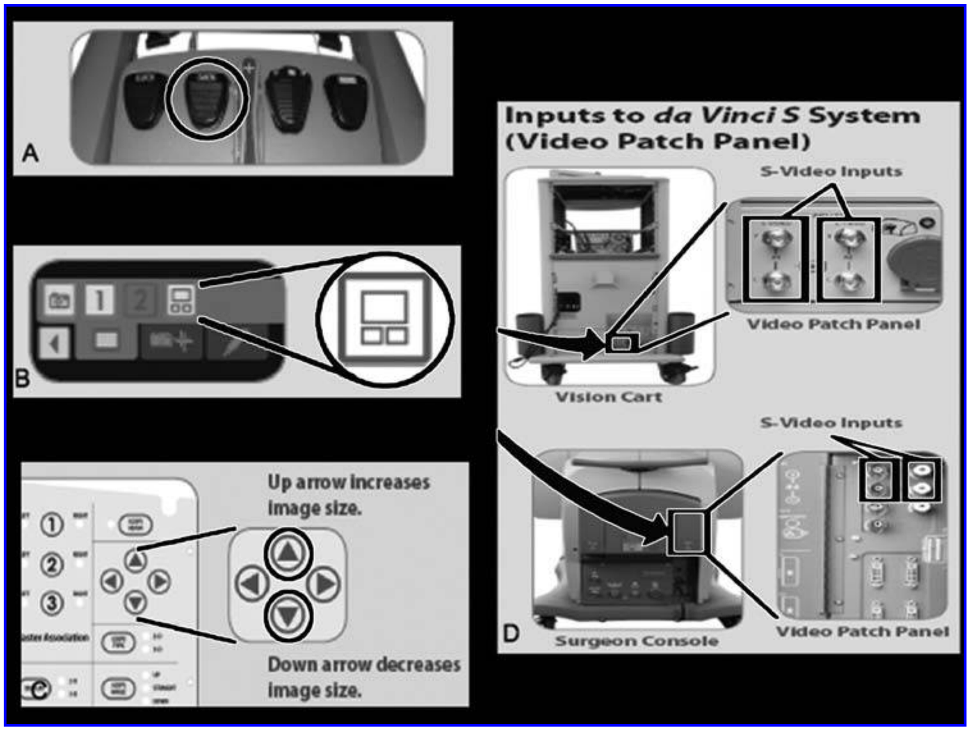


**FIG. 6.** Setup and activation of TilePro. (**A**) Surgeon console activation by tapping the camera control foot pedal (circle). (**B**) Activation of TilePro images on other monitors for the assistant and recording by selecting Surgeon's View in the menu of the patient side touch screen. (**C**) Change size of three-dimensional surgical image using the up or down arrow on the left side pod. (**D**) S-video connection of equipment to surgeon console and vision cart video inputs for transmission of auxiliary images via TilePro.

tant to note that activation of the robotic hemolock instrument on the da Vinci S system is done by rotation of the wrist, not by pinching the fingers, because this may cause the applicator to misfire. In our experience, no clips were misfired or misplaced. In the event that a robotic hemolock clip were to misfire and not close completely, it could be removed from the surrounding tissue by the robotic surgeon and handed to the assistant to remove through the assistant port.

One disadvantage of the robotic hemolock clip applier is that it is single use only and requires removal and reloading between applications, which can be cumbersome. Development of a multifire clip applicator could increase efficiency of clip application. We recommend having two robotic hemolock clip applicators available so that one can be loaded while the other is being used. The use of hemolock clips for vascular control during donor nephrectomy had been questioned after Teleflex (Research Triangle Park, NC) had made a contradictions statement in 2006. A recent multi-institutional study of 1695 laparoscopic nephrectomy procedures using hemolock clips for vascular control, however, demonstrated no clip failures in any procedures.[14]

The robotic fourth arm allowed for successful application and removal of bulldog clamps by the console surgeon to achieve warm ischemia during RPN. The ProGrasp instrument has sufficient closing force to open the bulldog clamp when applied to the flat surface of the clamp. It is not specifically designed for this purpose, however, and we are uncertain how this use will affect the lifespan and function of the instrument. Also, the need to grasp the clamp at a 90-degree angle makes application of the clamp somewhat cumbersome. Robotic application of the bulldog clamp may potentially be of benefit if the bedside assistant is inexperienced or lacks the necessary angle to clamp the hilum. Until a modified bulldog clamp or robotic instrument is designed to facilitate end-on grasping of the bulldog clamp, we recommend placement of the bulldog clamps by the assistant using the laparoscopic bulldog applier.

The fourth robotic arm could potentially avoid the need for an experienced laparoscopic surgeon as the bedside assistant. The fourth robotic arm allowed us to successfully complete robot-assisted kidney surgery with a resident or physician assistant who lacked formal laparoscopic training. Of the 24 partial nephrectomies that were performed with the fourth arm, 18 had a midlevel resident at the bedside, while 6 had a junior resident or physician assistant. A single bedside assistant is still necessary for basic tasks such as suctioning and irrigation, delivery and cutting of sutures, and changing of robotic instruments. The application of the fourth arm to robotic kidney surgery may be of particular benefit to those urologists who practice in centers with limited skilled assistance. In addition, the fourth arm port may also be used as an active assistant port when the fourth arm is undocked.

The TilePro feature of the da Vinci S system can facilitate tumor localization and identification of tumor margins during RPN. During RPN, TilePro allows the surgeon to view live intraoperative ultrasonographic footage and preoperative CT images as a picture-on-picture display on the console screen, providing information such as tumor location, depth, proximity to hilar structures, and margins of resection without the need to leave the console to view external images. TilePro can also be used to access any information on the hospital computers, such as laboratory values and other imaging studies.

The fourth robotic arm has some benefits over traditional robot-assisted surgery. The fourth robotic arm was associated with shorter mean operative times for RRN, although there was no statistically significant improvement in operative times for RPN. During this study, we experimented with different port locations and instrumentation with the fourth robotic arm, which may have masked any potential improvement in operative times with RPN. Even without an improvement in operative time, however, there could be a theoretical benefit of facilitating more complex surgeries by the console surgeon because of less dependence on the surgical assistant.

Although the fourth robotic arm can facilitate robot-assisted kidney surgery, it is not essential, and we do not necessarily advocate its use in all cases. We do think, however, that it may be useful in selected patients with tumors that are large or in challenging locations.

There are limitations to the fourth robotic arm and TilePro that should be mentioned. The fourth robotic arm on a da Vinci Standard system is difficult to use for robot-assisted kidney surgery because its design makes it harder to clear the hip of the patient. The fourth arm of the da Vinci S system is less likely to encounter this problem, although it still may be difficult to use in obese patients, patients with prominent hips or a short torso, and with a retroperitoneal approach. We recognize that our selection criteria for use of the fourth robotic arm is somewhat subjective and that development of more specific criteria in future studies would be beneficial.

A limitation of TilePro is that the laparoscopic ultrasound probe is still under control of the bedside assistant, although the console surgeon can direct the probe tip with the robotic instruments. Future development of a fourth robotic arm articulating ultrasound probe could provide the console surgeon additional control and autonomy during this step.

TilePro is not an image-guided system that integrates a superimposed image during partial nephrectomy, as described by Ukimura et al.[15] Therefore, the console surgeon may need an assistant to scroll through CT images being imported to the console screen via TilePro. We overcame this limitation by using a wireless mouse taped to the console, allowing the console surgeon to scroll through radiographic images independently.

## Conclusion

The fourth robotic arm of the da Vinci S surgical system may be used to provide the console surgeon with greater independence from the surgical assistant during robot-assisted kidney surgery when performing tasks such as kidney retraction and ligation or clamping of renal hilar vessels. The TilePro feature can be used to view intraoperative ultrasonography and preoperative images on the console display to guide tumor resection during RPN.

## Disclosure Statement

No competing financial interests exist.

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Address reprint requests to:
*Craig Rogers, M.D. Henry Ford Hospital*
*Vattikuti Urology Institute*
*2799 West Grand Blvd.*
*Detroit, MI 48202-2689*

*E-mail:* Crogers2@hfhs.org

### Abbreviations Used

BMI = body mass index
RPN = robot-assisted partial nephrectomy
RRN = robot-assisted radical nephrectomy

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