

INVITED REVIEW SERIES

Invited Review Series: Emerging Innovations, Interventions and Directions in Thoracic Imaging

Current trends in image-guided chest interventions

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Abstract

Interventional radiology (IR) is a rapidly expanding medical subspecialty and refers to a range of image-guided procedural techniques. The image guidance allows real-time visualization and precision placement of a needle, catheter, wire and device to deep body structures through small incisions. Advantages include reduced risks, faster recovery and shorter hospital stays, lower costs and less patient discomfort. The range of chest interventional procedures keeps on expanding due to improved imaging facilities, better percutaneous assess devices and advancing ablation and embolization techniques. These advances permit procedures to be undertaken safely, simultaneously and effectively, hence escalating the role of IR in the treatment of chest disorders. This review article aims to cover the latest developments in some image-guided techniques of the chest, including thermal ablation therapy of lung malignancy, targeted therapy of pulmonary embolism, angioplasty and stenting of mediastinal venous/superior vena cava occlusion, pulmonary arteriovenous malformation treatment and bronchial artery embolization for haemoptysis.

KEYWORDS

bronchial artery, cancer, central vein occlusion, chest, embolization, interventional radiology, pulmonary arteriovenous malformation, pulmonary embolism, thermal ablation, thrombectomy

INTRODUCTION

Interventional radiology (IR) is a rapidly expanding medical subspecialty and refers to a range of procedural techniques that are guided by imaging equipment, including fluoroscopy/digital subtraction angiographic (DSA) unit, ultrasound (US), computed tomography (CT) or MRI with or without the use of contrast agents. Most of the IR procedures are minimally invasive and could be diagnostic such as biopsy, angiogram or ductogram; or therapeutic through catheter-directed balloon dilatation, stent insertion, embolization, retrieval or drug delivery. The image guidance allows real-time visualization and precision placement of a needle,

catheter, wire and device to deep structures of the body through a body orifice or small skin incision.

The main advantages of these image-guided procedures include reduced risks, faster recovery and shorter hospital stays, lower costs and less patient discomfort. Many of these procedures require the use of ionization radiation, such as with fluoroscopy/DSA and CT, bringing a radiation risk to patients and operators. The benefits of these interventional procedures commonly outweigh these risks.

Recent advancement in imaging technology allows for the range of conditions that utilize IR to continuously expand. The rapid technological improvement of cross-sectional imaging techniques, in particular multidetector row CT and high-field strength MRI, produces image quality with excellent spatial and temporal resolution that aids accurate diagnosis of pathology and localization. Hence, IR

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has become the preferred way to diagnose and treat many types of conditions in the hospital setting.

Percutaneous transthoracic lung biopsy was first brought into the spotlight by the work of Dahlgren and Nordenstrom over 50 years ago, and has been widely accepted as a highly accurate method of obtaining lung tissue with an acceptably low rate of morbidity.¹ Since then, chest diagnostic procedures have expanded to include mediastinal, pleural and bone masses; drainage of pleural effusions and empyema; and drainage of pulmonary abscess. Therapeutic procedures encompass bronchial artery embolization for haemoptysis, lung tumour ablation therapy, pulmonary arteriovenous malformation treatment, targeted therapy of pulmonary embolism (PE), angioplasty and stenting of mediastinal venous/superior vena cava (SVC) occlusion.

This review article aims to increase awareness of respiratory physicians to some of the IR techniques in the chest, the latest developments, indications, contraindications and potential procedural complications.

THERMAL ABLATION THERAPY FOR LUNG TUMOURS

Lung cancer screening programmes are leading to the discovery of more early-stage asymptomatic lung cancers. Incidental pulmonary nodules are also found on non-dedicated multidetector CT scans such as CT coronary angiograms and trauma CT scans, with a significant proportion being malignant.²

For stage I non-small cell lung cancer (NSCLC), lobectomy and hilar nodal sampling remain the gold standard of treatment. However, a significant proportion of patients diagnosed with early-stage NSCLC are not surgical candidates, mainly due to cardiopulmonary comorbidities. These patients are usually offered stereotactic body radiation therapy (SBRT).

The search for treatment alternatives has led to promising non-radiotherapy based local treatment options emerging over the past 20 years. Percutaneous CT-guided thermal ablation is one major category.

The most comprehensive data available by far is for radiofrequency ablation (RFA), followed by microwave ablation (MWA) and cryoablation,³ the former two modalities utilizing heat-based tissue destruction, while the latter destroys the tumour tissue by freezing. Laser ablation and irreversible electroporation have been attempted as well, but have been abandoned due to poor local control, high complication rate, high cost and only small lesions being targetable.⁴

A large, early, multicentre lung cancer RFA study known as the RAPTURE reported a 2-year overall survival rate of 48%. However, most of the deaths in these high-risk patients were from non-cancer-related causes, as reflected by their much more favourable 2-year cancer-specific survival of 92%.⁵

This discrepancy highlights the need for a minimally invasive therapy option that requires a short course of treatment and hospitalization, provides local disease control, has relatively low cost and preserves lung function and quality of life.

There are no prospective randomized trials comparing SBRT with percutaneous thermal ablation. A very recent comprehensive review article emphasizes that in the therapeutic approach with curative intent, there is no significant difference 'in overall survival or progression-free survival between patients with early-stage NSCLC treated with SBRT or percutaneous RFA', with slightly better local control attributed to SABR over RFA and similar safety profiles; the great advantage of percutaneous thermal ablation is the paucity of long-term side effects and that 'thermal ablation does not preclude future resection, SBRT or repeat thermal ablation'.⁶

Indication and patient selection

Careful patient selection and multidisciplinary discussion and decision-making are mandatory.

Primary early-stage NSCLC and pulmonary oligometastatic/oligoprogressive disease both qualify for percutaneous thermal ablation with curative intent. For best treatment outcomes, the tumours should ideally measure less than 3 cm in maximum diameter and should not abut major structures such as the heart and mediastinum or be close to the oesophagus or nerves. In the oligometastatic setting, the primary tumour needs to be under control; a total of five lesions with up to three per hemithorax can be accepted for treatment, with best outcomes achieved with one to two metastases.⁷ The largest published study on RFA for oligometastatic disease showed overall survival rates comparable to surgery and SBRT.⁸

The only requirement for the thermal ablation patient is their ability to lie flat, no need of supplemental oxygen at rest⁹ and the absence of uncontrollable coagulation disorder. Life expectancy should ideally be 6 months or longer.

Mechanism and ablations

All percutaneous thermal ablation therapies, whether heating or freezing the tumour, have the common goal of achieving local tumour control via a minimally invasive treatment option with the aim of preserving surrounding healthy (lung) tissue and quality of life. Under image-guided CT in the lung setting, one or several electrodes/antennae are inserted into the target lesion (Figure 1) and one or more treatment cycles are applied during a single sitting until the planned treatment outcome—a circumferential rim of ground-glass opacity (GGO) surrounding the index lesion—is achieved. Depending on the modality used, treatment duration ranges from less than 5 min to over an hour per tumour. Lesion size, location and differentiation are important variables dictating treatment parameters. The treatment can be performed on an ambulatory patient under conscious sedation. Some centres prefer general anaesthesia. Usually, the patient remains in hospital overnight to monitor for potential subacute complications. CT chest at 24 h post procedure is performed for detecting any complications and serves as the baseline for subsequent follow-up imaging.



FIGURE 1 A 74-year-old woman post right mastectomy and chest wall radiotherapy 35 years prior with significant right upper lobe radiation fibrosis with traction bronchiectasis. Biopsy-proven right lower lobe non-small cell lung cancer at the periphery of former radiation field involving oblique fissure. (A) Saline-cooled percutaneous microwave ablation (MWA) antenna during the test run of 1 min at 130 W; generator display indicates countdown from 1 minute (0:39) and wattage level (130). (B) The patient in left lateral decubitus position under conscious sedation in the computed tomography (CT) gantry, antenna in situ. (C) MWA antenna in the target lesion, single ablation cycle of 4 min at 80 W performed. (D) CT scan 24 h post ablation showed circumferential ground-glass opacity delineating the area of thermal damage (arrows) surrounding the ablated lesion, also crossing the adjacent fissure (superior-most arrow)

RADIOFREQUENCY ABLATION

RFA has been around the longest, with the first publication of its use for pulmonary malignancy in 2000.¹⁰ With RFA, an electrical circuit is created between one or more active electrodes percutaneously inserted into the tumour and the grounding pads (dispersive electrode), positioned on the patient's back or thighs. High-frequency (approximately 500 kHz) alternating current flows between the active electrode and the dispersive electrode, leading to frictional heat in the target tissue created by oscillating ions that follow the changing direction of the alternating current. When the tissue temperature rises above 60°C, protein denaturation and coagulation necrosis ensue, leading to instantaneous cell death.¹¹ The main limitation of RFA in lungs is the insulating effect of the air-filled lung surrounding the target, which may be beneficial in small spherical lesions with the heat being kept at the intended site. However, in irregular, spiculated lesions, which are mostly seen in primary lung cancers, the air prevents dissipation of the heat to the outskirts of the target area, thus preventing complete tissue destruction. Another insulator is the formation of charred, desiccated tissue preventing uniform distribution of the heat, and yet another is the so-called 'heat sink effect', caused by blood flow and air flow through larger vessels or airways in the area, dispersing the applied heating.^{12,13}

For best results, the thermal treatment needs to include some of the normal lung tissue surrounding the target. A

histologic workup of NSCLC treated with RFA showed that treatment margins around the tumour edge of 8 mm for adenocarcinoma and 6 mm for squamous cell carcinoma are required to encompass 95% of microscopic disease.¹⁴ A ratio of at least 4:1 between the area of RFA-induced peritumoural GGO and the tumour area before ablation (Figure 1D) was shown to correlate with a significantly higher rate of complete ablation at 18 months.¹⁵

MICROWAVE ABLATION

MWA also uses electromagnetic energy to destroy pulmonary neoplastic tissue, its greatest advantage being that it is not affected by the heat insulation and conduction problems of RFA that we have described. An antenna is inserted into the tumour under CT guidance, and electromagnetic waves in the microwave spectrum (915 MHz or 2.45 GHz in the human ablative setting) are produced by a generator (Figure 1A) and radiate from the antenna. These waves are converted to kinetic energy and heat because the polar molecules in the target tissue are forced to continuously realign with the oscillating electric field (dielectric hysteresis).¹⁶ Direct heating occurs in a volume of tissue around the antenna and is not restrained by the air-filled spaces.

Microwave energy produces faster and more intense heating of larger volumes with less susceptibility to heat-sink effects,^{17,18} making it more effective than RFA. In a recent

systematic review article covering 12 studies of 1336 MWAs of both primary and secondary lung tumours in 985 patients, the cut-off target size was at 4 cm diameter with a local recurrence rate of only 5%–19%.¹⁹ MWA is preferred over RFA in patients with implanted cardiac devices.²⁰

In a study by Zheng et al., including 52 patients with stage I NSCLC, the cancer-specific overall survival rates at 1, 2, 3 and 4 years were 98.0%, 85.7%, 80.0% and 80.0%, respectively,²¹ which have significantly improved from the same group's earlier study,²² likely due to better patient selection and growing technical experience and expertise.

CRYOABLATION

In contrast to heat-based tissue destruction, cryoablation causes cellular damage through a cycle of freezing and thawing. The main cause of tumour destruction is intracellular ice crystal formation disrupting organelles and cell membranes, helped by extracellular crystallization causing cell dehydration. Post-freezing thawing causes coalescence of ice crystals that further disrupt cell membranes.¹³

The most recent recommendation to achieve 5 mm circumferential safety margins in pulmonary nodules is to have a triple-freeze protocol and to use two cryoprobes in nodules of

4–13 mm in diameter and three probes for lesions of 14–20 mm in size.²³ While successful pulmonary cryoablation is confined to lesions no larger than 20 mm and is more time-intensive and significantly more expensive than heat-based ablations, it is the preferred image-guided thermal ablation option for small central lesions and lesions abutting the heart, pleura and mediastinum. It is less painful and causes less irreversible or major thermal damage to adjacent organs than heat-based alternatives.²⁴

The multicentre SOLSTICE (Study of Metastatic Lung Tumors Targeted by Interventional Cryoablation Evaluation) study data that evaluated the safety and local recurrence-free survival of patients with pulmonary metastases treated with cryoablation showed a promising 77.2% local recurrence-free response. Furthermore, locally recurrent metastases treated with a further cryoablation showed a 91.1% secondary recurrence-free response.²⁵ The rather high pneumothorax rate requiring pleural catheter placement of 26% was owing to the requirement of multiple applicators traversing the pleura.

Imaging follow-up

The post-procedural evolution of the thermal ablation zone is divided into three phases—early (<1 week), intermediate

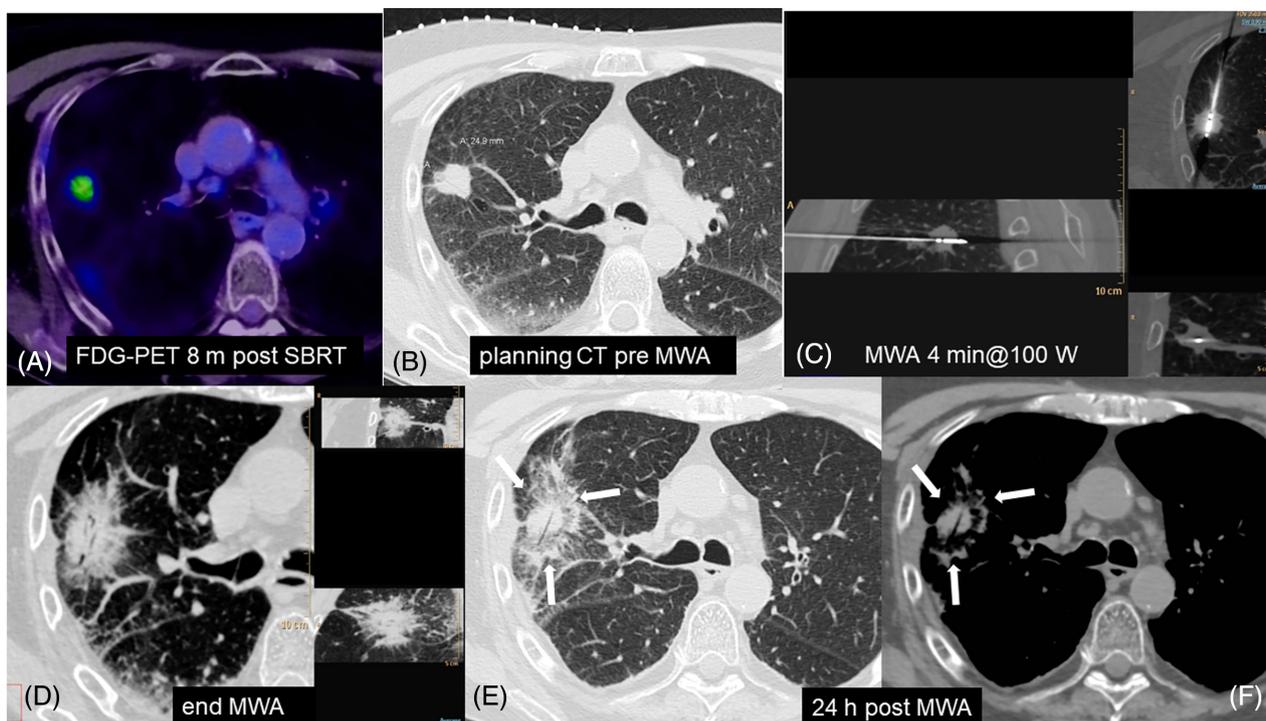


FIGURE 2 A 70-year-old male with complex medical history—stroke, prostate cancer, bladder cancer with pelvic exenteration and ileal conduit. Right upper lobe (RUL) T1N0M0 non-small cell lung cancer (adenocarcinoma), stereotactic body radiation therapy (SBRT). (A) Fluorodeoxyglucose-positron emission tomography scan 8 months after the completion of SBRT showing residual avidity in the RUL cancer, biopsy-proven residual disease. (B) Planning computed tomography (CT), lung window, showing RUL 2.5 cm index lesion; right pectoral grid visible on the patient's skin for determining the needle entry site. (C) CT multiplanar reformats showing microwave ablation (MWA) antenna centrally within the tumour. (D) CT multiplanar reformats immediately after the end of the 4-min ablation cycle showing ovoid density surrounding the target lesion; no pneumothorax, subcutaneous emphysema or other complication was seen. (E, F) Axial CT lung window and soft tissue window 24 h post MWA showing circumferential rim of ground-glass opacity (arrows) around the lesion. Figures 3 and 4 that follow are from the same patient

(1 week–3 months) and late phase (>3 months)—with corresponding histologic²⁶ and imaging findings.²⁷ While there is no standardized post-ablation imaging protocol, most centres perform a combination of CT and fluorodeoxyglucose-positron emission tomography (FDG-PET) imaging after the ablation. CT is usually performed at 24 h or within 1 week post ablation, at 3-monthly intervals during the first year, at 18 months, 24 months and yearly thereafter (Figures 2–4). FDG-PET imaging should not be performed earlier than 6 months post ablation, unless there is high suspicion of incomplete ablation or early recurrence on CT imaging, in view of a high false-positive rate²⁸ (Figure 3B,D) caused by inflammatory changes.

It is paramount to understand that to achieve local tumour control, a perilesional circumferential safety margin of as close to 1 cm should be aimed for. When the surface area of GGO surrounding the tumour is at least four times the tumour area at 24–48 h post ablation (Figure 2E,F), 96% complete ablation is achieved.¹⁵

While ablation volume tends to eventually shrink below pre-ablation size by 12 months post RFA and cryoablation at the latest, with the more potent MWA, larger volumes are being ablated and the ablation area will often not reduce to or below the initial tumour size (Figure 4).²⁹

Complications

While complications in the acute setting are common, the vast majority are CTCAE (Common Terminology Criteria for Adverse Events) grade 1 or 2 and self-limiting, not requiring any further intervention. Pneumothorax is by far the most common complication, requiring chest tube placement in 10%–30%; tract embolization is shown to reduce the requirement of chest tube insertion from 29% of pneumothoraces to 10%.³⁰ Reactive pleural effusion is a common occurrence, especially with lesions close to or abutting the chest wall, and normally resorbs spontaneously. Pleural effusions requiring drainage occurs in less than 7%.^{31,32} Alveolar haemorrhage with or without accompanying haemoptysis is also usually self-limiting; cryoablation is associated with a higher haemoptysis rate than RFA or MWA.^{9,33} CTCAE grade 3 and 4 complications range below 3% in studies originating from large centres with high ablation numbers, and include bronchopleural fistula (Figure 5), aseptic pleuritis, pneumonia, abscess, pleural seeding and nerve damage.^{31,34,35} Air embolism and development of pulmonary artery aneurysm are reported at less than 0.3%.³⁶

The main delayed complications are rib fractures (Figure 3D) and delayed haemorrhage with haemoptysis.

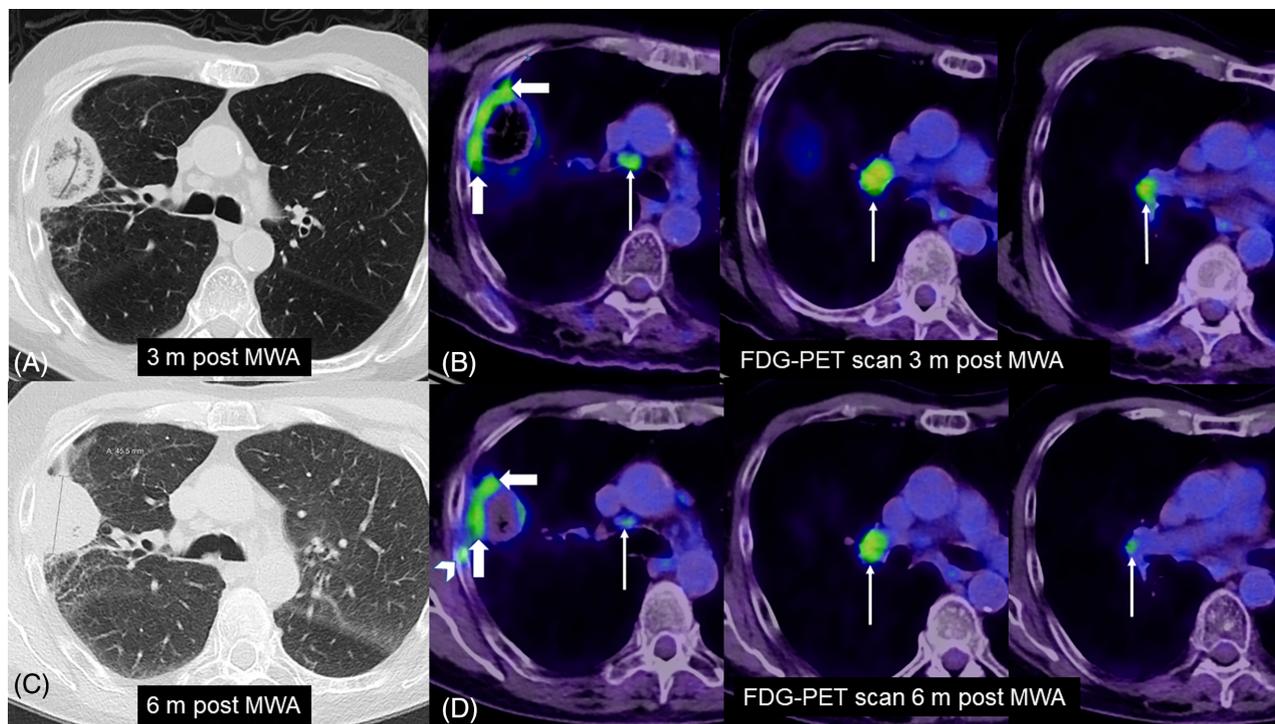


FIGURE 3 A 70-year-old male with complex medical history—stroke, prostate cancer, bladder cancer with pelvic exenteration and ileal conduit. Right upper lobe T1N0M0 non-small cell lung cancer (adenocarcinoma), stereotactic body radiation therapy. (A) Axial computed tomography (CT) lung window 3 months post microwave ablation (MWA) showing the outline of the target lesion embedded within an area of ground-glass opacity (GGO), circumferentially surrounded by a thick rim. The track of the antenna was shown as a black line traversing the lesion. (B) Fluorodeoxyglucose-positron emission tomography (FDG-PET) scan 3 months post MWA showing band-like avid uptake along the outer ablation margin following the pleura outline (block arrows) and avid uptake of ipsilateral hilar and mediastinal lymph nodes (arrows); no uptake was seen at the ablated tumour site. (C) Axial CT lung window 6 months post MWA showing condensation of the entire ablation area without noticeable change in size. Neither the GGO nor the antenna track previously seen is any longer visible. (D) FDG-PET scan 6 months post MWA showing decreased avidity along pleura (block arrows) and at all nodal sites (arrows) of initial avid glucose uptake; a rib fracture adjacent to the ablation site also shows minor uptake (arrowhead).

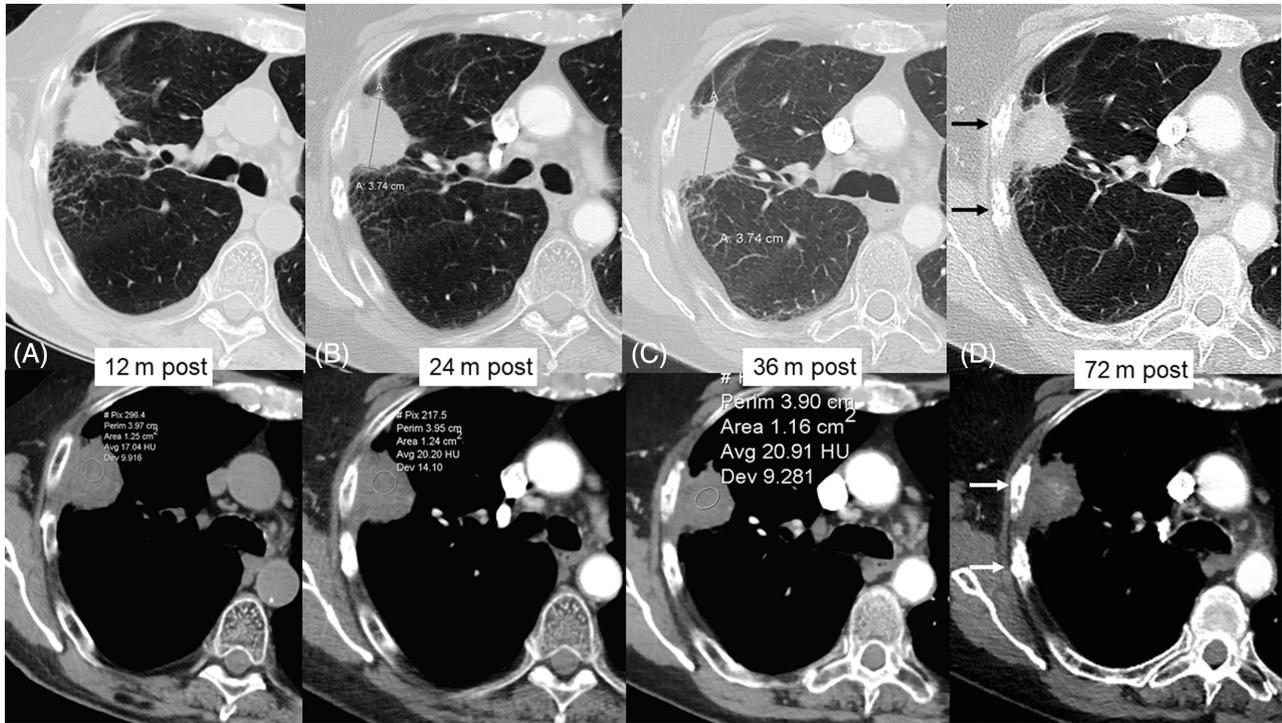


FIGURE 4 A 70-year-old male with complex medical history—stroke, prostate cancer, bladder cancer with pelvic exenteration and ileal conduit. Right upper lobe T1N0M0 non-small cell lung cancer (adenocarcinoma), stereotactic body radiation therapy. (A) Axial non-contrast computed tomography (CT) scan lung window and soft tissue window 12 months post microwave ablation (MWA) showing ablation site, density 17 HU. (B) Axial contrast-enhanced CT scan lung window and soft tissue window 24 months post MWA showing ablation site, unchanged in size, density 20 HU. (C) Axial contrast-enhanced CT scan lung window and soft tissue window 36 months post MWA showing ablation site, unchanged in size, density 21 HU. (D) Axial contrast CT scan lung window and soft tissue window 72 months post MWA showing ablation site, unchanged in size, density however more heterogeneous with early central calcification. Two adjacent rib fractures (arrows) with irregular cortices

While haemoptysis in the acute phase is usually self-limiting, fatal outcomes have been reported.³⁷ The reported incidence of rib fractures is up to 13.5%, with those ribs close to the ablated peripheral tumours more commonly involved.³⁸

Caution is needed with thermal ablation of local recurrence of previously radiated lung tumours, often associated with higher morbidity owing to radiation-associated vasculopathy,³⁵ resulting in larger ablation zones, higher rates of bronchopleural fistula, septic complications and vascular injury.

Periprocedural mortality, reported at less than 1% in heat-based pulmonary thermal ablation, is usually linked to an exacerbation of underlying interstitial lung disease³⁹ or very poor respiratory function with post-ablation empyema or sepsis. Most importantly, thermal ablation has not been shown to adversely affect pulmonary function, even in elderly patients with comorbidities.^{2,40}

In summary, percutaneous thermal (both heating and freezing based) ablation of lung tumours—early-stage NSCLC and oligometastatic disease—is a safe, minimally invasive, single-session therapy option with outcomes comparable to sub-lobar resection and SBRT. Complications are usually self-limiting. It is repeatable in local recurrences without an associated increase in morbidity or decrease in survival rate, spares healthy lung tissue and preserves lung function and quality of life.

RADIOLOGICAL INTERVENTION IN PE

Venous thromboembolism (VTE) affects up to 600,000 people in the United States every year and between 60,000 and 100,000 of these patients will die from PE.⁴¹ Early diagnosis and treatment of PE represents an important preventable cause of death worldwide. The following is a discussion of risk stratification of patients with PE and a review of IR treatment of PE.

Risk stratification

Acute PE has traditionally been risk stratified into the following categories: ‘massive’, ‘submassive’ or ‘low risk’. The distinction between massive and submassive is often the most relevant to clinical management. While this distinction was previously made on the basis of embolic burden on CT angiography (CTA), embolic burden is not considered a predictor of adverse outcome in the absence of right ventricular (RV) dysfunction.⁴² As a replacement surrogate for PE severity, the American Heart Association’s (AHA) 2011 statement on VTE management outlines an algorithm for risk stratification based on three clinical features associated with significant short-term mortality: haemodynamic instability, RV strain and myocardial necrosis. Under these guidelines, haemodynamic

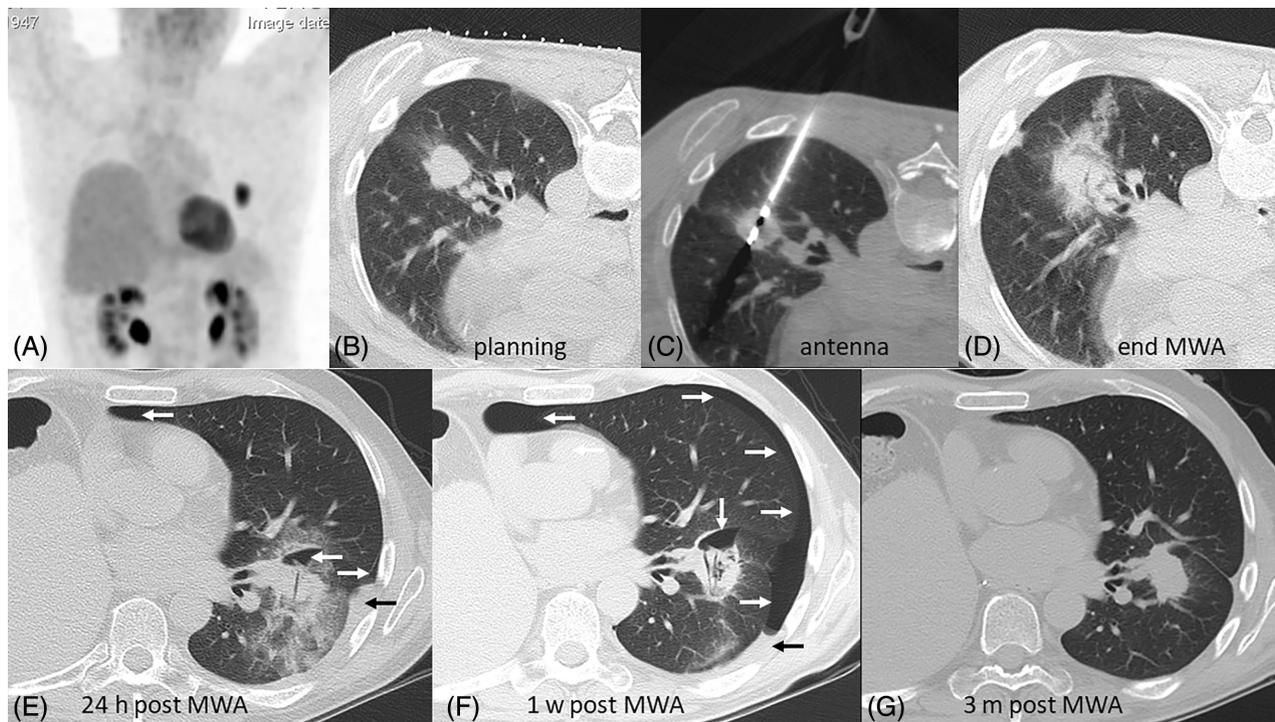


FIGURE 5 A 61-year-old male post right-sided pneumonectomy 8 years prior for central squamous cell carcinoma (SCC). Left lower lobe metachronous T1N0M0 parahilar SCC 3 years prior, treated with radiotherapy, enlarging and increasing in fluorodeoxyglucose (FDG) uptake, local progression. (A) FDG-positron emission tomography scan coronal reformats showing FDG-avid left central lesion. (B) Computed tomography (CT) planning scan for microwave ablation (MWA), prone position, grid visible on skin. (C) Prone position, MWA antenna centrally within the target lesion. (D) Prone position, control scan at the end of procedure after the removal of MWA antenna. (E) CT scan 24 h post ablation, lung window supine view showing small pneumothorax (white arrows) and small-volume pleural fluid (black arrow). (F) CT scan 1 week post ablation, lung window supine view showing enlarging pneumothorax (white arrows), suggestive of bronchopleural fistula and decreasing volume pleural fluid (black arrow); desiccated needle tracks were also seen within the target lesion. (G) CT scan 3 months post ablation, lung window supine view showing resolution of pneumothorax and pleural effusion (An intercostal catheter had been inserted and kept under suction for 3 days) and disappearance of central needle tracks within the ablated lesion

instability is defined as: systolic blood pressure < 90 mm Hg for at least 15 min; the requirement of inotropic support, pulselessness or persistent bradycardia with a heart rate < 40 bpm; and signs or symptoms of shock. The diagnosis of RV strain can similarly be made in a multimodal fashion. CT, echocardiography, serum B-type natriuretic peptide (BNP)/pro-BNP and ECG are all viable modalities for demonstrating RV strain. Myocardial necrosis is most specifically defined by increases in serum troponin.⁴³

A diagnosis of massive PE requires evidence of each component of the clinical triad: haemodynamic instability, RV strain and myocardial necrosis. A 2006 analysis of the International Cooperative Pulmonary Embolism Registry (ICOPER) compared massive and non-massive PE mortality, noting a significantly higher 90-day mortality rate with massive PE (52.4% vs. 14.7%).⁴⁴ Of note, the ICOPER study predated the 2011 AHA definition of massive PE, instead of defining massive PE solely by a systolic blood pressure < 90 mm Hg. More contemporary data on mortality rates for patients presenting with all components of the AHA-defined massive PE clinical triad are lacking. Submassive PE does not present with haemodynamic instability, but must be associated with either RV strain or myocardial necrosis. Given the broad clinical presentation associated with this definition, more granular categorization is often utilized. The 2019 European Society of

Cardiology (ESC) PE guidelines provide such stratification with two additional categories: ‘intermediate high’ and ‘intermediate low’ risk. Intermediate high-risk PE fits the criteria of submassive PE with the constraint that both RV strain and myocardial necrosis must be present. Intermediate low-risk PE is also not associated with haemodynamic instability, but may present with RV strain, myocardial necrosis or neither.⁴⁵ In patients with submassive PE, multiple registries indicate a short-term mortality rate of just 3%.^{46–48} A recent single-institution study further stratified submassive patients into intermediate low and intermediate high-risk, noting a similar long-term mortality rate between the groups.⁴⁹ While submassive PE is generally associated with a low risk of mortality, signs of clinical deterioration portend a poorer prognosis and warrant repeat evaluation for massive PE. Low-risk PE is defined as having neither haemodynamic instability, RV strain or evidence of myocardial necrosis. Such patients comprise the majority of the PE population and have an excellent prognosis, with short-term mortality rates nearing 1%.^{50–52}

Management of acute PE

PE management always follows a requisite diagnostic workup and appropriate risk stratification. In the absence of any

contraindications, all patients presenting with acute PE should be started on anticoagulation (AC) therapy. The choice of AC agent is multifactorial, with a general preference for subcutaneous low-molecular weight heparin, fondaparinux or oral Xa inhibitors over unfractionated heparin. In the setting of massive PE, AC therapy must be supplemented by a more aggressive reperfusion adjunct. Systemic thrombolysis (ST) offers a rapid therapeutic option in the setting of unstable PE and/or delayed access to an angiography or operating studio.⁴² Available agents for thrombolysis include recombinant tissue plasminogen activator (tPA) (e.g., alteplase and tenecteplase), streptokinase and urokinase, all of which are well studied in the treatment of acute PE. However, of these options, only recombinant tPA agents are indicated for acute PE in the United States. The PE International Thrombolysis (PEITHO) trial demonstrated superiority of ST over heparin-alone in preventing early mortality and haemodynamic decompensation. However, this same trial noted a substantial increase in the risk of massive haemorrhage, particularly in patients over age 75.⁵³ In patients with submassive PE specifically, the Moderate PE treated with Thrombolysis (MOPPETT) trial found that lower dose ST had a survival advantage over heparin-alone, notably with a minimal risk of major bleeding.⁵⁴ In the case of low-risk PE, conservative management with AC alone is advised for a minimum of 3 months.

Given that advanced age and malignancy are both common to PE patients and a substantial risk factor for thrombolysis-induced haemorrhage, alternative reperfusion techniques are frequently considered. Reperfusion techniques include surgical embolectomy, venous–arterial extracorporeal membrane oxygenation, catheter-directed thrombolysis (CDT) and mechanical thrombectomy (MT).⁵⁵ Our discussion will focus on percutaneous reperfusion techniques.

Catheter-directed thrombolysis

CDT offers a method of localized low-dose thrombolytic delivery directly into the offending thrombus. CDT is indicated as first line for patients with massive or submassive PE and contraindications to ST. It can also be offered to intermediate-risk PE patients who deteriorate on AC therapy. Finally, CDT can be offered as an adjunct to low-dose ST when the procedure cannot be performed immediately.⁴² As with all thrombolytic alternatives, CDT is contraindicated in patients with severe bleeding risks. More importantly, the procedure is used with caution in the setting of left bundle branch block (LBBB).⁵⁶ Catheter occlusion of the RV outflow tract during the procedure risks exacerbating RV dysfunction, increasing the risk of right bundle branch block (RBBB). In the setting of LBBB, a concomitant RBBB results in life-threatening asystole. As such, candidates for CDT must receive a prior ECG and appropriate transvenous pacing if LBBB is identified. Additionally, prior sonography should be obtained to prevent agitation of an existing DVT in the femoral vein.⁴²

In CDT, a multi-side hole infusion catheter is advanced from the femoral vein into the occluded pulmonary artery,

until it is embedded in the thrombus. After embedding, low-dose tPA is infused at a standard rate of 1–2 mg/h for a total dose of 15–30 mg.⁵⁶ The OPTALYSE trial tested several CDT dosing regimens ranging from a total of 4 to 12 mg of tPA per lung administered over 2–6 h. The trial noted a similar efficacy between low- and high-dose tPA regimens comparing short-term clinical outcomes.⁵⁷

Alternatively, to optimize local thrombolytic diffusion, an EKOS EndoWave infusion catheter may be used (EKOS Corporation, Bothell, WA, USA). This technique, known as US-accelerated thrombolysis (USAT), utilizes ultrasonic pulsation to disaggregate fibrin and improve thrombolytic exposure. For submassive PE, the ULTIMA and SEATTLE II trials demonstrated superiority of EKOS USAT with heparin over heparin-alone in reducing the RV:left ventricular (LV) ratio within 24 and 48 h, respectively.^{58,59} However, more recent single and multicentre trials have demonstrated non-superiority of EKOS USAT over conventional CDT in improving short-term clinical outcomes.^{60,61}

Mechanical thrombectomy

Over the past 3–4 years, MT has garnered interest as a potential replacement or adjunct for thrombolytic infusion. In CDT, the primary goal of treatment is to divide a large thrombus into smaller clots that can be resolved less time-sensitively with AC therapy. On the other hand, an ideal endovascular MT device would safely remove thrombi without the need for thrombolysis. An endovascular approach

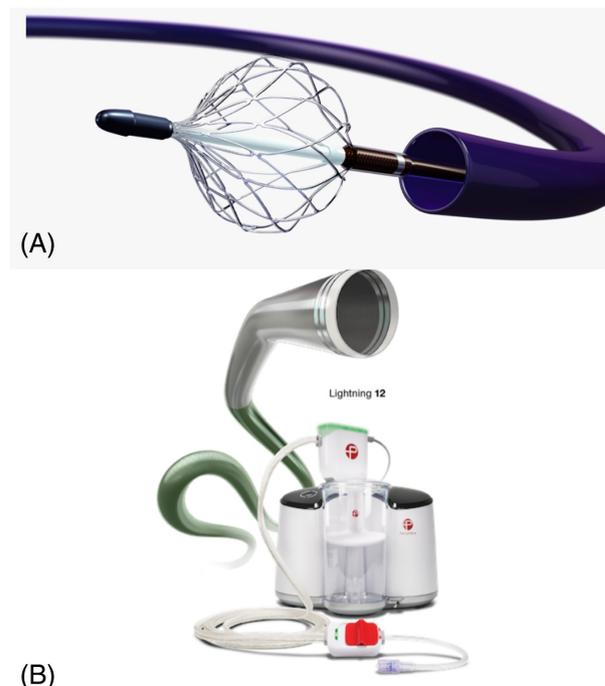


FIGURE 6 (A) The Inari FlowTrievers device with catheter and mechanical thrombectomy basket (Inari Medical, Irvine, CA, USA). (B) The Penumbra Cat-12 angled-tip suction catheter (green catheter) with aspiration catheter and tubing (Penumbra, Alameda, CA, USA)

for thrombectomy could offer a much-needed middle ground between CDT and open surgery. It could minimize bleeding complications from thrombolysis while avoiding the morbidity risks of an open procedure.

In 2018, the Society of Interventional radiology (SIR) released a position statement on the use of MT. The statement advised clinicians to avoid the use of such devices for submassive PE patients in stable condition. At the time, most MT devices involved aspiration catheters generally deemed safe only for peripheral and not pulmonary circulation. Indeed, the statement from SIR follows a meta-analysis noting procedure-related deaths following the use of the AngioJet thrombectomy system (Boston Scientific, Marlborough, MA, USA), which subsequently received a black-label Food and Drug Administration (FDA) warning against its use in PE thrombectomy.⁶² At present, most clinicians typically reserve MT for patients with contraindications to CDT and for whom surgery may pose a substantial risk of morbidity; however, recent FDA approval of several newer thrombectomy catheters

warrants an update on the indications and contraindications to MT usage.

The simplest, cheapest and most common means of mechanically recanalizing a pulmonary artery in the setting of PE is by catheter-mediated thrombus fragmentation. This technique involves manual rotation of a pigtail catheter in the embolic site,⁵⁶ resulting in embolization of fragments to distal pulmonary arteries. One study noted increased pulmonary hypertension following the use of pigtail fragmentation, while many others noted a reduction of pulmonary artery pressures.⁶³⁻⁶⁶ Decreasing pulmonary artery pressure reduces RV strain resulting in myocardial necrosis.

Two aspiration catheters recently approved by the FDA are the Inari FlowTrieve aspiration thrombectomy system (Inari Medical, Irvine, CA, USA) (Figures 6 and 7) and the Indigo Cat-8 device (Penumbra, Alameda, CA, USA). The FlowTrieve device utilizes a catheter with self-expanding mesh-like discs which open once the catheter has passed through the thrombus. The retrieving catheter is then aspirated back through a large-lumen aspiration catheter while

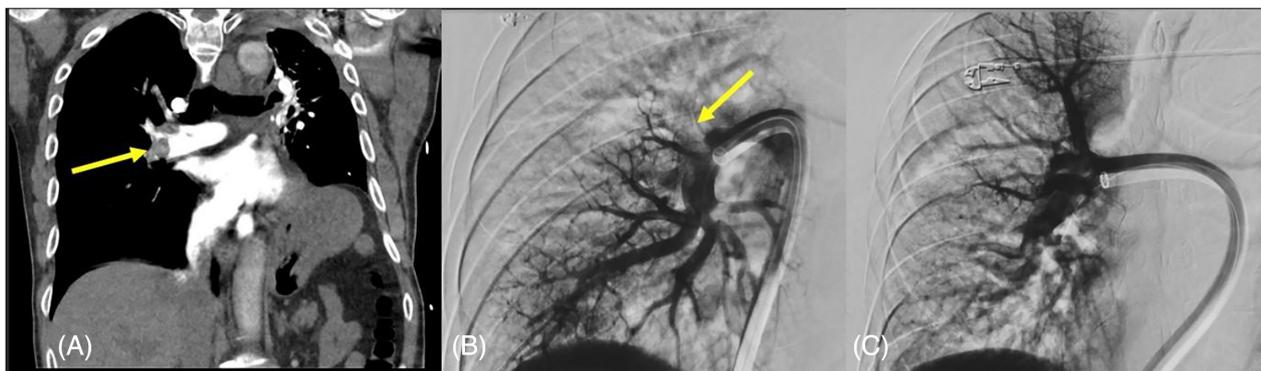


FIGURE 7 (A) A 67-year-old male with intermediate high-risk pulmonary embolism with occlusive thrombus in the right pulmonary artery (yellow arrow). (B) Absence of the superior segment pulmonary artery (yellow arrow) with the Inari FlowTrieve aspiration thrombectomy system in the main right pulmonary artery (Inari Medical, Irvine, CA, USA), pulmonary artery pressure decreased from 52 to 35 mm Hg following thrombectomy. Post-procedure pulmonary angiography (C) shows re-perfusion of the right pulmonary artery and the superior segment artery (Images courtesy of Nathan Cornish, DO, Staten Island University Hospital)

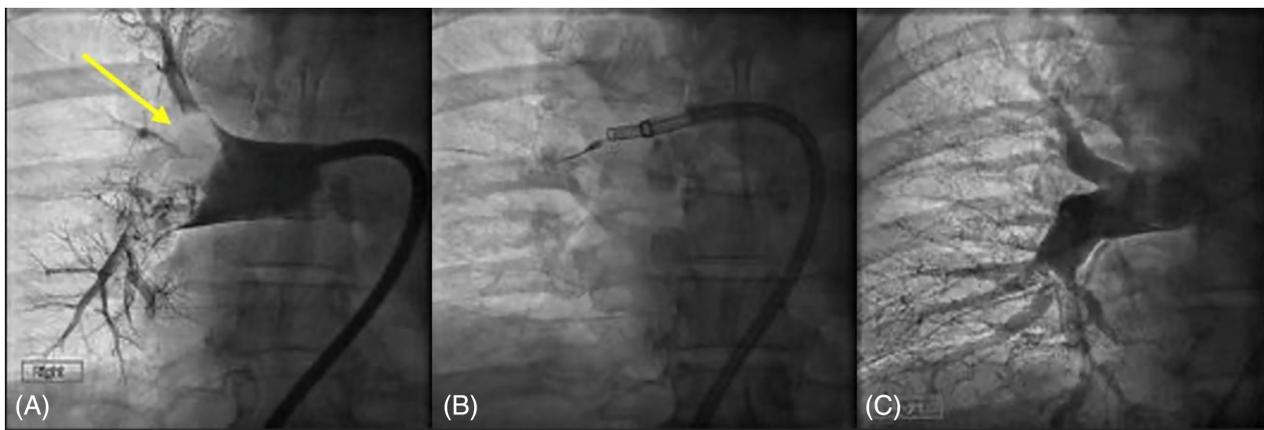


FIGURE 8 (A) A 42-year-old female with intermediate high-risk pulmonary embolism with occlusion of the right upper lobe pulmonary artery (yellow arrow). Mechanical thrombectomy with the Cat-12 device (Penumbra, Alameda, CA, USA) was performed (B) with decrease of pulmonary artery pressure from 42 to 26 mm Hg. (C) Post-procedure pulmonary angiography with improved perfusion of the right upper and lower lobe pulmonary arteries

the discs retrieve the offending thrombus. The device was approved in 2018 based on the results of the FLARE trial which demonstrated a 25.1% reduction in the RV:LV ratio at 48-h follow-up when compared to heparin-alone in submassive PE. However, the trial also observed a major complication rate of 2.6% and frequent haematocrit drops due to significant aspiration of blood.⁶⁷

The Indigo Cat-8 device, on the other hand, utilizes a continuous vacuum to directly aspirate the offending thrombus. This device was approved in 2020 based on the results of the EXTRACT-PE trial which demonstrated a 27.3% reduction in the RV:LV ratio at 48 h follow-up when compared to heparin-alone in submassive and massive PE. Additionally, the trial observed a major complication rate of 1.7%.⁶⁸ Both FDA-approved MT devices demonstrated a rate of major bleeding below 2%, comparing favourably with the 10% bleeding rate observed with CDT in the SEATTLE II trial.^{19,27,28} A promising new generation of the Indigo system is the Cat-12 Lighting system (Figures 6 and 8), which offers a 12-Fr aspiration catheter with a new clot sensing technology that limits blood loss. The STRIKE PE trial is currently enrolling patients to evaluate the lightning system in the treatment of PE.

Each FDA-approved MT device significantly reduces RV load compared to heparin-alone and significantly minimizes bleeding risk compared to CDT. However, significant haemorrhagic complications related to the large bore size of aspiration catheters cannot be discounted.

IVC filtration

In general, most patients presenting with acute PE of any risk type will not require placement of an inferior vena cava (IVC) filter. According to AHA guidelines, the placement of an IVC filter is indicated in patients who are ineligible for AC, patients who suffer bleeding consequences related to AC therapy and patients who experience recurrent PE despite AC therapy.⁴³ Patients with a temporary contraindication to AC therapy should receive a retrievable IVC filter while those with a permanent contraindication should receive a permanent filter.

In summary, the last decade has seen immense progress on endovascular therapies. While the management of submassive PE continues to challenge clinicians, targeted administration of tPA with CDT and the advent of MT devices has gradually improved efficacy while minimizing complications.

INTERVENTIONAL TREATMENT OF CENTRAL VEIN STENOSIS AND OCCLUSION

The SVC and brachiocephalic veins (BCV) carry deoxygenated venous blood from the upper half of the body, including head and neck regions, to the right atrium. The SVC is the largest systemic vein in the chest.

SVC and BCV obstruction is a distressing condition which degrades the patients' quality of life.⁶⁹ It is related to either an intrinsic blockage or extrinsic compression of the SVC, limiting the return of venous blood to the heart. Neck and facial swelling and/or swelling of one or both arms are frequently encountered as the initial symptoms related to SVC and BCV obstruction. More severe symptoms may include tachypnoea, cyanosis, dilatation of the upper body veins, mental status changes, lethargy, syncope and fluid collection in the arms and face.⁷⁰ Patients may suffocate due to glottis oedema. Malignant causes account for in excess of 90% of SVC and BCV obstruction.⁷¹ This is commonly due to direct invasion or extrinsic compression by carcinoma of the bronchus (both small cell and non-small cell), mediastinal lymphadenopathy (commonly from lung or breast primary, or lymphoma), mediastinal mass including thymoma or teratoma and less commonly pleural tumour such as mesothelioma. Thrombosis may develop in the SVC and BCV proximal to obstruction due to slowing or stagnating blood return. The use of transvenous cardiac devices and indwelling venous access devices are the main non-malignant causes of SVC and BCV obstruction.⁷² This can lead to thrombosis within the lumen of the vein or stricture of the vein. Other benign conditions include fibrosing, inflammatory or infectious mediastinal disease, compression from vascular anomalies and benign tumours.⁷³

The ways that the venous return is being altered depend on the level of the SVC obstruction. Obstructions can be classified into four types based on the superior vena cogram: type I, partial obstruction of the SVC (up to 90% stenosis) with antegrade flow in azygos vein; type II, near complete to complete obstruction (90%–100%) of the SVC with antegrade flow in azygos vein; type III, near complete to complete obstruction of the SVC with reversed flow in the azygos vein; and type IV, complete obstruction of the SVC and one or more caval tributaries, including the azygos vein.⁷⁴ When the occlusion is in the lower SVC or the atrio-caval junction, the blood flow is retrograde in the azygos system into iliac veins and IVC (type III) or via the internal mammary veins and chest wall channels if the azygos vein is also occluded (type IV). The pressure in the upper body, head and neck would be more elevated in type III and IV SVC obstructions. According to the study of Stanford et al., 80% of the patients with cerebral or airway compromise were found in type III or IV categories and had shortened length of survival—a 1.4-month average versus a 10.3-month average in patients without compromise.⁷⁴

Chemical and mechanical thrombectomy

When the central vein occlusion is due to thrombosis, systemic thrombolytic therapy is a simple, rapid and readily available therapy which can dissolve the thrombus. Besides the risk of major bleeding, thrombolytic therapy may be associated with a postulated risk of clot fragmentation and

migration leading to major or recurrent PE or even paradoxical embolization to brain and other organs if there is a right-to-left shunt in the heart following the partial resolution of the venous thrombus.⁷⁵ Percutaneous transfemoral catheter-directed chemical and MT would be an effective option to reduce the clot burden and alleviate acute venous congestion. Chemical thrombectomy also suffers the risk of clot fragmentation and potential major PE. MT, such as rheolytic thrombectomy (e.g., AngioJet system, Boston Scientific, Marlborough, USA), facilitates high-dose thrombolytic infusion in a short period of time in the power pulse mode and allows rapid debulking of thrombus to prevent iatrogenic PE,⁷⁵ while suction thrombectomy (e.g., Angiovac system, Angiodynamics, Latham, USA) removes the clot through an aspiration catheter by vacuum. A continuous aspiration MT system (e.g., Indigo, Penumbra, Alameda, CA) has three components in the device: a catheter, a separator and a vacuum pump. The separator allows thrombus fragmentation and mobilization as well as cleaning of the catheter when it is obstructed by thrombus. It helps remove the thrombus by both mechanical fragmentation and suction, without the requirement for concomitant use of thrombolytic medication⁷⁶ (Figure 9).

Stenting

Stenting of the SVC obstruction was first described by Charnsangavej in 1986.⁷⁷ It is established as the treatment of choice for malignant SVC and BCV obstruction and offers simple, rapid and safe palliation of the distressing condition. It also compares favourably with other therapies such as chemotherapy and radiotherapy which may take

time to work.⁷⁸ Stenting can also be performed in benign central vein stricture or obstruction. There is no absolute contraindication. Relative contraindication would include malignancy with a very good chance of cure or remission or benign stricture because patients have long life expectancies and long-term SVC stent patency is not well established. Most interventional radiologists perform this procedure via femoral or jugular veins under topical anaesthetic with patients under conscious sedation. Confirmation of severe stenosis or obstruction can be done with superior vena cavogram. The stricture/obstruction in SVC or BCV is then crossed by a wire. Pre-dilatation of the stricture/obstruction with balloon angioplasty catheter may be necessary to allow the passage of the stent system. The stent used is normally a self-expanding nitinol stent (Figure 10). For stricture or obstruction resistant to balloon dilatation, a balloon mountable stent is considered which offers stronger radial strength to keep SVC/BCV lumen patency. Peri-procedural and post-procedural complications are low, occurring in 0%–19% of patients.⁷⁸ Important procedural complications would include venous rupture or cardiac tamponade which is an uncommon though occasional catastrophic occurrence. This can be minimized with step-wise balloon dilatations pre and post stent insertion. A covered stent can be used to treat the venous leak if this happens. If the obstruction involves both BCVs, it may be sufficient to relieve the obstruction in one of the BCV with collateral veins enabling drainage from both sides. Stenting of both BCVs can also be undertaken in the same procedure for better results. Technical success rates of SVC stenting is 95%–100% and stents relieve SVC obstruction in 80%–95%.⁷⁸ Simple antiplatelet regime would be sufficient to maintain stent patency.⁷⁹ No



FIGURE 9 A 30-year-old male had a history of stent for the left innominate vein and superior vena cava presented with acute thrombotic occlusion (white arrows) of the stent as shown on post-iodinated contrast coronal CT (A) and venogram (B). Percutaneous mechanical and aspiration thrombectomy was undertaken, followed by balloon dilatation up to 8 mm, with good results (C)

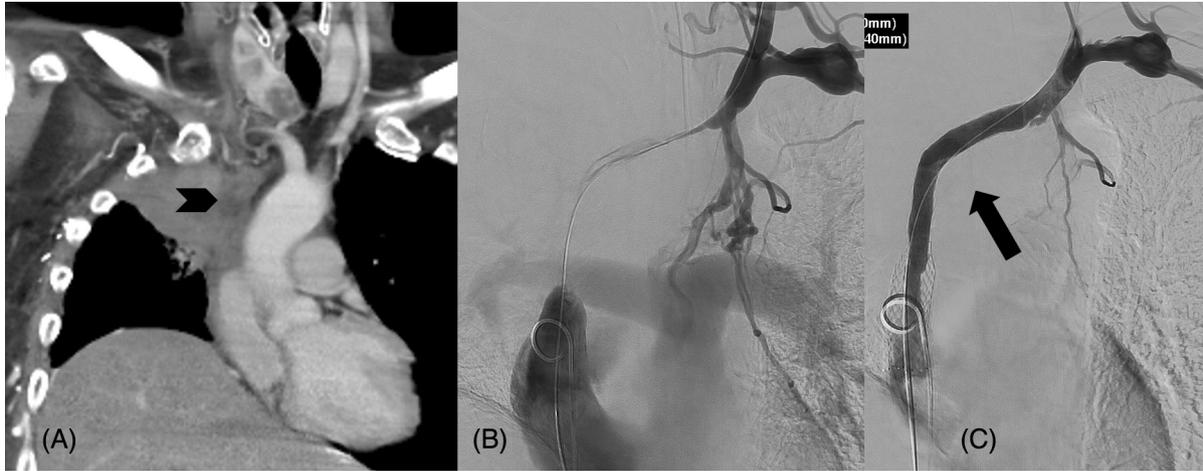


FIGURE 10 A 55-year-old male presented with occlusion of the superior vena cava and left innominate vein due to mediastinal extension of the right upper lobe lung malignancy (arrowhead) as shown on coronal reformat computed tomography (A) and venogram (B). The patency of the venous channel (arrow) was established after the venous obstruction was stented with a nitinol self-expanding stent and balloon dilated up to 10 mm (C).

formal imaging follow-up regime is established. If recurrent obstruction occurs, repeat stenting can be performed.

PAVM EMBOLIZATION

Pulmonary arteriovenous malformations (PAVM) are rare (1 in 2,600).⁸⁰ As a pathologic right-to-left shunt from pulmonary artery to pulmonary vein, gas exchange is impaired depending on the size of the PAVM. Regardless of the size, filtration of venous blood through the pulmonary circulation becomes defective. PAVM of any size can result in significant morbidity and mortality (in up to 50% of patients) with paradoxical embolic stroke (brain), abscesses (Figure 11) or myocardial infarction; or life-threatening haemoptysis/haemothorax/haemorrhage due to local rupture of PAVM.^{81–83} Most patients with PAVM suffer from hereditary haemorrhagic telangiectasia (HHT = Rendu-Osler-Weber disease), with PAVM found in 50% of that patient population.⁸⁴ PAVM diagnosis is usually based on transthoracic US contrast (or bubble) echocardiography and CTA.⁸⁵

Embolization

Embolization is the treatment of choice for symptomatic and asymptomatic PAVM. Surgical treatment is an alternative after failed embolization or in case of life-threatening bleeding after PAVM rupture. Treatment of PAVM is based on the occlusion of the feeding arteries of the PAVM with a multitude of approaches over time, starting with the use of detachable occlusion balloons to coils.

During informed consent, potential side effects and complications such as coil migration and air embolism causing embolic and ischaemic complications should be mentioned.⁸¹

A common femoral vein or jugular vein approach is used. The pulmonary trunk is engaged with a pigtail catheter.

Depending on the number and complexity of the lesion and patient preference, the procedure can be performed with patient under no sedation, conscious sedation or general anaesthesia. PAVM are classified as simple (the majority of PAVM with one feeding and one draining vessel) or complex malformations (with >1 feeding and draining vessels, respectively).⁸⁶ To avoid air bubbles or clots during insertion or exchange of catheters and embolization materials, continuous saline flush lines for all sheaths and catheters used during the procedure is advocated as well as systemic heparinization. Coils have been used in several designs starting with stainless steel coils to platinum coils to more recent techniques such as detachable coils or hydrogen coils. Recently, vascular occluders (plugs) have been used in peripheral embolization as well as embolization of PAVM with great success. They are either available as standard nitinol or polytetrafluoroethylene (PTFE)-covered nitinol plugs. Coils and plugs are available in various sizes and distributed by either microcatheters or diagnostic catheters (coils and plugs) or guiding catheters or long vascular sheaths (in case of plugs), depending on their diameter and type. Usually, coils are placed with approximately 20% oversizing for the first coil, and plugs are chosen with approximately 30% oversizing. Plugs/occluders are advocated in larger diameter or high-flow PAVM.⁸¹ For the application of coils or plugs/occluders, the catheter/microcatheter should be placed as close as proximal to the venous sac, ideally in the proximal venous sac. The guiding catheter/coaxial catheter should be placed as close as possible to the catheter tip to improve support. The coil or plug/occluder is placed in the distal afferent vessel upon retraction of the catheter/microcatheter. For some interventional proceduralists, venous sac embolization is an alternative to placement of coils and plugs/occluders in the distal afferent vessel.⁸¹

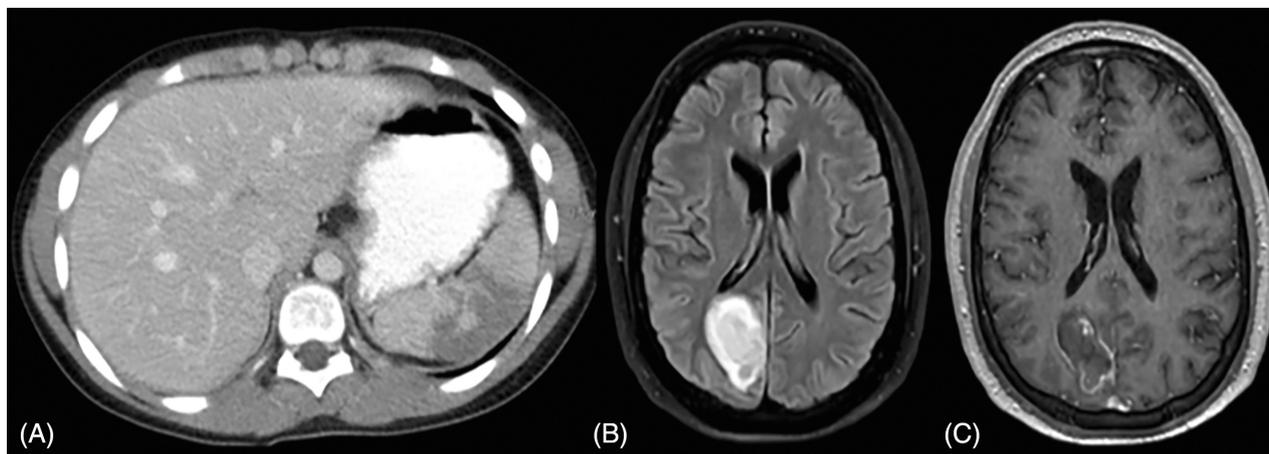


FIGURE 11 Depiction of complications of PAVM due to paradoxical embolization; Splenic infarction on contrast-enhanced computed tomography (A), and cerebral abscess in the right occipital lobe on axial fluid-attenuated inversion recovery (FLAIR) MRI sequence (B) and post Gadolinium axial T1 MRI sequence (C).

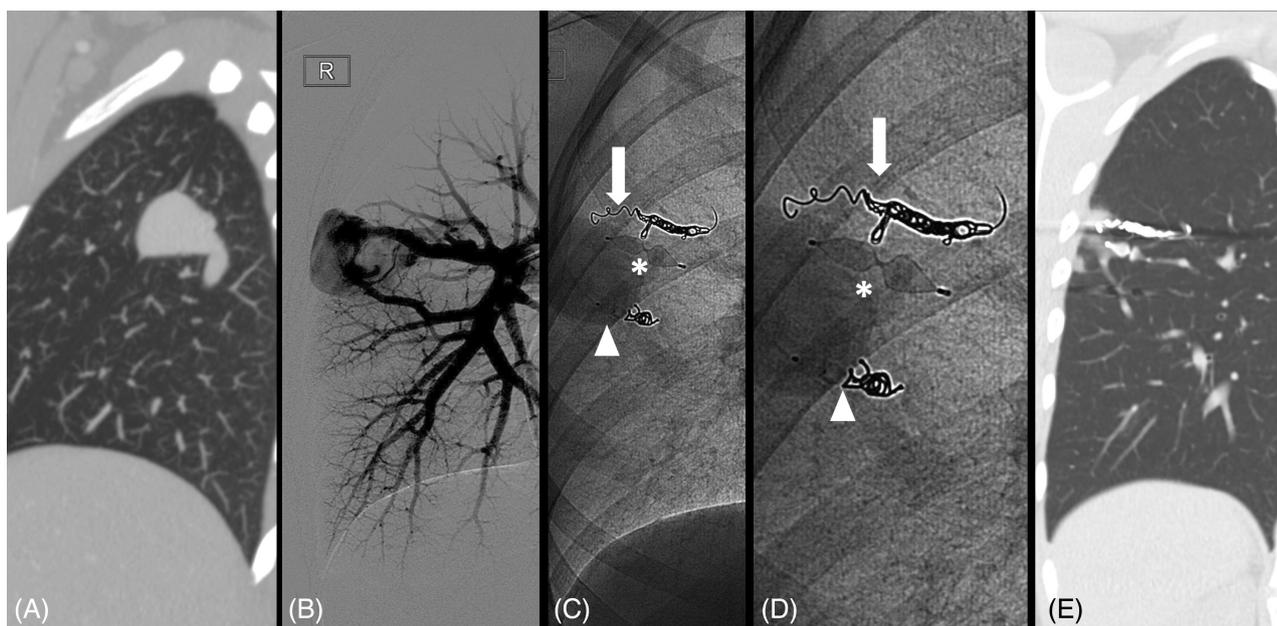


FIGURE 12 In the right lung, a large PAVM is demonstrated by sagittal reconstruction of iodinated contrast computed tomography (CT) in the right lower lobe (A). Pulmonary angiography revealed three feeders (B) that were treated by embolization (C). Three different approaches were used for treatment, coil embolization alone (arrows), plug embolization alone (asterisks) and the combination of plug and coils (arrowheads) (C) with magnified view of the implants (D). Follow-up CT after 1 year demonstrated shrinkage of the PAVM (E) (Images courtesy of Martin Freund, Department of Radiology/Medical University Innsbruck - Tirol-Klinik/Austria)

An arbitrary size of <3 or $<2-3$ mm diameter of the afferent vessel was considered not suitable for embolization. However, this is not followed anymore.^{82,87-90} Pregnancy, pulmonary hypertension and renal impairment are relative contraindications to elective embolization procedures, although benefits may outweigh risks, particularly in the setting of life-threatening haemoptysis.⁸² Complications related to endovascular treatment include allergy to contrast agents, local puncture site complications (with common femoral vein or jugular vein as access sites), fever and pleurisy.^{81,91} Complications such as coil dislodgement or stroke are not reported on a regular basis in larger series; some larger trials report no complications after embolization.⁸¹

The technical success rates are usually over 80% and approaching 95% in some series.^{80,82-88,92,93} Although most PAVMs are successfully treated, recanalization or reperfusion (in up to 15%)⁹⁴⁻⁹⁶ can occur after the first successful embolization in some patients after 8 years of follow-up.^{94,95} Reperfusion puts the patient again at risk for the typical complications of the shunt.

Coils or plugs

The first aim of coiling is to achieve the highest packing density possible and to detect and prevent reperfusion by

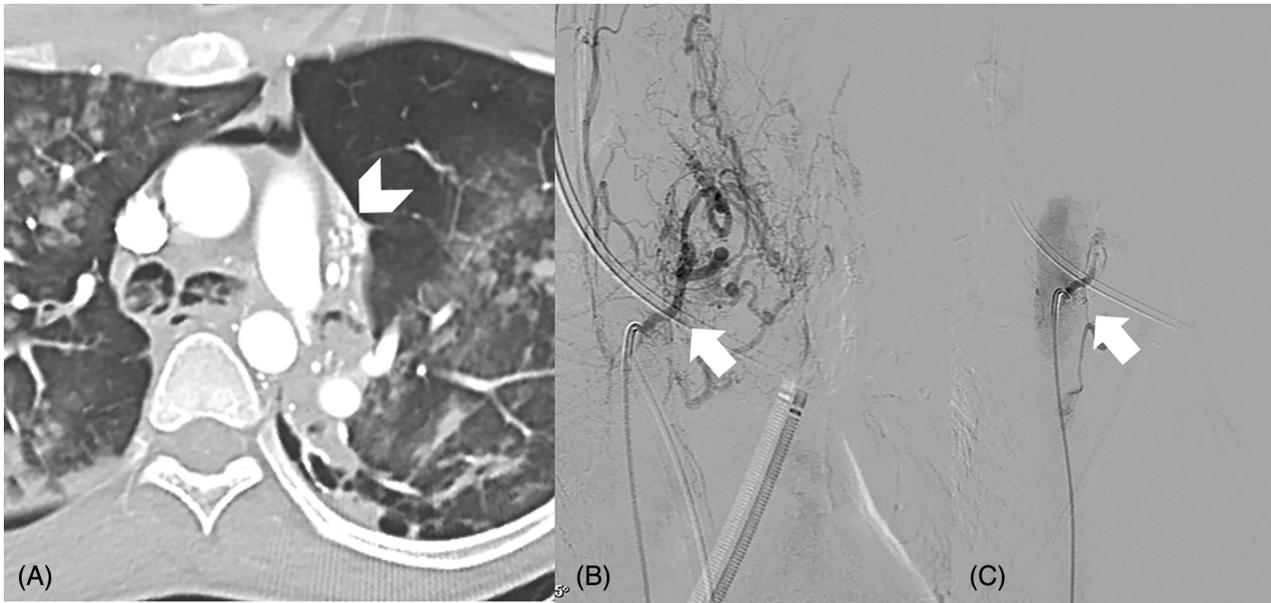


FIGURE 13 A 32-year-old female with a past history of tuberculosis presented with massive haemoptysis. Iodinated contrast computed tomography angiogram (A) showed blood in both lungs and tracheal and bronchial lumen, with a cluster of abnormal vessels in the left suprahilar region (white arrowhead). Selective left bronchial angiogram (B) revealed a cluster of abnormal ectatic and tortuous vessels arising from the left bronchial artery (white arrow) with no definite Rasmussen aneurysm. Her haemoptysis ceased after this abnormal left bronchial artery had been embolized with polyvinyl alcohol particles (C).

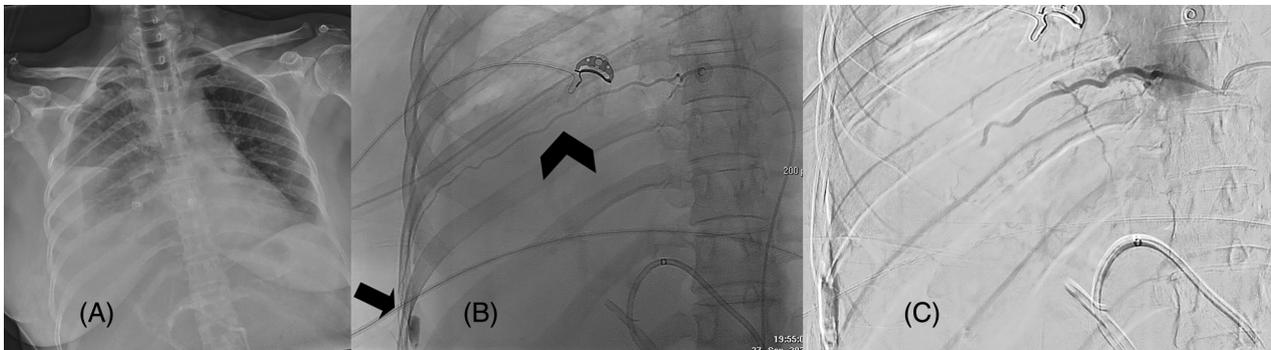


FIGURE 14 A 45-year-old female presented with an expanding right haemothorax after the percutaneous transhepatic cholangiogram and biliary drainage procedure for an obstructing cholangiocarcinoma (A). Selective right intercostal arteriogram (B) with a microcatheter demonstrated leaking intercostal artery (arrowhead) anterolaterally with contrast extravasation (arrow) due to inadvertent puncture during the percutaneous biliary procedure. The bleeding point was successfully embolized with polyvinyl alcohol particles (C).

embolization of collateral vessels. The second aim is to prevent non-target embolization and an excess of vessel loss. In theory, advanced technical qualities of coils such as enhanced thrombogenesis (fibred coils), controlled detachment (detachable coils) and coating (expanding hydrogel coating)⁹⁷ should enable better results (reduced incidence of reperfusion) and reduced complication rates, which were proven in animal models.^{98,99} Only one randomized trial comparing outcomes with detachable versus pushable coils is available; no significant differences were reported at 1-year follow-up.¹⁰⁰

Otherwise, no randomized clinical trials are available for the comparison of the efficacy between various types of coils (fibred vs. non-fibred vs. hydrogel), the comparison of coils

versus plugs/occluders or various types of plugs/occluders or plugs/occluders without additional coil placement versus plugs/occluders with additional coil placement. Despite this, single-centre (sometimes with long-term follow-up) experience and recommendations are available in the literature. Tau et al.¹⁰¹ reported improved technical success rates and lower recanalization rates (0/21) for Amplatzer plugs when compared to standard coils (7/37) at a mean follow-up of 7.7 years. Andersen et al.¹⁰² reported significantly lower recanalization rates when comparing plugs (4.5%) to coils (11.7%). The combination of coils and vascular plugs is also able to achieve high technical and clinical success rates and low reperfusion rates^{93,102} (Figure 12).

Feeding artery versus feeding artery and venous sac embolization

In addition to embolization materials, the choice of embolization technique—feeding artery embolization alone versus venous sac/nidus *and* feeding artery embolization^{103–107}—is also not clarified. The latter technique can also be used when the target artery of the PAVM is too short to avoid sacrifice of large normal pulmonary artery branches or when the artery is a high-flow type with a higher risk of paradoxical embolization of a coil.

Additional venous sac embolization led to 0% reperfusion (42 months mean follow-up) incidence in smaller retrospective series when compared to afferent vessel embolization alone (50% reperfusion at 58 months mean follow-up).^{105,106}

Follow-up after embolization

Surveys on follow-up post embolization of PAVM in HHT centres of excellence demonstrated inconsistency in practice and timing.¹⁰⁸ Usually, clinical and imaging follow-up after embolization must be performed to detect delayed treatment failures with reperfusion of the PAVM through recanalization of the embolized feeding artery or developing collateral feeding vessels. Basic tests are chest radiography and oxygen shunt testing. CT with contrast (CTA) is not necessary as a regular follow-up modality; low-dose CT without contrast is sufficient for follow-up.^{81,82}

Magnetic resonance angiography is also a potential alternative to CTA in selected cases.¹⁰⁹

In summary, embolization has become the standard of treatment of PAVM. There is no clear cut-off of vessel size for treatment as even small PAVM can result in clinical symptoms. Due to the paucity of high level of evidence data and the wide range of technical approaches possible, treatment in specialized centres is advocated. The choice of material and interventional approach is usually left to the endovascular specialists performing the treatment. Up-to-date coil and plug and combined coil/plug approaches have led to high success and low complication and reperfusion rates. Clinical and imaging follow-up must be performed after diagnosis and management (embolization).

OTHER CHEST INTERVENTIONAL PROCEDURES

Bronchial artery embolization is another frequently performed procedure in IR. This is commonly performed for control of life-threatening haemoptysis, such as that seen with tuberculosis, cystic fibrosis, aspergillosis, malignancy, other infection, pneumoconiosis, sarcoidosis, vasculitis or hydatid disease. The procedure uses percutaneous transarterial approach with microcatheter super-selectively

inserted into the abnormal branch of bronchial artery (Figure 13). Embolization agents commonly used for bronchial arteries include polyvinyl alcohol particles or *n*-Butyl-2-cyanoacrylate (*n*-BCA) glue. The tip of the microcatheter is positioned as far distal as possible in the bleeding bronchial artery to avoid any inadvertent embolization of the anterior spinal artery or arteriovenous shunt that may arise from the bronchial artery.

Intercostal artery embolization can be performed to control the bleeding into the pleural cavity that results in a large haemothorax which could be due to traumatic or iatrogenic cause. Access of the intercostal artery can be from either descending thoracic aorta posteriorly or internal thoracic artery anteriorly, and not infrequently both sides, to achieve effective embolization (Figure 14). Similar embolization agents as for bronchial artery are commonly used.

Thoracic duct embolization is a rare and technically difficult interventional radiological procedure for patients who have chylous effusions resulting in severe protein malnutrition and electrolyte imbalance, and who have failed the conservative management such as chest tube drainage, diet modification, total parenteral nutrition and intravenous infusion of octreotide.¹¹⁰ Lymphangiogram is initially performed to confirm the chylous leak, commonly by injecting contrast into the inguinal lymph node under US guidance. Percutaneous puncture with a 22-G needle into the target afferent and efferent lymphatic from the cisterna chyli is followed by the insertion of microcatheter. The target lymphatic is then embolized with either platinum coils or *n*-BCA glue to impede the lymphatic flow.

Fibrin sheath management is often required as the fibrin sheath can develop around the tip of a tunnelled central venous catheter that prevents its proper function. If the low-dose thrombolytic infusion fails to resolve the fibrin sheath, the fibrin sheath can be disrupted by balloon venoplasty or removed by internal snare technique under fluoroscopy.

CONCLUSION

Rapid advancement of imaging technology has markedly reduced the need of some diagnostic angiographic procedures such as pulmonary and bronchial digital subtraction angiograms in the past 20 years. At the same time, the range of chest interventional procedures keeps on expanding due to improved angiographic, CT and US technology; better percutaneous assess devices; and advancing ablation and embolization techniques. All these permit procedures to be undertaken safely and effectively, and are able to escalate the role of IR in the treatment of chest diseases. Wider range and more complex conditions in the chest can be treated with IR. Constant review of indications and contraindications of various interventional procedures, and strategies to minimize the procedural risks are paramount for ensuring these chest image-guided procedures are performed appropriately and at the highest standard to achieve the best patient care.

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CONFLICT OF INTEREST

None declared.

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