Pneumodissection during Percutaneous Renal Ablation Resulting in Air Embolism: Percutaneous Management and a Review of the Literature

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Abstract

Keywords

- ▶ vascular air embolism
- ▶ pneumodissection
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- ▶ complications
- ▶ interventional radiology

Percutaneous renal ablation is a nephron-sparing approach for selected patients with renal cell carcinoma. Common complications include hemorrhage, injury to the urinary collecting system, and abscess formation. The purpose of this article is to present a case of vascular air embolism as a complication of pneumodissection performed during percutaneous ablation of renal cell carcinoma, discuss its successful percutaneous management, review common complications of renal ablation, and outline steps physicians can take to lessen these complications.

Renal cell carcinoma (RCC) accounted for ~64,000 new cancer diagnoses and ~15,000 patient deaths in 2018.¹ The incidence of RCC has grown over the past several decades, as an increased reliance on cross-sectional imaging in the diagnosis of intra-abdominal pathology has led to a rise in the detection of smaller, asymptomatic renal masses.^{2–5} While active surveillance can be pursued in certain populations, most patients are directed toward definitive surgical or percutaneous management.⁶ Partial nephrectomy is the standard of care for noncentral, stage T1a (≤ 4 cm) lesions; however, image-guided, percutaneous ablation (PA) is a nephron-sparing technique that should be considered for patients who either cannot tolerate or do not wish to pursue traditional surgery.⁶ PA can be undertaken using a variety of technologies, including radiofrequency ablation (RFA), microwave ablation (MWA), cryoablation, and irreversible electroporation. Each modality has its own advantages and disadvantages with no strong evidence to conclude superiority of one technology over the other in RCC.^{7,8} When compared with partial and radical nephrectomy, PA has similar technical and oncologic outcomes for stage T1a lesions with an overall lower rate of complications.⁹ Major complications occur in 3 to 7% of patients after PA with the most commonly reported complications being off-target organ/tissue damage, hemorrhage, urinoma, damage to the urinary collecting system, and abscess formation.¹⁰ Com-

plications are most often due to the tumor's proximity to critical structures such as the bowel or ureter, but tumor size, tumor geometry, and the number of probes employed can also play a role.^{11,12} We present a case of vascular air embolism (VAE) as a complication of pneumodissection performed during PA of RCC, discuss management strategies, review common complications encountered during PA of RCC, and outline steps physicians can take to mitigate complications.

Case Report

A 69-year-old male with class II congestive heart failure (CHF) from nonischemic cardiomyopathy, severe tricuspid regurgitation (TR), stage 3A chronic kidney disease, and a remote history of deep venous thrombosis, for which he takes an anticoagulant, presented to the emergency department with a chief complaint of abdominal pain and nausea. He denied hematuria, dysuria, or weight loss. Physical exam was unremarkable. A contrast-enhanced computed tomography (CT) scan of the abdomen and pelvis revealed an endophytic, 3.5×3.3 cm, enhancing mass in the interpolar region of the right kidney (▶ **Fig. 1**). The patient was referred to urology as an outpatient for consideration of either partial or radical nephrectomy. The urologist considered the patient a poor surgical candidate and referred the patient to

Fig. 1 (a) Axial contrast-enhanced CT image shows an enhancing, endophytic, 3.5 × 3.3 cm mass in the right kidney (white arrow). (b) Coronal reformat also demonstrates the lesion (white arrow).

interventional radiology (IR) for consideration of PA. The patient was evaluated in the IR clinic and reported no changes to his medical history. Relevant laboratory values included a hemoglobin of 13.7 g/dL, a hematocrit of 41%, a platelet count of 144,000/ μ L, an international normalized ratio of 1.7, and a serum creatinine of 1.5 mg/dL. After a discussion of the benefits, risks, and alternatives, the patient elected to proceed with PA. The patient was scheduled for cryoablation of his tumor.

Procedure. The procedure was performed under general anesthesia and ceftriaxone (1 g IV) was administered, both of which are standard practice at our institution. The patient was instructed to withhold anticoagulation therapy for 3 days prior to the procedure per institutional guidelines.

Appropriate percutaneous access was identified with CT, with the patient in supine position. Four cryoablation probes (IceForce; Galil Medical, Arden Hills, MN) were placed within the lesion under CT-fluoroscopy guidance (**Fig. 2**). At this point, it was felt that the right colon was too close to the ablation zone and would be at risk of thermal injury (**Fig. 3a**). Given the antidependent location of the colon, pneumodissection was performed by inserting a 20G needle in between the kidney and colon under CT-fluoroscopy guidance. Once in appropriate position, ~100 cc of room air was instilled, assuring a safe distance from the colon prior to cryoablation (**Fig. 3b**). Cryoablation was then performed with a 10-minute freeze (100% on all probes), an 8-minute passive thaw, a 10-minute freeze (100% on all probes), and then an active thaw. Intermittent CT was performed during cryoablation to monitor the ablation zone. Cautery was performed on all probes.

Fig. 2 (a) Axial CT image obtained during the ablation showing the upper two ablation probes. (b) Same axial CT image shows the lower two ablation probes.

Fig. 3 (a) Axial CT image obtained during the ablation shows a loop of bowel < 2 cm away from one of the upper ablation probes, placing it at risk of damage during the ablation (white arrow). (b) Axial CT image shows that the colon is now safely away from the ablation zone after pneumodissection (white arrow).

One of the intermittent scans obtained during the ablation demonstrated air tracking from the retroperitoneum into the renal vein, inferior vena cava (IVC), hepatic veins, and right heart (**Fig. 4**). The patient was hemodynamically stable throughout and without an increased oxygen requirement. Out of caution, increased supplemental oxygen was provided. Serial monitoring of the intravascular air via CT demonstrated decreasing amounts within the right heart and hepatic veins despite no intervention (**Fig. 4a**). However, there were no appreciable changes in the IVC (**Fig. 4b**). To reduce the amount of air in the IVC, we considered the option of moving the patient to the angiography suite for catheter-based, intravascular aspiration of the air, but we did not want to risk changing the patient's position, as this could potentially reposition the air within the heart and hepatic veins into the pulmonary outflow tract. Therefore, we elected to advance a 22G needle into the IVC under CT-fluoroscopy guidance to aspirate the air (**Fig. 5a**). Approximately 50 cc of air was aspirated. Once we had confirmed through CT that minimal intravascular air remained (**Fig. 5b**), we terminated the procedure. The patient was entirely asymptomatic throughout. Due to his multiple comorbidities, he was admitted for overnight observation. A CT was obtained the next morning showing minimal air in the IVC but no residual air in the renal vein, hepatic veins, or right heart (**Fig. 6**). He was discharged to home. The patient returned to clinic for a routine 2-week follow-up visit and had recovered fully. A 3-month postablation CT scan demonstrates no evidence of residual disease, intravascular air, or other complication.

Case Discussion and Review of Renal Ablation Complications

Even though PA has an excellent safety profile, complications do occur.^{9,10} Given the vascular nature of the kidney, postablation hemorrhage is a common concern. Many patients will experience a small amount of asymptomatic perinephric hemorrhage and/or self-limiting hematuria after PA. Larger perinephric hematomas (**Fig. 7**) may warrant overnight observation with serial monitoring of hemoglobin and hematocrit levels. If the patient remains asymptomatic,

Fig. 4 Axial CT images obtained during the ablation show air tracking from the retroperitoneum into the right renal vein (a), IVC (b), hepatic veins (c), and right heart (d). Axial slices from a CT obtained ~10 minutes later show that the air had lessened in the hepatic veins (e) and right heart (f). No significant change in the amount of air in the IVC was seen (g). Arrows—air noted in the respective organs.

they are discharged the following day. At our institution, patients with hemodynamic compromise, significant hematuria, or worsening anemia undergo CT angiography. If a bleeding source is identified, angiography with embolization is performed (►Fig. 8).

Injury to the renal collecting system can also occur after PA, which is of special consideration for central, medial, and anterior tumors. Damage to the renal collecting system can manifest as urinary obstruction, infection, or urinary leak. Obstructed collecting systems can be treated with percutaneous nephrostomy tubes, ureteral stents, or both depending on the degree and location of the stricture. Small urinary leaks may be self-limiting, but persistent leaks are likely to require a ureteral stent to facilitate the forward flow of urine with percutaneous drainage of the associated urinoma (►Fig. 9).

The most serious cases of infection after PA involve damage to adjacent bowel. Perforation of the bowel wall results in leak and possible colo-nephric fistula formation. In these cases, ureteral stent placement should be considered to

encourage forward flow of urine with percutaneous drainage of leaked bowel contents. If these conservative measures fail, surgery may be ultimately required. Other less common complications of PA (<1%) include pneumothorax, tract seeding, skin injury, nerve injury, ileus, hypertension, arrhythmias, myocardial infarction, stroke, pulmonary embolism, pneumonia, pulmonary edema, and segmental renal infarction.¹⁰

Several scoring systems, including the R.E.N.A.L nephrometry score,¹³ PADUA score,¹⁴ and ABLATE score,¹⁵ have been designed as a means to aid physicians in patient

Fig. 5 (a) Axial image during CT-fluoroscopy shows the 22G needle within the IVC (white arrow). (b) Axial CT image obtained after image-guided needle aspiration shows a reduced amount of air in the IVC (white arrow).

Fig. 6 Abdominal CT obtained the following day shows no residual air in the renal vein (a), minimal residual air in the IVC (open white arrow) (b), no air in the hepatic veins (c), and no air in the right heart (d). A small perinephric hematoma is seen in images a and b (solid white arrows).

Fig. 7 (a) Axial image from a contrast-enhanced CT from a 60-year-old woman demonstrates an enhancing, 3.3×4.1 cm, mass in the right kidney (white arrow). The patient was referred to interventional radiology for percutaneous ablation due to multiple medical comorbidities. (b) CT image obtained during the ablation procedure demonstrates two of the three ablation probes used (white arrow). These parallel probes were placed ~ 1.8 cm apart. (c) Unenhanced CT obtained ~ 2 hours after the procedure due to abdominal pain demonstrates a large perinephric hematoma (white arrows). The patient was admitted for overnight observation and serial monitoring of hemoglobin and hematocrit. She remained hemodynamically stable throughout her hospital course and was discharged to home the next day.

selection and risk stratification. Each system attempts to categorize tumors based on size, location (upper pole vs. lower pole, anterior vs. posterior), geometry (endophytic vs. exophytic), and proximity to critical structures such as the renal pelvis. Multiple authors have attempted to validate these scoring systems to determine which, if any, of their components are most associated with complications after PA. For example, a review of 573 renal ablations (254 RFAs;

311 cryoablations) found that advanced patient age, increased tumor size, increased number of ablation probes, and a central location to be associated with an increased risk for major complications.¹¹ A more recent analysis of 95 renal

Fig. 8 A 75-year-old man was referred for percutaneous ablation of a 3.7×3.2 cm right renal mass (not shown). Due to distance from home, the patient was admitted for overnight observation in the hospital after percutaneous cryoablation. The patient experienced an episode of hypotension ~ 12 hours after the procedure. (a) Axial image from non-contrast-enhanced CT demonstrates a large retroperitoneal hematoma measuring $\sim 14 \times 8$ cm. (b) Axial image during arterial phase CT angiography demonstrates extravasation of contrast into the hematoma (white arrow). (c) Selective right renal digital subtraction angiography (DSA) demonstrates hemorrhage from the lower pole of the right kidney (white arrow). (d) Right renal arteriogram demonstrates cessation of hemorrhage after coil embolization (white arrow).

Fig. 9 Images from a 58-year-old man referred to interventional radiology for percutaneous ablation of a 3.5×3.1 cm left renal mass due to a known colovesical fistula and obesity. (a) Contrast-enhanced CT scan shows the mass in the left kidney (white arrow). (b) Coronal reformat from a contrast-enhanced CT scan shows the mass in the left kidney (white arrow). After an uneventful percutaneous cryoablation, the patient was discharged to home on the same day. He presented to the emergency department approximately 2 months after the procedure with abdominal pain and fevers. A contrast-enhanced abdominal CT was obtained (c) that demonstrated an abscess in the ablation bed (white arrow) with an associated collection in the retroperitoneum (double white arrow). The high-density material within the abscess represents a urine leak. The patient was treated with percutaneous drainage of the collections. (d) A spot radiograph taken during percutaneous catheter placement demonstrates contrast in the collection (white arrow) that communicates with the urinary collecting system (double white arrow), indicative of a fistula. Given this finding, urologist placed a ureteral stent. The patient was managed conservatively with ureteral stent and percutaneous drainage for approximately 4 months after which the fistula healed.

cryoablation procedures found that an endophytic location was the only independent factor associated with postprocedural complications.¹² Similarly, a retrospective review of 177 cryoablation procedures sought to assess the validity of both the PADUA and R.E.N.A.L nephrometry scores in predicting complications (unpublished data). In this cohort, nearness to the collecting system was the only factor in either system associated with an increased risk for complications by multivariate analysis. Regardless of their prospective ability, these scoring systems do provide physicians with an important starting point for patient selection, risk stratification, and patient counseling. Thus, familiarity with one (or many) of these scoring systems is important when performing PA.

Even when faced with complex tumors, there are several adjunctive techniques that can be used to minimize the risk of complications from PA. Prior to PA, some practitioners advocate angioembolization of larger or particularly hypervascular tumors. Several case series have demonstrated that embolization prior to PA is both safe and technically feasible^{16–18}; however, a recent propensity score matching analysis failed to show an objective benefit to the combined approach as it relates to bleeding complications.¹⁹ Both larger retrospective and prospective data are needed to address its clinical utility in either preventing complications or improving oncologic outcomes.

For central tumors, a ureteral stent can be placed prior to the procedure which is then used to slowly infuse fluid (at room temperature for cryoablation; cooled in an ice bath for RFA or MWA) during the ablation. The fluid protects the urinary collecting system and the stent can typically be removed immediately following the case.^{20,21} During the procedure, there are several maneuvers available to move the tumor away from critical structures such as the ureter or bowel. For instance, one must not discount the effects of patient positioning on the tumor's relation to adjacent structures. While the majority of PA procedures for RCC are performed in prone position, we will place the patient in supine or lateral decubitus position if this will provide for a safer ablation zone. Other authors have described the ability to place gentle traction on the cryoprobes after several minutes of freezing as a mechanism to move the ablation zone away from the ureter.²² Finally, displacement techniques such as hydrodissection and pneumodissection can be used to create a safe distance between the ablation zone and critical structures. Some authors suggest that there should be at least 5 to 10 mm between the ablation zone and adjacent bowel to insulate it from off-target injury.^{23,24} For displacement in a dependent location, we prefer hydrodissection with normal saline (or dextrose 5% in water, if using RFA). After placing the ablation probe(s), a 20 to 22G needle is inserted in between the tumor and critical structure. To confirm positioning of the needle, ~20 cc of fluid is instilled. If the fluid is collecting in an appropriate position, more fluid is instilled until a safe ablation zone is created. For displacement in an antidependent location (as in this case), pneumodissection can be performed in a similar fashion.

Complications due to pneumodissection occur in up to 9% of cases and can include tissue damage, subcutaneous emphysema, and VAE.²⁵ Pneumodissection with carbon dioxide (CO₂) (instead of room air) decreases the risk of VAE due to its increased blood solubility and faster body clearance.²⁶ VAE can lead to cardiac arrest and stroke²⁷; thus, early recognition and appropriate management is crucial for reducing patient morbidity and mortality. VAE may manifest as hemodynamic compromise and/or increasing oxygenation requirements, but it should be noted that ~15% of cases are asymptomatic.²⁷ In patients under general anesthesia, a reduced end tidal CO₂ may be one of the earliest indicators of VAE.²⁸ Existing literature describes three principal management goals: (1) prevention of further air entry, (2) a reduction in the volume of air entrained, if possible, and (3) hemodynamic support.²⁹ In our case, after recognizing VAE and stopping any further air entry, we employed a percutaneous, needle-based approach to aspirate the air from within the IVC. An alternative approach to consider would be catheter-based aspiration, which may be appropriate depending on the clinical situation. In this case, we did not wish to move the patient and risk air entering the pulmonary outflow tract. Finally, after minimizing the volume of intravascular air, 100% supplement oxygen should be administered via a non-rebreather mask or, if the patient is intubated, the FiO₂ should be set to 100%. High-flow oxygen maximizes end-organ oxygenation and may also reduce the size of the air embolus by aiding the reabsorption of nitrogen gas.²⁹

It is unclear how the air entered the vascular system in this case. In laparoscopy, VAE is believed to be secondary to inadvertent vascular puncture during port or trocar placement.³⁰ Thus, it is possible that the pneumodissection needle punctured the renal capsule or vein during placement. A less likely possibility is that the pressure accumulated during instillation forced the air itself to dissect into the vasculature, which has been described in the endoscopic literature.³¹ Notably, the patient remained asymptomatic and hemodynamically stable throughout the event. One potential explanation is that only ~100 cc of air was injected. Although there is no safe amount of intravascular air, some theorize that 300 to 500 cc of gas introduced at a rate of 100 cc/sec is a fatal dose for humans.³² Additionally, positioning may also have had a role as the patient was supine with the right side slightly elevated, placing the right heart in a favorable, antidependent position that prevented the air from entering the pulmonary outflow tract.³² A final explanation could be that the patient had severe CHF with a left ventricular ejection fraction of ~15% and severe TR. Therefore, the inefficient cardiac output and severe TR may have also contributed to the air settling in the right heart rather than being forced through into the right ventricle. Regardless of the exact cause, prompt recognition, patient positioning, and percutaneous aspiration of the air helped the patient avoid an unfavorable outcome.

In conclusion, percutaneous renal ablation is an overall safe, nephron-sparing approach to the management of RCC with similar oncologic outcomes to partial nephrectomy in

stage T1a disease.⁹ A comprehensive understanding of both the common and uncommon complications of this procedure is important for early recognition and appropriate management.

Disclosures

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