INTRODUCTION

Radical nephrectomy (RN) is established as the gold standard treatment for renal cell carcinoma (RCC). The technological advancements and the widespread adoption of robot-assisted surgery have led to an increased implementation of robot-assisted RN [1,2]. The occurrence of inferior vena cava (IVC) thrombus is observed in 4%–10% of RCC patients [3]. Post-RN with IVC thrombectomy, the 5-year survival rate for patients with nonmetastatic RCC ranges between 50%–65%. Despite robot-assisted RN (RARN) with IVC thrombectomy proving to be feasible and potentially lessening complication rates, it remains technically demanding, with significant associated morbidity and mortality risks. Thus, meticulous patient selection and careful surgical planning are of paramount importance. This review aims to encapsulate the latest advancements and outline the detailed surgical processes involved in RARN with IVC thrombectomy.

Key Words: Renal cell carcinoma, Tumor thrombus, Nephrectomy, Thrombectomy, Surgical technique

RCC with IVC thrombus, the evolution of minimally invasive surgery technologies has facilitated a growing adoption of robot-assisted RN (RARN) with IVC thrombectomy in selected cases [5-8]. For individuals undergoing RN for RCC, robot-assisted surgeries confer benefits over the open surgical approach, including reduced hospital stay durations and diminished complication rates. RARN yields outcomes comparable to those of laparoscopic RN, albeit at increased expenses [9]. Crocerossa et al. [9] conducted a subgroup analysis of 2 studies [10,11] to evaluate the benefits and drawbacks of robotic versus open level I–II [12] IVC thrombectomy alongside RN. This subgroup analysis unveiled a significantly reduced transfusion rate for the
robotic surgery cohort, alongside a pronounced advantage of the robot-assisted technique in reducing the length of hospital stays and the overall rate of complications, without impacting the rate of major complications [9]. Nevertheless, conducting RARN with IVC thrombectomy poses significant technical challenges and is linked with considerable risks of morbidity and mortality. Thus, meticulous patient selection and strategic surgical planning are paramount. This review aims to encapsulate the latest progress and provide a detailed account of the step-by-step surgical techniques involved in RARN with IVC thrombectomy.

**DIAGNOSTIC IMAGING**

The preoperative evaluation of the thrombus's extent and characteristics is crucial for guiding decision-making and surgical strategy, including the selection of a surgical approach and determining the necessity for cardiopulmonary bypass. While venacavography was once regarded as the gold standard for imaging, it carries risks of vascular complications and contrast-induced renal insufficiency. Presently, computed tomography (CT) and magnetic resonance imaging (MRI) stand as the primary imaging modalities for preoperative assessment in RCC cases with IVC thrombosis. Multiplanar CT imaging has emerged as the go-to for the diagnosis and staging of RCC, boasting a sensitivity and specificity of 93% and 97%, respectively, in identifying tumor thrombus [13]. MRI surpasses CT in sensitivity regarding the evaluation of a thrombus's extent and features, providing both direct and indirect signs of caval wall invasion, such as contact with the caval wall, unusual signals from the IVC wall, obstruction of the IVC lumen, and alterations in IVC diameter [14-16]. The timing of these imaging assessments is critical for surgical planning, as the evolution of the tumor thrombus might necessitate significant alterations to the surgical approach. Consequently, it is advised that both CT and MRI be performed within a 30-day window, and ideally no more than 14 days prior to the operation [17].

**IVC THROMBUS LEVEL CLASSIFICATIONS**

While numerous classifications have been suggested, lacking consensus on the optimal one for determining the surgical strategy, the classification by Neves and Zincke [12] subsequently modified by Blute et al. [18] is presently the most widely utilized. The levels of tumor thrombus are categorized as 0 (thrombus confined to the renal vein, identified either clinically or during pathological examination), I (thrombus extending ≤ 2 cm above the renal vein), II (thrombus extending >2 cm above the renal vein but remaining below the hepatic veins), III (thrombus at the level of or surpassing the hepatic veins but not reaching the diaphragm), and IV (thrombus extending above the diaphragm). The management of a level III thrombus in the IVC presents a significant challenge to surgeons due to its reduced accessibility. Ciancio et al. [19] developed an alternative classification to more precisely define level III thrombus by its anatomical position relative to the hepatic veins (categorized into IIIa: infrahepatic thrombus, IIIb: hepatic thrombus, IIIc: suprahepatic, infradiaphragmatic thrombus, and IIId: suprahepatic, supradiaphragmatic, infraatrial thrombus), introducing a method for the safe resection of these tumors via a transabdominal route without the need for cardiopulmonary bypass (Table 1). The determination of the surgical approach (e.g., open vs. robot-assisted, and the usage of cardiopulmonary bypass) primarily depends on the thrombus level. Other considerations include tumor size and location, as well as the surgeon’s expertise and preference. For patients with thrombi at a lower level, robot-assisted surgery may be executed by experienced surgeons at high-volume institutions.

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PREOPERATIVE PREPARATIONS

The 2 primary constituents linked to IVC thrombosis include the tumor thrombus, harboring tumor cells, and the bland thrombus, comprised solely of blood coagulum without tumor cells. Patients with RCC are subjected to a heightened risk of pulmonary embolism, attributed to the malignancy-associated hypercoagulability alongside venous thrombosis. The administration of anticoagulants prior to surgery is capable of mitigating the risk of pulmonary embolism and diminishing the thrombus size; thus, contemplating anticoagulant administration is advised. Low-molecular -weight heparin emerges as the preferred choice, with its last dosage recommended 24 hours before the operation while warfarin serves as an alternative, ceasing at least 5 days before and bridged until the operation.

To date, no randomized, controlled studies have been performed to assess the utility of renal artery embolization prior to RN. Preoperative angioembolization can be considered since tumor thrombi have an independent blood supply arising from the renal artery and/or aorta in one third of cases. Angiographic infarction of the blood supply to the tumor thrombus can help shrink a large thrombus to a more manageable size, potentially avoiding the need for bypass or extensive mobilization of the liver [20]. Although we seldom use angioembolization, it can be considered in patients with (1) left RCC with thrombus when IVC thrombectomy is performed first and then left nephrectomy, (2) bulky retroperitoneal lymph nodes, or (3) extensive collateral circulations that get access to renal artery is difficult. The optimal timing for embolization is unknown. Despite angioembolization generally being executed the day preceding surgery, the potential for iatrogenic pulmonary embolism, flank discomfort, and tumor lysis syndrome warrants consideration [20]. Hence, opting for embolization immediately before surgery might prove advantageous.

The deployment of IVC filters may be contemplated to avert thrombus migration during surgical intervention; however, it is crucial to acknowledge the potential for inducing contralateral renal and hepatic vein thrombosis, embolism, and interference with IVC thrombectomy [20]. Should the implantation of an IVC filter be contemplated, positioning it within 48 hours before surgery is advised to minimize the possibility of thrombus infiltration into the filter [21].

For level II–IV thrombus, the employment of transeosophageal echocardiography (TEE) is advocated to assess the thrombus extent, monitor for intraoperative thrombus dislocation, detect residual tumor, and evaluate cardiac function during IVC clamping [22-25].

Foremost in the preoperative preparations for RARN with IVC thrombectomy is ensuring the availability of a vascular surgeon on standby, prepared for any exigencies and conversion to open surgery.

STEP-BY-STEP SURGICAL PROCEDURES

1. Port Configuration

A 12-mm disposable trocar is strategically positioned at the umbilicus for assistant use. Four 8-mm robotic trocars are systematically inserted in a linear yet slightly oblique arrangement lateral to the rectus abdominis muscle, optimizing operational efficiency. A 5-mm trocar is strategically placed below the xiphoid process to facilitate liver retraction (Fig. 1A).

2. Step 1. Adhesiolysis and Liver Retraction

Existing intestinal, omental, and liver adhesions, when encountered, are meticulously lysed. By dividing the right triangular ligament of the liver, a non-traumatic locking grasper can be securely affixed to the diaphragm muscle, ensuring adequate liver retraction. Dissection is methodically advanced superiorly to the upper pole of the kidney, with both the hepato-renal and posterior coronary ligaments incised, facilitating an extension to the diaphragm.


Medial reflection of the bowel is achieved through precise blunt and sharp dissection along the white line of Toldt, just lateral to the colon. With the colon reflected, the duodenum is carefully mobilized medially to comprehensively expose the IVC up to the level of the aorta.
4. Step 3. Renal Hilum Control

The standard practice entails accessing the renal artery via the interaortocaval space, aiming to minimize kidney and renal vein manipulation thus preserving the integrity of the tumor thrombus. An exhaustive interaortocaval dissection reveals necessary for a comprehensive IVC dissection, isolation of the left renal vein, and ligation of lumbar veins. The Carter-Thomason needle (CooperSurgical, Trumbull, CT, USA) assists in retracting the bowel to the abdominal wall, unveiling the IVC and left renal vein (Fig. 2A). Diligent dissection posterior to the vein aids in spotting the artery with minimal engagement, hence avoiding any disruption to the IVC tumor thrombus. Upon encountering enlarged aortocaval lymph nodes during dissection, their removal is imperative. The artery, identified by its pulsating white, tubular structure running transversely towards the kidney and situated posterior to the IVC, is securely clipped and severed at the interaortocaval space (Fig. 2B). The left renal vein is meticulously liberated and encircled with a twice-wrapped and clipped vessel loop.

5. Step 4. IVC Dissection

Initiating at the lateral border, the IVC is dissected, with the gonadal vein subsequently identified, dissected, and divided. The ureter undergoes isolation and division. Utilizing the fourth arm, the lower pole of the kidney is manipulated anterolaterally to unmask the renal hilum. Applying gentle techniques, the hilar tissue attachments, positioned posterior and inferior to the vein, are cautiously dissected and liberated using Maryland bipolar forceps and monopolar curved scissors (Intuitive Surgical Operations, Inc., Sunnyvale, CA, USA) (Fig. 2C).

6. Step 5. Posterior IVC Dissection

Commencing at the infrarenal level, the IVC’s posteromedial surface is liberated, extending upwards to the liver, superior to the tumor thrombus. Lumbar veins, draining into the IVC posteriorly, are meticulously isolated, clipped, and divided (Fig. 2D), a strategy crucial in averting massive bleeding during cavotomy and thrombus extraction. Upon thorough liberation and mobilization, the infrarenal IVC is encircled with a vessel loop, securely clipped using a Hem-o-lok (Fig. 2E). The posterior liver surface might reveal short hepatic veins; each vein is carefully isolated, clipped, and divided. Severing a short hepatic vein enhances the available space above the upper thrombus margin for safe vascular clamping. Progressing superolaterally and slightly inferior to the liver, the right adrenal vein is dissected, ligated, and cut. Beyond the short hepatic veins, the IVC is meticulously
encircled with a vessel loop. Ultrasound deployment offers precise tumor thrombus extent evaluation, guiding the optimal vessel loop positioning.

7. Step 6. Completion of Kidney Dissection

Employing both blunt and sharp dissection techniques, the kidney is liberated and secured within a laparoscopic bag; a clip application on the thread ensures its closure. A Carter-Thomason needle is utilized to draw the thread to the skin surface, maintaining minimal traction (Fig. 2F).

The laparoscopic bag further serves to retract the kidney and isolate the thrombus immediately post-IVC incision.

8. Step 7. IVC and Left Renal Vein Clamping

A systematic approach is employed for the sequential clamping of the infrarenal IVC, left renal vein, and suprarenal IVC. The vessel loop is then retrieved, tightly cinched over the vein, and clipped (Fig. 2G).

A strategic lateral incision on the IVC, just inferior to the renal vein ostium, initiates this phase. The incision extends vertically and cranially to the ostial margin, calibrated to an optimum width for thrombus delivery. Employing the thread of the laparoscopic bag facilitates the kidney and thrombus retraction. The tumor thrombus extraction process is executed with utmost precision, ensuring no force or excessive manipulation is applied to prevent thrombus disintegration or tumor spillage (Fig. 2H). The IVC’s posterior wall, at the renal vein ostium level, undergoes incision. Both the renal vein and tumor thrombus are introduced into a laparoscopic bag, sealed and secured by thread pulling. An exhaustive inspection of the vena cava lumen is conducted to detect residual tumors or wall invasion, with any suspicious regions subjected to biopsy or resection.

10. Step 9. Closure of the Cavotomy

A continuous running suture using 4-0 Prolene suture facilitates the IVC closure (Fig. 2I). Heparinized saline irrigation is performed concurrently with suturing. Prior to the final closure, releasing the infrarenal vessel loop clamp expels any trapped air or blood clots, ensuring a thoroughly sealed cavotomy. Following the cavotomy closure, both the renal vein and suprarenal IVC vessel loop clamps are sequentially disengaged. A reinforcement, employing a second-layer closure, is enacted. Notably, the IVC lumen can be appropriately narrowed to approximately 50% of its preoperative diameter without necessitating additional operative maneuvers.

11. Step 10. Specimen Retrieval and Wound Closure

A comprehensive reassessment of the dissection field for bleeding is conducted, applying hemostatic agents as necessary. Following the insertion of a drain, the fascia at the 12-mm port sites is meticulously sutured closed. The specimen’s removal proceeds through a Gibson incision, with the wound subsequently sutured in layers for optimal closure.

12. IVC Thrombectomy With Left-Sided Tumor

The surgical management of left-sided RCC with IVC thrombus presents unique challenges due to the requisite access to both retroperitoneal facets and the proximity of the superior mesenteric artery. Two main surgical approaches exist for tackling left-sided RCC with IVC thrombus. The initial approach consists of placing the patient in a left-side-up position for the nephrectomy, followed by a repositioning to a right-side-up orientation to gain access to and control the IVC. The alternative strategy begins with the patient in a right-side-up position to immediately access and manage the IVC, subsequently repositioning to left-side-up for the nephrectomy. Both techniques necessitate patient repositioning and subsequent robot redocking. A strategic port configuration designed to minimize trocar placement for bilateral access is depicted in the Fig. 1B.

Recently, a novel supine, single-dock strategy has been introduced, offering concurrent access to the retroperitoneum on both sides, thereby eliminating the necessity for repositioning the patient and redocking the robot [26] (Fig. 1C). This novel technique facilitates simultaneous access to both sides of the retroperitoneum, effectively rendering patient repositioning and robot redocking redundant. We have successfully employed this method in multiple patients with left RCC and IVC thrombus. This approach proves efficient for surgeries on the right side including IVC dissection and thrombectomy; however, performing a left nephrectomy in a supine position poses significant challenges. Consequently, we favor a segmented approach for each side, initiating with control of the right IVC followed by the left nephrectomy. In scenarios where IVC surgery on the right precedes left nephrectomy, left renal embolization is advised to mitigate the challenges encountered in isolating and ligating the left renal artery from the right approach.

The procedural steps for securing IVC control mirror those employed in surgeries for right-sided tumors. Unlike during right RN with IVC thrombectomy, where left renal artery clamping is not standard, we advocate for clamping both the right renal artery and vein during left RN with IVC thrombectomy. Failing to clamp the right renal artery while the right renal vein is clamped could precipitate renal damage from congestion, due to the absence of compensatory
backflow, given the unique venous architecture of the right renal vein compared to the left. Following clamping of the infrarenal IVC, right renal artery and vein, and suprarenal IVC, the thrombus-containing left renal vein is sectioned using an Endo-GIA stapler. For the nephrectomy, the camera is moved to the port on the patient’s left side without patient repositioning and robot redocking.

**INNOVATIVE TECHNIQUES**

RARN when dealing with high-level thrombectomy poses challenges, including prolonged operative times due to the need for dissecting the suprarenal IVC and an elevated mortality risk. For a level II thrombus situated above the porta hepatis, mobilization of the liver’s right lobe is necessary to ensure comprehensive IVC control; likewise, for a level III thrombus, both liver lobes must be mobilized.

Kundavaram et al. [27] introduced a pioneering approach in their report on 4 cases of RCC with level II–III IVC thrombus, achieving proximal intra- or retrohepatic IVC control exclusively through an intracaval Fogarty balloon catheter. Impressively, in one instance, a residual or secondary skip thrombus was excluded via robot-assisted flexible cystoscopy within the IVC lumen.

In a novel endoluminal strategy, Alahmari et al. [28] employed a Reliant® stent graft balloon catheter, maneuvered endovascularly through the right internal jugular vein under fluoroscopic guidance and positioned above the tumorous thrombus. Utilizing a balloon to occlude the suprarenal IVC emerges as a groundbreaking technique that can significantly diminish both the duration of surgery and the risk of complications in thrombectomies located beneath the portal vein. This is because it obviates the necessity for dissecting the suprarenal IVC in level II or III thrombectomies.

Following cavotomy, the extraction of the thrombus can be facilitated by gently retracting the balloon. However, this method warrants further optimization regarding balloon size and placement. Precise positioning directly above the thrombus requires accurate measurement of the thrombus length via MRI, appropriate balloon insertion depth, and verification of thrombus and balloon placement with TEE. Nevertheless, postclamp visibility of the balloon within the infrarenal IVC and renal vein becomes compromised. Even substituting air or dye for water does not enhance visibility on TEE. Consequently, despite the bleeding risks, clamping the infrarenal IVC and renal vein subsequent to balloon positioning might provide a more reliable method for confirming balloon location. Balloon sizing should reflect the measured IVC diameter above the thrombus, with water injection guidelines from the product manual closely followed. Opting for a conservative water volume initially is advisable, with the option to safely add more water if the balloon’s presence is confirmed through cavotomy, thereby minimizing the risk of back bleeding and IVC damage.

Cephalic IVC nonclamping method that significantly reduces operative time and complication rates in patients with level II–III IVC thrombus compared to conventional techniques [29]. By elevating pneumoperitoneum pressure from 12 to 20 mmHg, this method aids in achieving effective cephalic IVC control, thus expediently shortening surgery duration and mitigating complications associated with suprarenal IVC dissection. However, potential risks such as carbon dioxide embolization, hypercapnia, and challenging intraoperative bleeding from the cephalic IVC raise critical considerations.

**PERIOPERATIVE OUTCOMES**

Published data directly comparing the operative and oncologic outcomes of robot-assisted and open nephrectomy with IVC thrombectomy is scarce.

Gu et al. [10] conducted a retrospective, matched comparison involving 68 patients who underwent levels I–II IVC thrombectomy, dividing them into 31 robotic and 37 open IVC thrombectomies. The study revealed that the robotic cohort benefitted from a significantly reduced median operative time (150 minutes vs. 230 minutes, p<0.001), with the exception of left tumors which necessitated a conversion from a left to a right decubitus position for anatomical reasons. Contrarily, findings from Rose et al. [11] and Vuong et al. [30] indicated that the robotic group experienced a longer operative time compared to the open group (284 minutes vs. 242 minutes, p=0.03; 350.5 minutes vs. 208 minutes, p<0.01, respectively). A multi-institutional analysis leveraging the National Cancer Database dataset found no significant differences in operative times between the open and robotic groups (226 minutes vs. 260 minutes, p=0.922).
Thus, the limited number of studies prevents drawing definitive conclusions regarding surgical time.

Gu et al. [10] also reported superior outcomes for the robotic group in terms of median estimated blood loss (250 mL vs. 1,000 mL, p<0.001), the rate of blood transfusion (6.5% vs. 54.8%, p<0.001), and the median transfusion requirement (420 mL vs. 790 mL, p=0.012) in comparison to the open group. Rose et al. [11] corroborated these findings, noting fewer blood transfusions in the robotic group (21% vs 82%, p<0.01) compared to the open group. The robotic platform facilitates meticulous hemostasis through enhanced visualization, enabling the surgeon to accurately identify and cauterize bleeding vessels. Additionally, the creation of pneumoperitoneum helps to reduce venous bleeding during the dissection of dilated perinephric vessels. These advantages are believed to contribute to reduced blood loss in robotic surgery over open surgery. The total postoperative complication rate was lower in the robotic group than in the open group (9.7% vs 29.0%, p=0.070). Two of the 3 complications (6.4%) in the robotic group were minor, while 1 patient (3.2%) experienced respiratory failure requiring mechanical ventilation [10]. The robotic group had 26% fewer complications compared to the open group (17% vs 43%, p<0.01) and there were no Clavien-Dindo classification grade IIIb or worse complications and no mortalities occurred in the robotic group [11].

ONCOLOGIC OUTCOMES

Studies involving robotic IVC thrombectomy are noted for their variability and typically have brief follow-up intervals, spanning from 3 to 27 months) [32]. Chopra et al. [8] documented a median follow-up duration of 16 months (range, 12–39 months) for patients who underwent robotic caval thrombectomies, with all patients being alive at the last follow-up. Among these, 42% had undergone adjuvant therapy, and 45.8% experienced the emergence of metastatic disease. Although no direct, prospective comparisons have been made between open and robotic IVC thrombectomy, and questions regarding the long-term oncological superiority of robotic over open procedures remain unaddressed, existing oncologic data thus far are limited. Gu et al. [10] noted that the median follow-up durations for robotic and open surgery cohorts were 27.0 and 44.8 months, respectively (p<0.001), finding no significant disparities in progression-free survival (p=0.708) or overall survival (p=0.181) between the 2 groups; the surgical approach did not correlate with either progression-free or overall survival outcomes. Similarly, Rose et al. [11] found no significant statistical differences in either overall survival or recurrence-free survival during short-term follow-up. In the comparison of open versus robotic groups, the mean estimated overall survival was 48.7 months versus 50.6 months (p=0.16), while the mean estimated recurrence-free survival was 36.5 months versus 33.2 months (p=0.68).

CONCLUSIONS

RARN with IVC thrombectomy is intricate and demanding, carrying significant risks of morbidity and mortality. The decision to opt for an open versus robotic approach must hinge on meticulous patient selection, comprehensive preoperative planning, and the surgeon’s depth of experience.

NOTES

• Author Contribution: Conceptualization: SB, SHH; Writing - original draft: SB, SHH; Writing - review & editing: SB, SHH.

• ORCID

Seokhwan Bang: https://orcid.org/0000-0002-0450-8763
Sung-Hoo Hong: https://orcid.org/0000-0002-1952-4010

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