0022-5347/03/1692-0435/0
THE JOURNAL OF UROLOGY®

Vol. 169, 435–444, February 2003
Printed in U.S.A.
DOI: 10.1097/01.ju.0000047230.49976.bf

Review Article

SURGICAL TECHNIQUES FOR TREATING A RENAL NEOPLASM INVADING THE INFERIOR VENA CAVA

ANIL VAIDYA, GAETANO CIANCIO AND MARK SOLOWAY*

From the Departments of Urology and Surgery (Division of Transplantation), University of Miami School of Medicine, Miami, Florida

ABSTRACT

Purpose: Historically inferior vena caval thrombus associated with renal cell carcinoma was a deterrent to surgery. During the last 3 decades there has been steady improvement in surgical techniques and perioperative care, which has dramatically improved the ability to resect safely these tumors. We acknowledge these improvements in chronological order.

Materials and Methods: A comprehensive literature review of the different techniques used for resecting renal cell carcinoma with inferior vena caval involvement was performed using MEDLINE. Data focused on surgical techniques, including various incisions, exposures, adjuncts to surgery and outcomes.

Results: Tumor thrombus associated with renal cell carcinoma is no longer considered to have a detrimental impact on survival. Patients who are acceptable surgical candidates have survival rates as high as 68%. Although there is a great deal of emphasis on the importance of an aggressive surgical approach, a uniform operative strategy based on the level of the tumor thrombus has not been established. Surgical techniques derived from liver transplant surgery and cardiac arrest with cardiopulmonary bypass have drastically decreased operative complications associated with extensive involvement of the inferior vena cava with tumor thrombus.

Conclusions: The only curative approach to renal cell carcinoma is surgery. An aggressive approach is warranted when tumor involves the renal vein and inferior vena cava. Surgical strategy depends on the level of the inferior vena caval thrombus. Patients with extension of the thrombus above the diaphragm are a greater technical challenge. Hypothermic circulatory arrest should be considered when treating vena caval-atrial tumor thrombus. Surgeons familiar with liver mobilization can greatly facilitate the exposure needed for safely operating in these cases.

KEY WORDS: kidney; vena cava, inferior; venous thrombosis; kidney neoplasms

The inferior vena cava is involved in 4% to 15% of patients with renal cell carcinoma.[1] During the last 3 decades there have been steady improvements in surgical techniques and perioperative care, which have dramatically improved the ability to remove safely these tumors. Tumor thrombus associated with renal cell carcinoma is no longer considered to have a detrimental impact on survival. Patients who are acceptable surgical candidates have survival rates as high as 68% at 5 years.[2,3]

Despite experimental protocols using various methods of immunotherapy, treatment for renal cell carcinoma requires surgery. Although laparoscopic surgery is being increasingly used for renal cell carcinoma confined to the kidney, laparotomy is required when tumor involves the inferior vena cava. The extent of surgery depends on the level of inferior vena caval extension. Preoperative radiological studies such as magnetic resonance imaging (MRI) accurately delineate the level or extent of thrombus.

Many surgical techniques have been described. They can be discussed in 2 major time frames, that is before and after the introduction of hypothermic cardiac arrest with cardiopulmonary bypass. We reviewed the literature for details regarding types of incisions and adjunct procedures used to treat renal cell carcinoma extending into the inferior vena cava.

CLASSIFICATION OF TUMOR THROMBUS IN THE INFERIOR VENA CAVA

The operative technique is dictated by the extent of tumor thrombus. Thus, it is imperative to determine and classify how much of the inferior vena cava is involved by thrombus. Pritchett et al identified 3 groups, namely subhepatic thrombus, thrombus extending into the intrahepatic or retrohepatic vena cava below the diaphragm and supradiaphragmatic thrombus (figs. 1 and 2).[4]

Wilkinson et al classified inferior vena caval thrombus as type 1—renal vein involvement, type 2—suprarenal inferior vena cava below the diaphragm and type 3—supradiaphragmatic.[5] Libertino redefined this classification into 2 major groups, namely infradiaphragmatic and supradiaphragmatic.[6] The supradiaphragmatic group was divided into intracardiac and intrapericardial, while all infradiaphragmatic thrombi could be above or below the hepatic veins. The Mayo Foundation classification used the 4 groups renal vein, infrahepatic, intrahepatic and atrial.[7] Independent of the classification it is evident that thrombus extension at and above the level of the hepatic veins poses a particular challenge because of limited access and difficulty in vascular control of this portion of the inferior vena cava.

* Financial interest and/or other relationship with Astra Zeneca, Matritech, Merck and TAP.

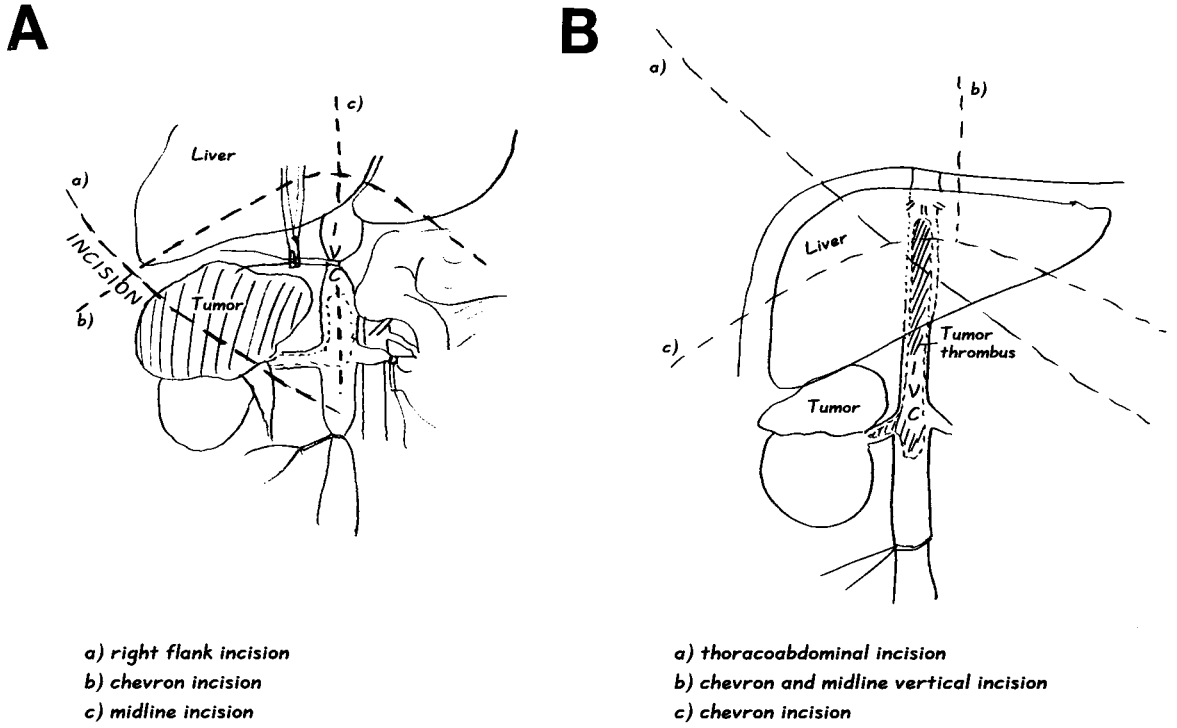

FIG. 1. Operative approaches to tumor thrombus in inferior vena cava. *A*, levels 1 and 2 thrombus. *B*, level 3 thrombus

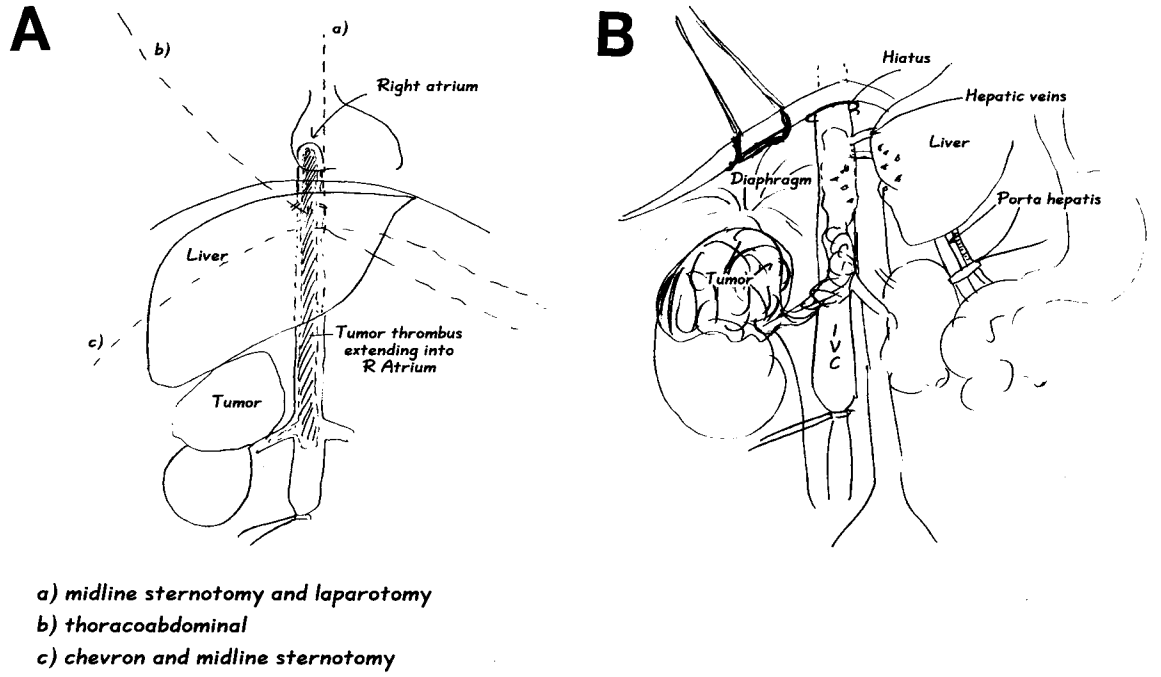

FIG. 2. Operative approaches to tumor thrombus in inferior vena cava (*IVC*). *A*, level 4 tumor. *B*, intra-abdominal approach using piggyback technique of liver mobilization.

Stief et al stratified extension into the inferior vena cava into 2 types depending on the need for circulatory arrest.[8] Type 1 included intracaval protrusions with an infrahepatic cranial margin. These patients do not require circulatory arrest. Type 2 is divided into 2a and 2b. Type 2a thrombi have suprahepatic but infradiaphragmatic extension or supradiaphragmatic extension of a free floating thrombus. Circulatory arrest in these patients is not usually required. Type 2b involves the suprahepatic inferior vena cava, hepatic veins or right atrium and these patients are at high risk for thrombotic embolism or had a large suprahepatic thrombus. Circulatory arrest is usually necessary in these situations.

In 1988 Belis et al suggested a simple classification of inferior vena caval thrombus into 2 levels with 2 surgical approaches based on preoperative MRI as 1—below the major hepatic veins requiring transabdominal excision and 2—at or above the major hepatic veins with the need for cardiopulmonary bypass, deep hypothermia and circulatory arrest.[9] They stressed the importance of preoperative cardiovascular evaluation and therapy, including carotid endarter-

ectomy and percutaneous transluminal coronary angioplasty if necessary, to decrease the risk of myocardial infarction and stroke.

HISTORY

In 1688 Blancardus described inferior vena caval involvement by tumor.[10] Except for the few sporadic reports of successful excision of tumor thrombus in the inferior vena cava of Berg,[11] Rehn,[12] and Walters and Priestley,[13] this operation was considered futile since operative mortality was excessive. Furthermore, a system of staging was missing and many clinicians of that time concluded that extension into the inferior vena cava was synonymous with an incurable stage. The other limiting factor was the lack of accurate preoperative knowledge of the presence and extent of inferior vena caval thrombus. In 1949 Robson defined renal cell carcinoma staging and endorsed thoracoabdominal incision through the bed of the 9th or 10th rib (fig. 3).[14] He adopted a routine of approaching most renal cell carcinomas through a thoracoabdominal incision. This approach allowed him to remove regional lymph nodes, which were involved in 22.5% of his cases, ligate the renal pedicle before extensive manipulation, 3) remove the kidney with its perinephric fat and fascial envelope, and provide adequate exposure of the inferior vena cava.

In 1970 Marshall et al presented their experience with the surgical management of renal cell carcinoma with inferior vena caval involvement in 4 cases.[15] These cases were presumably approached through a midline (xiphisternum to symphysis pubis) incision. In case 1 the tumor was suctioned out of the inferior vena cava via the 4 cm. diameter stump of the renal vein without vascular control of the vena cava or opposite renal vein. They expressed concern about an air embolism and placed the patient in the Trendelenberg position. In the next case tourniquets were placed above and below the inferior vena caval thrombus before extracting the thrombus from the inferior vena cava. Shortly thereafter cardiac arrest occurred and an incision in the pulmonary artery revealed thrombus. Thus, even with adequate precautions they could not prevent a tumor embolus. As early as 1924, Judd and Scholl described similar experiences with pulmonary embolism.[16]

In patient 3 a preoperative venacavogram demonstrated tumor thrombus above the diaphragm.[15] Cardiopulmonary bypass was performed. After occlusion of the inferior vena cava within the pericardium venous return from the 2 femoral catheters passed into the heart via a cannula in the superior vena cava without other extracorporeal assistance and without hypotension. This report may represent the first case of extracorporeal circulation without a pump, hypothermia or cardiac arrest.

Patient 4 was treated similarly with adequate inferior vena caval occlusion above and below the thrombus. Extracorporeal circulation was not used. The contralateral renal vein was occluded, which caused transient postoperative renal failure. Retrospectively Marshall et al thought that it would have been better to occlude temporarily the renal artery rather than the vein on the contralateral side,[15] a technique described by Heaney et al.[17] They described occlusion of the inferior vena cava within the pericardium as well as aortic cross-clamping below the diaphragm to prevent sequestration of blood in the lower extremities and portal system. It also prevented blood loss from the hepatic veins that empty into the opened inferior vena cava.

In 1971 Skinner et al concluded that proper management of inferior vena caval involvement from renal cell carcinoma depends on preoperative angiographic evaluation of the tumor and its thrombus, obtaining control of the inferior vena cava or right atrium proximal to the tumor to prevent intraoperative embolization and the thoracoabdominal approach.[18] They described a technique in which adequate vascular control above the level of the thrombus may involve slight modification, especially when thrombus extends into the right atrium. In this setting the intrapericardial inferior vena cava cannot be encircled since thrombus extends into the right atrium. Thus, a Satinsky clamp with the desired curvature is used on the right atrium. The inferior vena cava is then opened below the diaphragm and a Fogarty balloon catheter is used to milk the tumor thrombus from the atrium. Hemorrhage from the hepatic veins was managed by reapproximating the inferior vena cava with vascular clamps and restoring the blood volume by rapid transfusion.

In 1972 Lome and Bush described the results of an experimental technique involving resection of the inferior vena cava in cases of renal cell carcinoma with venous extension.[19] Left nephrectomy with en bloc resection of the inferior vena

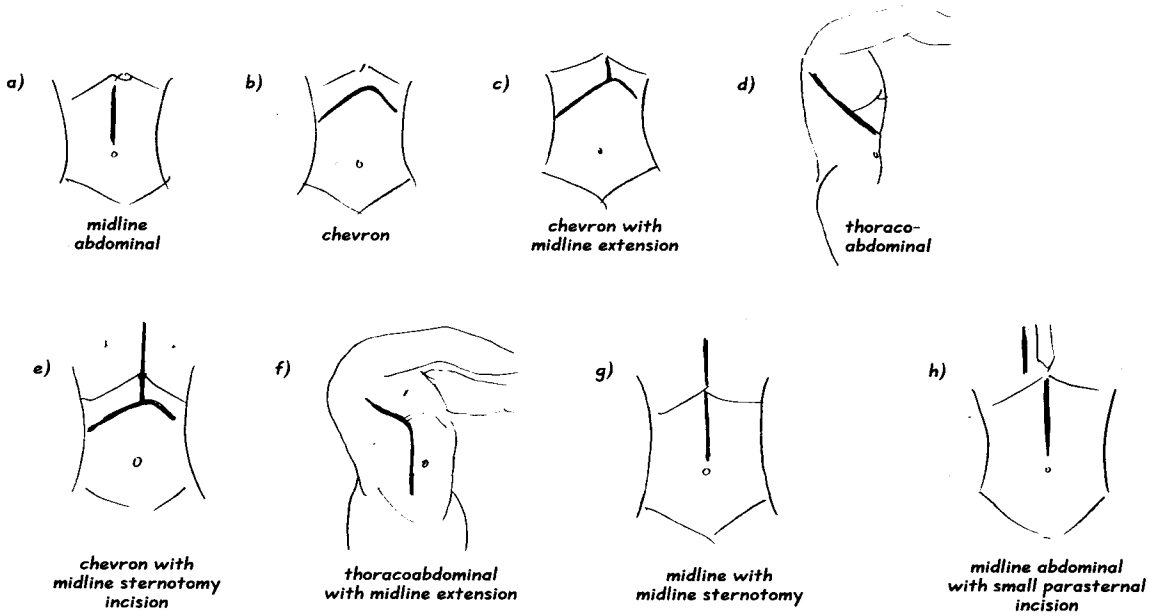

FIG. 3. Various incisions used for inferior vena caval involvement by renal cell carcinoma

cava from below the level of the liver to the bifurcation of the inferior vena cava was performed in dogs. End-to-side renoportal venous anastomosis was formed on the contralateral kidney. The dogs were followed for 9 months. This group detected neither adverse effects on renal function nor histological abnormalities after renoportal venous anastomosis. They concluded that in select patients such extended radical nephrectomy may increase survival if renal cell carcinoma involves the inferior vena cava by neoplastic thrombus or direct invasion.

In 1975 Cole et al reported a case of renal cell carcinoma with inferior vena caval thrombus treated with nephrectomy and inferior vena caval resection.[20] A review of the literature at that time revealed 7 previous cases. Although postoperative morbidity was minimal, only 1 patient survived more than 2 years. All patients with metastases at surgery died within 1 year. Cole et al cautioned that the duration and quality of anticipated survival must be carefully weighed before performing this major surgical procedure. In the same year Freed and Gliedman described a technique using a Foley catheter to extract the thrombus through a cavotomy, followed by immediate application of a vascular clamp on the inferior vena cava.[21] This procedure was accompanied by a substantial gush of venous blood after removal of the tumor thrombus, which was believed to be helpful in flushing any remaining thrombus.

In 1978 Abdelsayed et al reported their experience with renal tumors involving the inferior vena cava in 12 patients.[22] Six patients underwent a thoracoabdominal incision, while the remainder underwent an abdominal approach. This group divided the management of these cases into 3 groups, namely infrahepatic, hepatic and suprahepatic. All patients underwent a venogram preoperatively.

In infrahepatic cases the renal artery was ligated and the ureter was divided. The inferior vena cava was dissected cephalad and caudal to the renal veins, and the renal vein on the uninvolved side was exposed. Vascular clamps were applied to the inferior vena cava caudal to the renal veins, cephalad to the tumor thrombus and on the uninvolved renal vein. The renal vein of the involved kidney was then circumferentially incised at its junction with the inferior vena cava. Gentle traction was exerted on the mass, extracting the thrombus. The cavotomy incision was then rapidly repaired with a running 5-zero suture. In hepatic cases if thrombus extended to the hepatic veins but not above them, management was similar to that for infrahepatic extension except the inferior vena cava was clamped just below the hepatic veins. Abdelsayed et al recommended thoracoabdominal exposure for this maneuver and division of the liver attachments from the diaphragm.[22] In suprahepatic cases the pericardium was opened through a thoracoabdominal incision or median sternotomy and the inferior vena cava was clamped at that level they also recommended the Pringle maneuver to control the hepatic circulation. This maneuver, which was described by Pringle in 1908, was used during elective resection of the liver.[23] Abdelsayed et al first reported its use for resecting renal cell carcinoma with inferior vena caval involvement.

McCullough and Gittes reported on 4 patients with renal cell carcinoma involving the inferior vena cava. All patients had tumor on the right side.[24] The inferior vena cava was resected below the hepatic veins and the left renal vein was ligated with no ill effects in 3 of the 4 patients. In 1978 Schefft et al reported their experience with 21 patients with renal cell carcinoma extending into the inferior vena cava.[25] They made an anterior transperitoneal subcostal incision in most cases. In a few patients median sternotomy was done in addition to the subcostal incision. Six patients underwent resection of the inferior vena cava. Schefft et al suggested preoperative angio-infarction.

In 1979 Cummings et al described a new technique for inferior vena caval tumor thrombectomy in which vascular isolation of the inferior vena cava from right atrium to pelvis was achieved by temporary circulatory arrest of the lower torso.[26] They removed a neoplastic thrombus from the intrapericardial inferior vena cava under direct vision with minimal blood loss. In 1966 Heaney et al had previously described this new technique.[17] A midline abdominal incision was made and extended cephalad into a sternotomy. The liver was mobilized to expose the retrohepatic inferior vena cava. The portal triad was exposed at the porta hepatis. Umbilical tapes were placed around the intrapericardial and distal inferior vena cava. The abdominal aorta was exposed at the aortic hiatus. The patient was placed in the 20-degree Trendelenberg position and the aorta was cross-clamped. When pulmonary artery wedge pressure (monitored by a Swan-Ganz catheter) increased to 15 mm. Hg and systolic blood pressure was 120 mm. Hg the intrapericardial inferior vena cava was clamped. A Rumel tourniquet was applied to the distal inferior vena cava and an occlusive clamp was applied to the porta hepatis before cavotomy.

A 20Fr Foley catheter was advanced up the inferior vena cava until its tip was palpable above the apex of the tumor thrombus within the pericardium. The tumor thrombus was delivered intact with gentle downward traction on the catheter, followed by manual compression of the inferior vena cava. The inferior vena cava was flushed vigorously with sterile water. A Satinsky clamp was placed across the vena caval incision. The distal vena caval and hepatic vascular clamps were released first to allow air and debris to escape through the cavotomy. Circulation was restored by releasing the intrapericardial vena caval and then aortic clamps. The incisions were then closed.

In 1979 Clayman et al described their approach to renal cell carcinoma invading the inferior vena cava.[27] They highlighted the importance of the collateral circulation, not only of the obstructed, tumor filled renal vein, but also of the nonobstructed, unaffected renal unit (fig. 4). Five of their 6 patients had an infradiaphragmatic inferior vena caval thrombus. Their approach to atrial thrombus was through a thoracoabdominal incision. They favored a midline incision because it precludes blood loss from the lateral, engorged, superficial abdominal collaterals and intercostal veins. Their experience was that blood loss with a supine abdominal approach was half that of the thoracoabdominal approach. The midline incision also allowed abdominal exploration for metastatic disease and it could be extended cephalad to create sternotomy if cardiopulmonary bypass were required. In addition, with the patient in the supine rather than the flank position the possibility of cardiac arrest from acute thrombus obstruction of the tricuspid valve is less likely.

They referred to a technique of liver mobilization in which the liver is rotated to the left side of the abdomen to expose the retrohepatic inferior vena cava. This technique was first described in 1894 by Langenbuch[28] and it has been used extensively by surgeons to gain adequate exposure of the retroperitoneum. Clayman et al also described 2 simple but crucial tests that can be performed intraoperatively to assess the functional potential of the remaining renal unit in the event of the need for inferior vena caval resection and renal vein ligation.[27] With the inferior vena cava clamped above the thrombus pressure in the proximal unaffected renal vein can be determined. Renal congestion, proteinurea and possible renal failure ensue if the pressure is greater than 40 mm. Hg. The second test is performed after the renal artery of the tumor bearing kidney is clamped. Blue urine should appear in the bladder drainage bag within 12 minutes of intravenous administration of 5 ml. indigo carmine. If inferior vena caval clamping produces unfavorable hypertension in the renal vein and the indigo carmine test is negative, the surgeon should pursue renoportal anastomosis or autotransplantation of the remaining kidney.

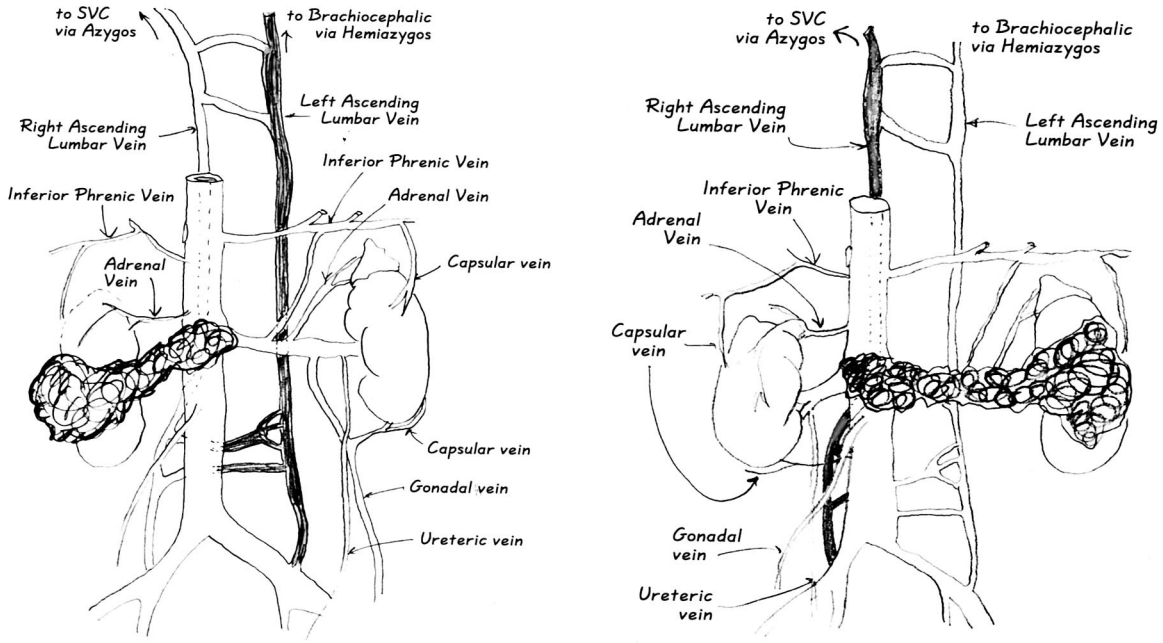

FIG. 4. Venous collaterals that develop with obstruction of left and right renal vein by tumor thrombus emanating from contralateral kidney tumor. *SVC*, superior vena cava. Reproduced with permission.[27]

Their approach to supradiaphragmatic thrombus was through a midline sternotomy. If the lesion was below the atrium, they gained control of the intrapericardial inferior vena cava and infradiaphragmatic cavotomy was used to extract the thrombus. Hepatic blood loss was controlled with the Pringle maneuver. If the patient did not tolerate inferior vena caval clamping or was a floating intracardiac thrombus, they advocated cardiopulmonary bypass.

In 1980 Novick and Cosgrove reported their approach to complete removal of renal cell carcinoma thrombus from the right atrium.[29] They re-emphasized the importance of accurate preoperative evaluation of the supradiaphragmatic extension of disease. The abdomen was entered through a bilateral subcostal incision. The kidney was mobilized except for its attachment to the inferior vena cava. The pericardium was opened through a median sternotomy. The heart was cannulated with the arterial return placed in the ascending aorta and venous drainage cannulas placed in the superior vena cava and right common femoral vein. The patient was placed on cardiopulmonary bypass and the left atrium was vented through the right superior pulmonary vein. A tourniquet was tightened around the superior vena cava cannula and the inferior vena cava was clamped below the renal veins. The aorta was cross-clamped and cold cardioplegic solution injected into the aortic root to induce cardiac arrest. The right atrium was opened through a 4 cm. incision. The intra-atrial tumor thrombus was visualized and severed at its entrance into the right atrium.

Attention was redirected to the abdomen, where a vascular clamp was applied to the uninvolved renal vein. The involved renal vein was incised circumferentially at its junction with the inferior vena cava and the tumor thrombus was extracted. A 24Fr Foley catheter was passed into the right atrium through the cavotomy. The balloon was inflated and gently extracted, removing the thrombus with it. Removal was confirmed by inserting fingers into the inferior vena cava above and below the diaphragm. There was brisk bleeding from the hepatic veins, which required replacement. The atriotomy and venacavotomy were closed and the patient was weaned from bypass. Abdominal and chest tubes were placed.

According to Novick and Cosgrove the operative approach is determined by the presence or absence of intra-atrial tumor when treating a supradiaphragmatic tumor thrombus.[29] When there is tumor within the right atrium, they recommended cardiopulmonary bypass with atriotomy as a necessary adjunct to safe, complete removal of the thrombus. When cardiopulmonary bypass is necessary, they advocated median sternotomy since it provides optimum exposure and can be combined with a midline or bilateral subcostal incision. When there is no atrial tumor, the intrapericardial inferior vena cava can be temporarily occluded and the tumor can be extracted without bypass. For this procedure they advocated a thoracoabdominal incision. An important technical point in their approach was kidney mobilization before cardiopulmonary bypass since the patient did not systemically receive heparinized during radical nephrectomy and, thus, excessive bleeding was avoided. Careful retroperitoneal hemostasis was secured before cardiopulmonary bypass.

A year later Kearney et al reported the results in 24 patients with renal cell carcinoma involving the inferior vena cava.[30] All patients underwent radical nephrectomy with tumor thrombus removal through a thoracoabdominal incision. They described the removal of tumor thrombus by an open or closed technique. The closed technique involved resection of the inferior vena cava with the tumor thrombus without trying to milk the thrombus out of a cavotomy incision. Resection of the inferior vena cava was not feasible when the tumor thrombus extended above the hepatic veins. In these cases venacavotomy and a Foley catheter technique or compression of the porta hepatis to decrease hepatic blood flow were recommended. They stressed the importance of collateral venous drainage of the kidneys. They maintained that the uninvolved right renal vein would be better served with renoportal anastomosis, while an uninvolved left renal vein can be tied off with minimal morbidity.

In 1983 Vaislic et al advocated cardiopulmonary bypass and deep hypothermic arrest when treating tumor thrombus extending to the right atrium.[31] Although they had routinely used this technique since 1973, this report was one of the first few documenting the efficacy and safety of the procedure with no operative deaths or postoperative complications.

In 1984 Marshall et al described a new technique using hypothermia, cardiac arrest and temporary exsanguination

combined with cardiopulmonary bypass to create a bloodless field for renal cell carcinoma excision with thrombus extending to the right atrium.[32] Access to the heart was gained through a right thoracoabdominal incision through the 5th intercostal space. The diaphragm was divided, the renal tumor was mobilized and the renal artery was ligated posterior. The liver was mobilized into the chest after division of its posterior attachments. The lumbar veins were divided and the inferior vena cava was mobilized to the level of the hepatic veins. The pericardium was opened lateral and anterior to the right phrenic nerve. Cardiopulmonary bypass was begun and the patient was cooled to 19.5C during a 25-minute interval. The head was placed on ice for further cooling. Cardiopulmonary bypass was then discontinued. The patient was exsanguinated to the oxygenator and the inferior vena cava was opened. The vena cava was incised from just above the left renal vein to just below the hepatic veins. The right atrium was opened and the tumor was removed. Copious irrigation allowed inspection of the interior of the inferior vena caval wall, hepatic veins and the uninvolved renal vein. The right atrium and vena cava were then closed and the patient was resuscitated after reversing the bypass. This group indicated that hypothermia, cardiac arrest and temporary exsanguination of the patient after placement on bypass seemed an excellent solution that permitted careful dissection within the inferior vena cava in a bloodless field. In addition, tumor cells do not enter the circulation, theoretically decreasing the risk of tumor dissemination.

In 1986 Wilkinson et al discussed the need for cardiopulmonary bypass as an important adjunct to resecting supradiaphragmatic tumor thrombus.[33] With other techniques intraoperative pulmonary embolism was a risk and had resulted in deaths. This group suggested certain guidelines for anesthetic care and cardiopulmonary bypass. The anesthetist should have previous knowledge of tumor extent and be well versed in resultant pathophysiological and hemodynamic alterations, and probable complications. Cardiopulmonary bypass should be available in all cases with tumor thrombus extending above the hepatic veins. Tumor confined to the renal vein or only a small portion of the inferior vena cava does not require cardiopulmonary bypass and patients may be positioned in the lateral or thoracoabdominal position. During cavotomy without bypass the patient should be placed in the Trendelenberg position and positive pressure respiration should be maintained to prevent pulmonary emboli. If cardiopulmonary bypass is done, the technique should include circulatory arrest and moderate hypothermia to 30F because the pulmonary artery and aorta may need cross-clamping to prevent embolization. A vena caval umbrella filter in the orifice of the inferior vena cava during cardiopulmonary bypass was advocated to trap emboli. In addition, autotransfusion of washed red blood cells is contraindicated because of the risk of disseminating viable tumor cells.

In 1986 Giuliani et al presented their results of surgical treatment of 28 patients with renal cell carcinoma extending into the inferior vena cava.[34] Their surgical strategy depended on the kidney involved and the level of tumor extension into the inferior vena cava. When tumor involves the renal vein or infrahepatic inferior vena cava, the operation was performed through an anterior transperitoneal approach with satisfactory control of the inferior vena cava. When it extended into the retrohepatic inferior vena cava, a thoracoabdominal incision or median sternotomy for right and left tumors, respectively, was advocated. They routinely rotated the liver away from the diaphragm by dividing the triangular and coronary ligaments. Proximal control of the inferior vena cava was achieved through a pericardial incision with a tourniquet loop. The use of an inferior vena caval umbrella to prevent intraoperative pulmonary emboli is mentioned as well as the Pringle maneuver. They routinely performed cardiopulmonary bypass when tumors extended into the right atrium. Cavectomy was advocated in the event of vena caval wall involvement. However, they expressed their difficulty with resection of the vena caval wall when tumor extended into the hepatic veins because it may cause the Budd-Chiari syndrome.

In 1986 Pritchett et al presented their experience with tumor thrombus resection at various levels in the inferior vena cava.[4] They used a right thoracoabdominal approach, excising the 8th rib beginning at the midaxillary line, extending across the costochondral junction to the epigastrium and as a midline incision to below the umbilicus. For exceptionally large tumors originating in the left kidney the incision was extended across the midline to the left subcostal region using a vertical T-shaped inferior midline extension. To facilitate early ligation of the renal artery the peritoneal attachments to the ascending colon and small bowel mesentery were divided, so that the bowel, duodenum and pancreas could be retracted on the superior mesenteric artery pedicle. The remainder of the dissection and technique for removal of inferior vena caval thrombus is the same as in previous reports from the same institution.

A cardiothoracic surgeon performed atriotomy. An index finger was inserted through a purse-string atriotomy to explore the extent of tumor in the atrium and, if feasible, to push the thrombus out of the atrium and back into the vena cava before the intrapericardial Rummel tourniquet around the inferior vena cava was tightened. If the intra-atrial tumor was extensive or adherent to the wall of the atrium, cardiopulmonary bypass was advocated.

A vertical incision circumscribing the inferior vena cava at the level of the renal vein and extending cephalad almost to the level of the lowest hepatic vein was made. Using a Kittner the tumor thrombus was gently dissected and delivered en bloc with the involved kidney. With the patient in the Trendelenberg position the inferior vena cava was irrigated. Residual tumor attached to the inferior vena caval wall was resected.

In addition to the technique of thrombus resection, Pritchett et al recommended routine administration of Mannitol before the contralateral renal vein was occluded and a Fogarty vascular clamp on the contralateral renal artery to prevent venous congestion, especially for tumors on the left side. They did not advocate a Swan-Ganz catheter when there was atrial extension for fear of dislodging the clot. They also recommended complete control of the thrombus between it and the right ventricle during its extraction.

In 1987 Libertino et al lent their support to cardiopulmonary bypass for tumor thrombus extending into the right atrium.[35] Their incision of choice was a chevron combined with a median sternotomy. They stressed the importance of avoiding occlusion of the contralateral renal vein to minimize postoperative renal failure and dialysis. In their experience renal cell carcinoma rarely invaded the wall of the inferior vena cava and, therefore, it seldom required cylindrical inferior vena caval resection. They preferred reconstruction of the inferior vena cava after partial venacavectomy.

In a 1988 report Marshall et al summarized a strong argument in favor of cardiopulmonary bypass, hypothermia, cardiac arrest and exsanguination in patients with tumor thrombus above the hepatic veins.[36] In an editorial comment Novick wrote that "application of CPB and hypothermia to patients with suprahepatic IVC tumor thrombus is an important advance that has improved the safety and technical efficacy of a difficult surgical undertaking."[37] In another editorial Zinman commented that midline sternotomy combined with a transverse upper abdominal incision was a more flexible incision than right thoracotomy and it offered wider exposure for the retroperitoneal portion of the dissection without the necessity of an extensive diaphragmatic incision.[38] In addition, he contended that anterior exposure permits early control of the infrarenal portion of the inferior vena cava and prompt placement of a DeWeese clip around

the supradiaphragmatic portion of the inferior vena cava, which would eliminate the potential for tumor emboli during preliminary tumor manipulation. He recommended completion of the entire dissection before heparin was given and circulatory arrest was initiated. The venacavotomy should be controlled by a side clamp and closed after cerebral circulation is restored, thus, saving minutes of critical ischemic time.

In the late 1980s a surgical strategy for renal cell carcinoma with inferior vena caval involvement was evident. This strategy included preoperative evaluation of the level of thrombus with a venogram or MRI and preoperative cardiovascular evaluation and treatment, if necessary. The incision depended on surgeon preference and the extent of the thrombus. Inferior vena caval exposure often required mobilization of the liver from its diaphragmatic attachments and division of small hepatic veins to the caudate lobe. If required, the intrapericardial inferior vena cava was encircled with a Rummel tourniquet. This maneuver was reserved for the end of the procedure to avoid distention of the portal circulation. A purse-string suture or Satinsky clamp on the right atrial wall was considered suitable when there was minimal thrombus extension into the right atrium. In cases of a large atrial thrombus cardiopulmonary bypass and deep hypothermic cardiac arrest were preferred. Some surgeons controlled the hepatic veins by the Pringle maneuver or vascular clamps because the concept of warm hepatic ischemia was acceptable. The inferior vena cava was entered after vascular control was ensured. The thrombus was dissected off of the inferior vena caval wall. The inferior vena cava was resected only if tumor thrombus invaded the wall. These guidelines were gradually established through a cumulative effort of many surgeons for a century. Subsequent developments fine-tuned this strategy.

In 1989 Hartman et al described a technique of fiberoptic examination of the inferior vena cava during circulatory arrest.[39] Transesophageal echocardiography was described by Treiger et al in 1991 as an accurate diagnostic technique to determine the extent of the thrombus.[40] A 5 MHz. echocardiography transducer affixed to a gastroscope was used. Transesophageal echocardiography demonstrated the superior extent of an intracaval thrombus in real time during surgery. Furthermore, a transesophageal 4 chamber cardiac view delineated atrial extension of the thrombus.

In 1991 Stewart et al presented their experience with cavoatrial tumor thrombectomy using cardiopulmonary bypass without circulatory arrest.[41] All tumors were exposed through a median sternotomy combined with a midline celiotomy. Nephrectomy was performed after control of the intrapericardial inferior vena cava. The liver was mobilized to the patient left and the diaphragm was split into the central tendon. The infrahepatic, retrohepatic and suprahepatic portions of the inferior vena cava were exposed and the level of the thrombus was confirmed. Cardiopulmonary bypass was begun as required. Tumor thrombectomy was performed through incisions in the infrahepatic inferior vena cava and right atrium. Cardiotomy suction was used to aspirate hepatic venous and coronary sinus return. The tumor was dissected from the inferior vena cava and right atrium. All hepatic vein orifices were inspected and occasionally the Pringle maneuver was performed to allow better visualization. Circulatory arrest was done only when proper visualization was not possible. The cavotomy and atriotomy were repaired after air was expelled from the right atrium and inferior vena cava.

In 1994 Marsh and Lange applied liver transplant and organ procurement techniques to difficult upper abdominal urological cases.[42] The patient was placed supine with the arms extended. A bilateral subcostal incision was made approximately 2 finger breadths below the costal margins and extended lateral to the midaxillary line on the side of the lesion. A cephalad T extension up to the xiphoid was done to provide exposure of the anterior liver and diaphragm. An Olivier retractor (Copharm, Abcoude, Holland) and Iron Intern (Automated Medical Products, New York) provided exposure in the upper abdomen.

The liver was mobilized using the technique described by Langenbuch.[28] The spleen and pancreas were mobilized for left renal cell carcinoma with inferior vena caval extension by applying techniques used during procurement of the pancreaticoduodenal segment for pancreas transplantation. An Adam-DeWeese vena caval clip was placed above the thrombus as a useful adjunct before manipulating the liver, tumor or inferior vena cava.

A window was created in the diaphragm in the midline medial to the inferior vena caval foramen, providing an approach to the pericardium anterior and, thus, avoiding vital structures such as the phrenic nerve. After examination for thrombus and placement of a DeWeese clip or clamp the supradiaphragmatic inferior vena cava was encircled. Venovenous bypass from the saphenous-to-axillary vein was described for a large inferior vena caval thrombus using 7 mm. Gott shunts.

In 1994 Swierzewski et al stated certain principles that apply to vena caval surgery for renal cell carcinoma thrombus regardless of the level of the thrombus.[43] According to this group it was primarily a venal cava operation and, therefore, the approach should be from the right side even if the thrombus originated from a left renal tumor. Their approach was via a right thoracoabdominal incision through the 8th or 9th intercostal space. Minimal manipulation of the inferior vena cava and renal vein was advised until a DeWeese clip was temporarily placed on the vena cava above the tumor thrombus. When venacavotomy was required, the surgeon must obtain control of the inferior vena cava above and below the thrombus.

In 1998 Fitzgerald et al reported a minimal access approach for cardiopulmonary bypass while resecting a right atrial tumor thrombus from a renal cell carcinoma.[44] A chevron incision was used to mobilize the kidney with the tumor. The inferior vena cava was dissected up to the diaphragm (the Langenbuch maneuver). The patient was prepared for cardiopulmonary bypass and circulatory arrest. Fitzgerald et al used a minimally invasive, right parasternal incision to expose the right atrium. An 8 cm. skin incision was made over the heads of the 3rd and 4th ribs, which were removed. The pericardium was opened, and the right atrium, aorta and right superior pulmonary vein were exposed. Another 5 cm. skin incision was made under the right clavicle to expose the right subclavian artery. An arterial cannula was placed in the right subclavian artery for inflow. A 2-stage venous cannula was inserted into the right atrium with its tip swung up into the superior vena cava. The patient was placed on cardiopulmonary bypass and cooled to below 20C. Circulatory arrest was achieved and the right atrium was opened and explored. The inferior vena cava was opened anterior just below the diaphragm to the ostium of the renal vein and the thrombus was extracted. After reconstruction of the inferior vena cava and closure of the atriotomy the patient was warmed and weaned from cardiopulmonary bypass.

In 2000 Belis et al opposed the practice of complete mobilization of the kidney before cardiopulmonary bypass to minimize ischemic time.[45] They believed that it may increase the risk of tumor embolization before vascular control. Thus, they described a technique that provides full vascular control before renal manipulation and does not significantly increase circulatory arrest time or blood loss.

In 2000 Ciancio et al described the piggyback technique as well as the conventional technique of liver mobilization through a modified cruciate incision and the Rochard retractor as a useful technique for gaining access to the retrohepatic inferior vena cava (fig. 2, *B*).[46] This procedure obviated the need for sternotomy because most of their patients had minimal atrial extension. Intracardiac tumor extension was

generally managed by milking the thrombus into the subdiaphragmatic inferior vena cava under transesophageal echocardiography control. They contended that venovenous bypass (femoral-to-axillary vein) can be used effectively in these cases when necessary, and cardiopulmonary bypass with circulatory arrest should be reserved for patients with extensive intracardiac tumor thrombus.

CONCLUSIONS

The only curative approach to renal cell carcinoma with involvement of the inferior vena cava is surgery. The surgical strategy depends on the level of inferior vena caval involvement (Appendix 1). Patients with a thrombus that extends above the diaphragm are a greater technical challenge.

Traditionally a right thoracoabdominal incision was the incision of choice. With time incisions became more conservative. Surgeons discovered the advantages of a chevron incision and liver mobilization when the thrombus is infradiaphragmatic. It allows earlier recovery, less pain and eliminates the need for thoracic drains. If the tumor thrombus extends above the diaphragm, some groups still prefer a thoracoabdominal incision, while others prefer midline sternotomy combined with an abdominal incision. There seems to be a trend toward the latter technique.

Marshall et al first reported cardiopulmonary bypass but initial results were poor.[15] Significant bleeding from the lumbar or hepatic veins was a problem. Vaislic et al first reported hypothermic circulatory arrest in addition to cardiopulmonary bypass, which was the next evolutionary step.[31] This technique had the advantage of permitting careful, controlled dissection in a virtually bloodless field. Although the risk of tumor dissemination and pulmonary embolus was decreased, there was a risk of neurological sequelae, ischemic injury to other solid organs and postoperative coagulopathy.

In an attempt to decrease perioperative morbidity the concept of venovenous bypass was suggested for tumors with minimal supradiaphragmatic tumor extension. A shunt was created from the femoral or saphenous vein to the axillary vein. In some cases it also enabled decompression of the hepatic circulation with a reversed portal shunt.

When treating extensive tumor thrombus a number of options can be considered, including hypotensive anesthesia with vasodilatation and colloid administration, as described by Viljoen et al,[47] and the addition of cell saver. Cardiopulmonary bypass is an option that can be used when the tumor thrombus is suprahepatic, intrapericardial or intracardiac. Circulatory arrest and hypothermia facilitate excision of a tumor thrombus extending into the right atrium by allowing the surgeon to operate in a bloodless field. The pioneering report of Skinner et al demonstrated a survival advantage for aggressive surgical resection of inferior vena caval tumor thrombus from renal cell carcinoma and led to a dramatic change in the management of these cases.[18] Marshall et al described cardiopulmonary bypass with circulatory arrest as a reasonable adjunct for cavo-atrial tumors.[32]

Surgery for renal cell carcinoma with inferior vena caval thrombus is challenging. It requires accurate preoperative preparation and an experienced surgical team. When properly performed, perioperative morbidity and mortality are relatively low (Appendix 2).

APPENDIX 1: VARIOUS PREVIOUS SITE SPECIFIC APPROACHES FOR RENAL CELL CARCINOMA WITH INFERIOR VENA CAVA INVOLVEMENT

Level	Incisions	Technique	Cardiopulmonary Bypass/Venovenous Bypass	Modifications and Adjuncts
I	1) Flank	Inferior vena cava isolated above and below thrombus	No	Not specified
	2) Subcostal			
	3) Midline abdominal			
II	1) Subcostal	Inferior vena caval isolation and thrombectomy	Usually not required	None specified
	2) Midline			
	3) Chevron			
	4) Chevron with xiphisternal extension			
III	1) Chevron with xiphisternal extension	1) Aim is to have control of the inferior vena cava and major hepatic veins	Usually not done	May require inferior vena caval reconstruction with prosthetic graft
	2) Midline abdominal	2) Thrombectomy		
	3) Thoracoabdominal			
IV	1) Midline sternotomy with midline abdominal	Aim is to extract the thrombus in the atrium without fragmentation	Required most of the time	1) Foley catheter technique
	2) Chevron with xiphisternal extension			2) Up and down finger technique
	3) Thoracoabdominal			3) Milking the tumor into the subdiaphragmativ inferior vena cava

APPENDIX 2: UNIVERSITY OF MIAMI RECOMMENDATION FOR SURGICAL MANAGEMENT OF RENAL CELL CARCINOMA WITH INFERIOR VENA CAVAL INVOLVEMENT

1) Preoperative evaluation, including cardiac and pulmonary assessment.
2) Preoperative assessment of the level of thrombus by computerized tomography or additional MRI.
3) Transabdominal modified chevron incision and use of the Rochard retractor system.
4) Mobilization of the liver off of the inferior vena cava in piggyback fashion for complete visualization of the intra-abdominal inferior vena cava.
5) Control of the inferior vena cava above and below the tumor thrombus.
6) In cases of suprahepatic inferior vena caval involvement the aim is to milk down the thrombus below the major hepatic veins and then clamp the inferior vena cava cranial to the thrombus. This maneuver requires additional dissection of the inferior vena cava off of the posterior abdominal wall to enable the surgeon to gain circumferential control of the inferior vena cava while attempting to milk the thrombus.
7) Natural venovenous bypass channels, such as the gonadal vein, ascending lumbar and adrenal veins, are not ligated during inferior vena caval dissection. We believe that these channels are important for providing a natural bypass and facilitating safe cross-clamping of the inferior vena cava.
8) Removal of the thrombus through a linear venotomy or circumferential cut around the insertion of the renal vein.
9) Attention is then focused on the renal artery, which is approached posterior to the kidney, ligated and cut.
10) The kidney is then dissected in its entirety and delivered.
11) Postoperatively the patient is maintained on low molecular weight dextran and standard precautions are taken to prevent DVT.

REFERENCES

1. O'Donohoe, M. K., Flanagan, F., Fitzpatrick, J. M. and Smith, J. M.: Surgical approach to inferior vena caval extension of renal cell carcinoma. Br J Urol, **60:** 492, 1987
2. Emmott, R. C., Hayne, L. R., Katz, I. L., Scribner, R. G. and Tawes, R. L., Jr.: Prognosis of renal cell carcinoma with vena caval and renal vein involvement: an update. Am J Surg, **154:** 49, 1987
3. Hatcher, P. A., Anderson, E. E., Paulson, D. F., Carson, C. C. and Robertson, J. E.: Surgical management and prognosis of renal cell carcinoma invading the vena cava. J Urol, **145:** 20, 1991
4. Pritchett, T. R., Lieskovsky, G. and Skinner, D. G.: Extension of renal cell carcinoma into the vena cava: clinical review and surgical approach. J Urol, **135:** 460, 1986
5. Wilkinson, C. J., Kimovec, M. A. and Uejima, T.: Cardiopulmonary bypass in patients with malignant renal neoplasms. Br J Anaesth, **58:** 461, 1986
6. Libertino, J. A.: Renal cell cancer with extension into the vena cava. In: Rob & Smith's Operative Surgery: Urology, 4th ed. Edited by W. S. McDougal. London: Butterworths, p. 127, 1986
7. Neves, R. J. and Zincke, H.: Surgical treatment of renal cancer with vena cava extension. Br J Urol, **59:** 390, 1987
8. Stief, C. G., Schafers, H. J., Kuczyk, M., Anton, P., Pethig, K., Truss, M. C. et al: Renal-cell carcinoma with intracaval neoplastic extension: statification and surgical technique. World J Urol, **13:** 166, 1995
9. Belis, J. A., Pae, W. E., Jr., Rohner, T. J., Jr., Myers, J. L., Thiele, B. L., Wickey, G. S. et al: Cardiovascular evaluation before circulatory arrest for removal of vena caval extension of renal carcinoma. J Urol, **141:** 1302, 1988
10. Blancardus. Cited by Schecter, D. C.: Cardiovascular surgery in the management of exogenous tumors involving the vena cava. In: Surgery of the Veins. Edited by J. J. Bergan and J. S. T. Yao. Orlando: Grune & Stratton, chapt. 28, pp. 393–412, 1985
11. Berg, A. A.: Malignant hypernephroma of the kidney. Its clinical course and diagnosis, with a description of the author's method of radical operative cure. Surg Gynecol Obstet, **17:** 463, 1913
12. Rehn, E.: Gefasskomplikatnen und ihre Beherrschung bei dem hypernephrom. Z Urol Chir, **10:** 326, 1922
13. Walters, W. and Priestley, J. T.: Survey of the inferior vena cava. Clinical and experimental studies. Ann Surg, **99:** 167, 1934
14. Robson, C. J.: Radical nephrectomy for renal cell carcinoma. J Urol, **89:** 37, 1963
15. Marshall, V. F., Middleton, R. G., Holswade, G. R. and Goldsmith, E. I.: Surgery for renal cell carcinoma in the vena cava. J Urol, **103:** 414, 1970
16. Judd, E. S. and Scholl, A. J.: Thrombosis and embolism resulting from renal tumors. JAMA, **82:** 75, 1924
17. Heaney, J. P., Stanton, W. K., Halbert, D. S., Seidel, J. and Vice, T.: An improved technic for vascular isolation of the liver: experimental study and case reports. Ann Surg, **163:** 237, 1966
18. Skinner, D. G., Pfister, R. F. and Colvin, R.: Extension of renal cell carcinoma into the vena cava: the rationale for aggressive surgical management. J Urol, **107:** 711, 1971
19. Lome, L. G. and Bush, I. M.: Resection of the vena cava for renal cell carcinoma: an experimental study. J Urol, **107:** 717, 1972
20. Cole, A. T., Julian, W. A. and Fried, F. A.: Aggressive surgery for renal cell carcinoma with vena cava tumor thrombus. Urology, **6:** 227, 1975
21. Freed, F. Z. and Gliedman, M. L.: The removal of renal carcinoma thrombus extending into the right atrium. J Urol, **113:** 163, 1975
22. Abdelsayed, M. A., Bissada, N. K., Finkbeiner, A. E. and Redman, J. F.: Renal tumors involving the inferior vena cava: plan for management. J Urol, **120:** 153, 1978
23. Pringle, J. H.: Notes on the arrest of hepatic hemorrhage due to trauma. Ann Surg, **48:** 541, 1908
24. McCullough, D. L. and Gittes, R. F.: Vena cava resection for renal cell carcinoma. J Urol, **112:** 162, 1974
25. Schefft, P., Novick, A. C., Straffon, R. A. and Stewart, B. H.: Surgery for renal cell carcinoma extending into the inferior vena cava. J Urol, **120:** 28, 1978
26. Cummings, K. B., Li, W.-I., Ryan, J. A., Horton, W. G. and Paton, R. R.: Intraoperative management of renal cell carcinoma with supradiaphragmatic caval extension. J Urol, **122:** 829, 1979
27. Clayman, R. V., Gonzalez, R. and Fraley, E. E.: Renal cell cancer invading the inferior vena cava: clinical review and anatomical approach. J Urol, **123:** 157, 1979
28. Langenbuch, C.: Chirurgie der leber und gallenblase. Dtsche Chir, **45C:** 1, 1894
29. Novick, A. C. and Cosgrove, D. M.: Surgical approach for removal of renal cell carcinoma extending into the vena cava and the right atrium. J Urol, **123:** 947, 1980
30. Kearney, G. P., Waters, W. B., Klein, L. A., Richie, J. P. and Gittes, R. F.: Results of inferior vena cava resection for renal cell carcinoma. J Urol, **125:** 769, 1981
31. Vaislic, C., Puel, P., Grondin, P. and Vargas, A.: Surgical resection of neoplastic thrombosis in the inferior vena cava by neoplasms of renal-adrenal tract. Vasc Surg, September-October, p. 322, 1983
32. Marshall, F. F., Reitz, B. A. and Diamond, D. A.: A new technique for management of renal cell carcinoma involving the right atrium: hypothermia and cardiac arrest. J Urol, **131:** 103, 1984
33. Wilkinson, C. J., Kimovec, M. A. and Uejima, T.: Cardiopulmonary bypass in patients with malignant renal neoplasms. Br J Anesth, **58:** 461, 1986
34. Giuliani, L., Giberti, C., Martorana, G. and Rovida, S.: Surgical management of renal cell carcinoma with vena cava tumor thrombus. Eur Urol, **12:** 145, 1986
35. Libertino, J. A., Zinman, L. and Watkins, E., Jr.: Long term results of resection of renal cell cancer with extension into the inferior vena cava. J Urol, **137:** 21, 1987
36. Marshall, F. F., Dietrick, D. D., Baumgartner, W. A. and Reitz, B. A.: Surgical management of renal cell carcinoma with intracaval neoplastic extension above the hepatic veins. J Urol, **139:** 1166, 1988
37. Novick, A. C.: Editorial comment. J Urol, **139:** 1172, 1988
38. Zinman, L.: Editorial comment. J Urol, **139:** 1172, 1988
39. Hartman, A. R., Zelen, J., Mason, R. A., Bumpers, H. L. and Washeka, R.: Fiberoptic examination of the inferior vena cava during circulatory arrest for complete removal of renal cell carcinoma thrombus. Surgery, **107:** 695, 1990

40. Treiger, B. F. G., Humphrey, L. S., Peterson, C. V., Jr., Oesterling, J. E., Mostwin, J. L., Reitz, B. A. et al: Transesophageal echocardiography in renal cell carcinoma: an accurate diagnostic technique for intracaval neoplastic extension. J Urol, **145:** 1138, 1991
41. Stewart, J. R., Carey, J. A., McDougal, S., Merrill, W. H., Koch, M. O. and Bender, H. W., Jr.: Cavoatrial tumor thrombectomy using cardiopulmonary bypass without circulatory arrest. Ann Thorac Surg, **51:** 717, 1991
42. Marsh, C. L. and Lange, P. H.: Application of liver transplant and organ procurement techniques to difficult upper abdominal urological cases. J Urol, **151:** 1652, 1994
43. Swierzewski, D. J., Swierzewski, M. J. and Libertino, J. A.: Radical nephrectomy in patients with renal cell carcinoma with venous, vena caval, and atrial extension. Am J Surg, **168:** 205, 1994
44. Fitzgerald, J. M., Tripathy, U., Svensson, L. G. and Libertino, J. A.: Radical nephrectomy with vena caval thrombectomy using a minimal access approach for cardiopulmonary bypass. J Urol, **159:** 1292, 1998
45. Belis, J. A., Levinson, M. E. and Pae, W. E., Jr.: Complete radical nephrectomy and vena caval thrombectomy during circulatory arrest. J Urol, **163:** 434, 2000
46. Ciancio, G., Hawke, C. and Soloway, M.: The use of liver transplant techniques to aid in the surgical management of urological tumors. J Urol, **164:** 665, 2000
47. Viljoen, J. F. and Thangathurai, D.: Anesthetic management in radical surgery for urologic malignancies. In: Diagnosis and Management of Genitourinary Cancer. Edited by D. G. Skinner and G. Lieskovsky. Philadelphia: W. B. Saunders Co., pp. 595–600, 1988